Climate Change Impacts on Joint Riverine and Coastal Flooding on Calleguas Creek in Ventura County, CA

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Lily Verdone (TNC)

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Project Overview

- Through its Coastal Resilience Program, TNC has undertaken several studies to evaluate the influence of climate change on flood risk to natural and infrastructural resources.
- These studies, including Coastal Resilience Ventura, provide science driven information to inform planning and policy to address future flood risk.
- ESA and Argos Analytics have expanded on the Coastal Resilience Ventura Study to include Calleguas Creek.
- The goal of the project was to map changes in flood inundation for a series of climate scenarios.

Image source: TNC (http://maps.coastalresilience.org/network/)
Project Team

• The Nature Conservancy
  – Provided project funding and stakeholder coordination
  – Team members include Lily Verdone, Sarah Newkirk, and Kelly Leo

• ESA
  – Managed project and conducted technical analysis
  – Team members include Bob Battalio (PD), Andy Collison (technical lead), James Gregory (PM), and James Jackson (technical lead)

• Argos Analytics
  – Provided climate change technical analyses
  – Team members include Bob Dickinson and Bridget Thrasher
Project objectives

• Characterize impact of climate change on coastal and riverine flood risk for Calleguas Creek at the Naval Base Ventura County and Mugu Lagoon
• Develop geospatial flood risk data to be hosted online to enable informed planning and policy decisions and address the impacts of climate change on flood hazards
Site overview
Key Project Outcomes

• Through this project ESA developed:
  – Estimates of future 100-year discharge on lower Calleguas Creek and Revolon Slough for 2030, 2060, and 2100 for medium and high emissions pathways
  – A new 2D hydrodynamic model for the creek systems using HEC-RAS2D
  – Flood inundation extent and depth maps and GIS layers from the 2D model results for the six climate change scenarios and one existing conditions scenario

• A draft report was developed and geospatial data provided to TNC for hosting on the coastal resilience website: http://maps.coastalresilience.org/california/
Project Approach

• Hydroclimate data analysis
  – Conducted to assess future extreme rainfall-runoff and coastal flooding conditions
  – Developed estimates of extreme coastal flood levels
  – Developed estimates of 100-year discharge on Calleguas and Revolon for 2030, 2060, 2100 for medium and high climate scenarios

• 2D Hydrodynamic modeling
  – Conducted to capture floodplain storage and 2D flow routing for more accurate depictions of flood inundation patterns at the project site
  – Used HEC-RAS 2D (2015 beta)
Climate scenarios – watershed hydrology

Emissions scenarios

• Emissions scenarios
  – Latest IPCC emissions scenarios, known as Representative Concentration Pathways (RCPs), were used
  – RCP 4.5 used for medium conditions
  – RCP 8.5 used for high conditions

• RCP 4.5 – medium scenario
  – Comparable to SRES B1. Scenario assumes strong reforestation, decreased farming intensity, CO₂ emissions decline around 2040

• RCP 8.5 – high scenario
  – Between SRES A2 and A1F1. Emissions triple by 2100, increase in population to 12 billion and increase in farming, no successful implementation of climate policies

Comparison between SRES and RCP emissions scenarios. Reproduced from Figure 1-4 of IPCC AR5, WGII, Chapter 1
Climate scenarios – watershed hydrology

Climate data and routing

- Daily downscaled datasets for surface runoff and baseflow have been created by the IPCC modeling groups. The data is publically available at gdo-dcp.ucllnl.org/
- Daily data was routed to watershed outlet using University of Washington’s Variable Infiltration Capacity model
- Daily streamflow data was used to conduct flood frequency analysis on annual maxima
Climate scenarios – watershed hydrology

Flood Frequency

Future Conditions

Current conditions

100-year flow
2100 high

100-year flow
Existing conditions
Climate Model Uncertainty

- Climate models show wide range in results
- Selecting the median for high emissions scenarios could underrepresent potential changes
- Higher percentile should be selected to characterize high-risk conditions
Climate model 100-year flow analysis

High emissions scenario (RCP 8.5 at 90th percentile for all time horizons)

Medium emissions scenario (RCP 4.5 at 50th percentile averaged for three time horizons)
# Future 100-year discharge

<table>
<thead>
<tr>
<th>Flood Source</th>
<th>Medium emissions</th>
<th>High emissions</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>FEMA FIS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2030</td>
<td>2060</td>
</tr>
<tr>
<td>Revolon Sough</td>
<td>10,000</td>
<td>11,930</td>
</tr>
<tr>
<td>Calleguas Creek</td>
<td>37,630</td>
<td>44,880</td>
</tr>
</tbody>
</table>
Climate scenarios – Sea level rise

• Medium SLR curve
  - NRC 2012: Global SLR from table 5.3. Polynomial O(2) fit to obtain global SLR for intermediate yrs.

