Using LiDAR to document the relevance of hurricane-induced landslides to the sediment budget of the Lago Lucchetti Watershed, Puerto Rico

Carlos E Ramos-Scharrón, Eugenio Arima, Abby Guidry, Danielle Ruffe, Briella Vest

Department of Geography & the Environment, UT-Austin
Lucchetti Watershed

Area: 43.8 km$^2$
% cultivated: ~30%
Avg. Slope: 23% (up to 52%)
Precip.: 1,320-2,200 mm y$^{-1}$
Lithology: Volcaniclastic Sand & Siltstone
Lifezone: Tropical wet/moist
Soils: Ultisols
SY: 2,800 – 4,200 Mg km$^{-2}$ y$^{-1}$ (1952-2014)
Lucchetti Watershed

<table>
<thead>
<tr>
<th>Region</th>
<th>Median SY (Mg km$^2$ y$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>World Wide</td>
<td>315</td>
</tr>
<tr>
<td>Taiwan</td>
<td>7,150</td>
</tr>
<tr>
<td>Puerto Rico</td>
<td>1,080</td>
</tr>
<tr>
<td>Lucchetti</td>
<td>3,170, 139K Mg y$^{-1}$</td>
</tr>
</tbody>
</table>

Sedimentation Survey of Lago Lucchetti, Yauco, Puerto Rico, September 2013–May 2014

By Juliette Gómez-Fragosa
2016
Sediment Yield Issues in Puerto Rico

✓ Currently, about 30% of the island’s reservoir capacity is filled with sediment.

✓ About 0.77% of current capacity is lost every year to sediment.

✓ Hurricanes ~ X 5 Accumulation rate

* USGS bathymetric analyses; various sources
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Sediment Yield Issues in Puerto Rico

Downstream effects on coral reefs

✓ Coral reefs in decline
✓ Terrigenous sediment, key stressor

Percent live coral cover (%)

<table>
<thead>
<tr>
<th>Year</th>
<th>Nearshore</th>
<th>Further offshore</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td></td>
<td></td>
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<tr>
<td>2000</td>
<td></td>
<td></td>
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<tr>
<td>2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Sediment Yield Issues in Puerto Rico

Downstream effects on coral reefs

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✓ Terrigenous sediment, key stressor

Guánica Bay Watershed Management Plan
A Pilot Project for Watershed Planning in Puerto Rico

Application of a Structured Decision Process for Informing Watershed Management Options in Guánica Bay, Puerto Rico

by
Patricia Bradley1, William Fisher2, Brian Dyson2, Susan "ee", John Carriger3, Gerardo Gambrazio4, Justin Bousqui5, and Evelyn Huertas7

Linking Terrigenous Sediment Delivery to Declines in Coral Reef Ecosystem Services

Jessica L. Orlando1, Susan H. Yee2
Why concentrate on coffee growing areas?

- Coffee = 26% of all cropland in PR (ranked #1 in terms of area)
- Coffee-growing watersheds (> 5% land under cultivation) = ~1/3 of PR’s landmass
- ~46% of water reservoir capacity catches runoff from coffee-growing watersheds
- Coffee-growing watersheds drain close to ~10,000 ha of coral habitat
1. Surface erosion

Methods

Hillside- and road segment-scale quantification of soil erosion in two coffee farms of western interior Puerto Rico: Spatio-temporal variability and impacts to agricultural sustainability

By

Yasiel A. Figueroa Sánchez

a thesis submitted to the

DEPARTMENT OF ENVIRONMENTAL SCIENCES
FACULTY OF NATURAL SCIENCES
UNIVERSITY OF PUERTO RICO
RÍO PIEDRAS CAMPUS

Research article

Plot-, farm-, and watershed-scale effects of coffee cultivation in runoff and sediment production in western Puerto Rico

Carlos E. Ramos-Seharrón a,⁎, Yasiel Figueroa-Sánchez b

Journal of Environmental Management

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman
Results – Surface erosion

- At the farm-scale (San Carlos, Yauco)
- 77% cultivated, 15% forest, 8% unpaved roads
- Farm scale erosion: 12-18 Mg ha$^{-1}$ y$^{-1}$ or 20-40 times background rates

**90% roads**
Results – Surface erosion

• At the watershed scale
• 13.1 km² or ~30% of Lucchetti Watershed are active coffee farms
• Farms = 15,720 to 23,580 Mg y⁻¹
• Yet, 115,300 to 123,000 Mg y⁻¹ of accumulation rate in Lago Lucchetti missing a source!
Methods

2. Landslides (?)
Along came Maria

- Metrics while within Puerto Rico
  - 20-Sept: Category 4 – 3
  - Translational speed: 10 – 12 mph
  - Max sustained winds: 155 mph
  - Max 1-hr rain int.: 275 mm h\(^{-1}\) [max] (10.8 in h\(^{-1}\))
  - Total 24hr rainfall: 108 - 682 mm (4.2 - 26.8 in)