• High SLR curve
  - CCC 2013: Equation B-3 from draft SLR guidance document, based on NRC 2012 report
Future Extreme Tide Levels

- Medium and high sea level rise scenarios developed based on NRC sea level rise study and OPC guidance
- Coastal storm surge based on 10-year extreme tide from nearby NOAA tide gage plus wave setup

<table>
<thead>
<tr>
<th>Time period</th>
<th>Medium</th>
<th>High</th>
<th>Medium SLR</th>
<th>High SLR</th>
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<tbody>
<tr>
<td>2015</td>
<td>-</td>
<td>-</td>
<td></td>
<td>9.1</td>
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<tr>
<td>2030</td>
<td>0.5</td>
<td>1.0</td>
<td>9.5</td>
<td>10.1</td>
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<tr>
<td>2060</td>
<td>0.9</td>
<td>2.6</td>
<td>10.0</td>
<td>11.6</td>
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<tr>
<td>2100</td>
<td>3.1</td>
<td>5.5</td>
<td>12.1</td>
<td>14.6</td>
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</tbody>
</table>
HEC-RAS2D Model
Sedimentation and bed aggradation

- Existing Conditions Maximum 100-year WSE
- 2030 medium thalweg
- 2030 high thalweg
- 2060 medium thalweg
- 2060 high thalweg
- 2100 medium thalweg
- 2100 high thalweg
- Existing conditions thalweg

Elevation (ft NAVD)

Station (ft U/S of Pacific Ocean)
Comparison to FEMA 100-year Floodplain

- Existing conditions 100-year flow shows less inundation than FEMA 100-year flood map
- Primary differences are on Revolon Slough
- Differences are due to accounting for routing and volume using unsteady 2D model
Coastal vs Fluvial Effects

- Flood extents increase with greater flow and higher coastal water level
  - Fluvial flow dominates upstream of Highway 1
  - Coastal tide level dominates downstream of Highway 1
Results animations - Existing Conditions

Existing

High 2100
## 2D Inundation Results

<table>
<thead>
<tr>
<th>Time Horizon</th>
<th>Emissions and SLR conditions</th>
<th>Total inundated area (ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>On NBVC</td>
</tr>
<tr>
<td>2015</td>
<td>Existing conditions</td>
<td>1,950</td>
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<tr>
<td>2030</td>
<td>Medium</td>
<td>2,350</td>
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<td></td>
<td>High</td>
<td>2,720</td>
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<tr>
<td>2060</td>
<td>Medium</td>
<td>2,670</td>
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<tr>
<td></td>
<td>High</td>
<td>3,440</td>
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<td>2100</td>
<td>Medium</td>
<td>3,600</td>
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<tr>
<td></td>
<td>High</td>
<td>3,840</td>
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</tbody>
</table>
Spatial Aggregation =
Adding together overlapping hazard zones, pixel by pixel, to show relative probability.

Sources: ESA PWA 2012 (Figure), Google Earth 2012 (Image)
Spatial Aggregation Results

- Most of area east of Calleguas and between Calleguas and Revolon is inundated during all scenarios.
- Inundated area increases by 1,900 acres on NBVC and 3,300 acres upstream of Highway 1 by 2100.
Additional climate tool applications

- Estimate change in magnitude for given recurrence interval flood
  - For example, what is the peak flow for the 100-year event at the end of the century
- Estimate change in frequency for current flood event
  - For example, how frequent will today’s 10-year event be in 2050
- Estimate change in rainfall intensity-duration-frequency curves
  - For example, what is the 24-hour 10-year rainfall depth in 2050
- Estimate future functionality of existing facilities
  - For example, how frequently will the flow capacity be exceeded for a given channel or stormwater pipe by 2030. By 2050?
Additional climate and flooding project applications in coastal and fluvial settings

- **Fluvial and Coastal Flooding**
  - Ventura County
    - Calleguas Creek, Santa Clara River, Ventura River
  - Monterey and Santa Cruz Counties
    - Soquel Creek, Salinas River, Scott Creek and Waddell Creek
  - Santa Barbara County
    - Carpinteria Creek, Mission Creek Lagoon, Laguna Channel
  - City of Del Mar
    - San Dieguito River
  - San Luis Obispo County
    - Arroyo Grande Creek
  - San Diego County
    - San Diego Bay, Chula Vista Bayfront
  - Caltrans District 1 (Humboldt, Mendocino, Del Norte, Lake Counties)
  - Los Angeles County
    - Ballona Creek
  - Marin County
  - City of Albany
  - San Mateo County
  - Hayward Shoreline
  - FEMA Coastal Flood Guidelines
  - City of Eureka
  - Ocean Beach
  - Surfer’s Point Managed Retreat City of Ventura
  - CA Statewide
    - Inundation and erosion hazards mapped for Pacific Institute study (PWA, 2009)
Summary and Conclusions

• Combined fluvial and coastal flood hazard maps were produced for a range of climate scenarios. These maps will be hosted online and provide science-based data to inform planning and policy decisions.

• Analysis of global climate model data showed significant increases in future extreme streamflow. Combined with large changes in sea level, flooding in coastal areas is expected to increase significantly through this century.

• ESA has developed tools and methodologies to leverage existing downscaled hydroclimate datasets to evaluate common metrics for flood and stormwater management.

• These tools and methods have been applied extensively throughout the state and we continue to refine our approach to improve our understanding of how climate change will impact future fluvial and coastal flood dynamics and how communities can respond to expected changes.