Lucchetti: 125 – 250 mm; Max int. ~68 mm h\(^{-1}\) (2.7 in h\(^{-1}\)); Rec. Interval 1 – 10 y
Along came Maria

- **Landslide metrics**
- **Landslides:** >70,000 scars
- **Densities:** 112 scars km\(^{-2}\) (max: 432 km\(^{-2}\))
- **Factors:** Slope, lithology, rain, soil moisture, land cover, roads
Methods – Landslides

• Method 1: Volume
• On-screen digitizing images taken ~ 2 weeks after Maria
• Polygon delineation

Images: https://storms.ngs.noaa.gov/storms/maria/index.html#
Method 1: Volume

\[ \text{Vol} = \bar{h} \times A \]

LiDAR-based approach

- 2015
- 2018
Methods – Landslides

- Method 1: Volume
  - \( Vol = \bar{h} \times A \)
  - LiDAR-based approach
    - 2015
    - 2018
• Method 1: Volume

\[ V = \bar{h} \times A \]

LiDAR-based approach

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Methods – Landslides

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LiDAR-based approach
- 2015
- 2018
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\[ \text{Vol} = \bar{h} \times A \]

LiDAR-based approach

• 2015
• 2018
Methods – Landslides

• Method 1: Volume

\[ Vol = \bar{h} \times A \]

LiDAR-based approach

• 2015
• 2018
• \( |\bar{h}| = 2018 - 2015 \)
Results – Landslides

- Method 1: Volume
- On-screen digitizing images taken ~ 2 weeks after Maria
- Polygon delineation

- $\text{Vol}_i = 0.236 \times A^{1.144}$

(typical for shallow landslides; Larsen et al., 2010)
Method 2: Delivery

Landslide runout distances

Distance = f (Volume)

If estimated runout > downslope distance from scar to stream, then %delivered calculated.

If runout < downslope distance, then no delivery.
Results – Landslides

• Landslide Metrics @ Lucchetti
  • # of slides: 2,318
  • Landslide density: 53 slides km$^{-2}$
  • Area denuded: 0.8% of LLW
  • Volume mobilized: 272,170 m$^3$
  • Mass mobilized: 326,600 Mg
  • Mass delivered: 117,940 Mg
  • % Volume delivered: 43%
Results – Landslides

- Landslide Metrics @ Lucchetti
  - Mass deliv/area: 2,692 Mg km\(^{-2}\)
  - LLW sed yield: 3,170 Mg km\(^{-2}\) y\(^{-1}\)
  - Lake capacity: 10.21 x 10\(^{6}\) m\(^3\) *
  - Capacity loss rate: 0.6 – 0.8% *
  - HMA landslides: 1.1% loss of lake capacity

Results – Landslides

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  • HMA landslides: 1.1% loss of lake capacity

Therefore, landslides can account for much sediment accumulation at Lago Lucchetti if rain events like H. Maria occur frequently.

This is consistent with 1-10 y recurrence interval of H. Maria as a rainfall event within the Lucchetti watershed.

Methods – Landslides

• Method 3: Factors
  • **Frequency ratio**
  • FR > 1 indicates that the set of conditions led to a higher frequency of landslides than the area represented by those conditions
  • FR > 1, landslide prone
  • Factors evaluated: slope, H. Maria rainfall, geology, soils, land cover, distance from roads and streams
• **Method 3: Factors**
  
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Results – Landslides

• Method 3: Factors
  • Frequency ratio

![Graph showing frequency ratio vs. distance from roads (m)]
Results – Landslides

• Method 3: Factors
• **Frequency ratio:** Roads (LiDAR allows to ‘see’ & map them)

- 900 km of roads in LLW
- 20.7 km km\(^{-2}\)
Results – Landslides

- Method 3: Factors
  - Frequency ratio
• Conclusions

• Hurricane Maria mobilized and delivered an amount of sediment that is similar to a year’s worth of accumulation at Lago Lucchetti.

• Some of the factors that control sediment mobilization by landsliding include slope, current land cover, lithology/soils, and roads
Conclusions & hypotheses

• Hypotheses

• Landslides could be the ‘missing sediment source’ in the LLW if they occur very frequently.

• This seem plausible given the low recurrence interval of H. Maria and that the required frequency of landsliding (20-30 slides km$^{-2}$ y$^{-1}$) is within ranges reported in the literature in other parts of the world.

• High susceptibility to landslides and high sediment yields at LLW are likely the product of frequent intense events [not necessarily hurricanes], prominence of slopes 35-55°, current agricultural activities and roads from both current and abandoned farms.