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Current and Future Flood Risk Under Climate Change in New Paltz, New York

Summary

Inland floods are some of the most devastating natural disasters and are expected to worsen under climate change due to the intensification of extreme precipitation. In this study, present and future flood risk in New Paltz, NY, is examined through changes in the 1-in-100 year and 1-in-500 year flood events. Future rainfall and streamflow are estimated for two time periods, 2041-2060 and 2071-2090 representing the mid and late 21st century, respectively, using a regional climate model and river-reach scale hydrologic model.

The output of these simulations show that the historical 100-year rainfall event is 1.5x and 4x as likely in 2041-2060 and 2071-2090, respectively. The historical 100-year streamflow event is 2x and 3.7x as likely in 2041-2060 and 2071-2090, respectively. Greater changes in frequency were calculated for the 500-year rainfall and streamflow events.

Using these estimates as inputs into a flood model reveal significant increases in flood risk across New Paltz. The total inundated area for the 100-year event within the flood model domain increases by 7% and 20% by mid and late 21st century, respectively. The number of buildings inundated by the 100-year event increases by 12% and 34% by the mid and late 21st century, respectively. These metrics also increase in the future periods for the 500-year event but the changes are smaller in magnitude.

Introduction

Combustion of fossil fuels, deforestation, and other human activities release greenhouse gases (GHGs). These, in turn, have increased global average temperature at unprecedented rates. From 1901-2016, global average temperatures have already risen by 1°C (1.8°F) (Hayhoe et al., 2018). The rate of warming is not attributable to natural variability and has no natural explanation. United Nations Framework Convention on Climate Change goals aim to prevent the most catastrophic impacts of climate change by limiting global warming to 2°C (3.6°F). The way that Earth's natural systems respond to the rapidly warming climate and human disruption will impact our quality of life for generations to come. Understanding and preparing for these changes is critical.

The impacts of climate change on frequency and severity of physical hazards will put many communities at risk. Physical hazards include extreme precipitation events, severe storms, extreme heat events, and flooding. Socioeconomic consequences include adverse public health outcomes, loss of critical infrastructure, and agricultural yield reduction.

In this report, we examine climate change driven flood risk for New Paltz, NY. Due to climate change, New Paltz and much of the Northeast is expected to see an intensification of extreme precipitation events and therefore, flood events (Dupigny-Giroux, 2018). Changes in the climate have caused rainfall intensification in the Northeast to outpace other parts of the United States. Floods can lead to temporary displacement, infrastructure damage, and worsened economic/social inequalities. Much of the infrastructure, such as drainage and sewer systems, in the Northeast are nearing their planned life expectancy, and climate-related events will put further strain on these systems.

Flooding is the costliest and deadliest natural disaster in the United States (Perry, 2000; Miller et al., 2008). Flood risk is composed of three components: hazard, exposure, and vulnerability. Hazard refers to a destructive event (i.e. flooding), exposure represents the local community elements (e.g. people, buildings, infrastructure) that could be impacted by flooding, and vulnerability is the susceptibility of those community elements to be damaged by flooding (e.g. lack of resilient planning). This report will focus on flooding in New Paltz, New York, and will examine how flood events will be different in the future under climate change. The report will also discuss building exposure and general exposure across the area of interest.

There are three different types of flooding: fluvial, pluvial, and coastal. Fluvial (also known as riverine) flooding occurs when rivers exceed the boundaries of the river channel. Pluvial flooding takes place during extreme precipitation events and is not associated with riverine flooding. This usually occurs when a stormwater system or soils cannot effectively drain or infiltrate rainfall leading to standing water. Coastal flooding occurs during storm surge or high tide events. New Paltz is vulnerable to the first two: fluvial and pluvial. The main riverine flood risk in New Paltz is from the Wallkill River which runs directly adjacent to the downtown area; however, fluvial flooding also occurs in streams, creeks, and kills within the watershed. Pluvial flood risk exists in urbanized areas where the stormwater system cannot properly convey a rainfall event and in natural depressions where drainage is poor. Early spring is the most likely time of year for flooding due to snowmelt coinciding with heavy rainfall, but the largest floods in New Paltz have occurred during hurricanes which can form during the summer and early fall.

New Paltz has experienced several devastating flood events, the most recent being in 2011 when Hurricane Irene dropped almost 25 cm (10 inches) over a few days (Mansmann, 2011). The 2 to 3-day event had a return period between a 1-in-100-year and 1-in-200-year. The wastewater treatment plant suffered flood damage during the storm and the stormwater system was overwhelmed by the heavy rainfall. Yet, the record water level for the Wallkill River occurred in 1955 when Hurricanes Diane and Connie hit the region a week apart (USGS, 2020).

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Project Overview

This study first explores the present flood risk in New Paltz using historical (also referred to as present) rainfall and streamflow data. We focus on the 1-in-100 year (1% annual chance event) and the 1-in-500 year (0.2% annual chance event) due to the importance of these events in regulation. The Federal Emergency Management Agency (FEMA) determines flood risk and properties required to purchase flood insurance mainly through delineating the extent of the 100-year event. A comparison is made between the flood modeling results generated in this study to the currently effective FEMA flood maps to showcase the deficiencies in the present federal flood mapping methodology.

As mentioned previously, climate change is expected to exacerbate current flood risks across the United States. To provide New Paltz a window into how these changes will manifest locally, we use climate model simulations to calculate future streamflow and rainfall in two future periods: 2041-2060 and 2071-2090 each centered on 2050 and 2080, respectively. The first time period represents the mid-21st century climate, and the second represents the late 21st century climate. The results from these streamflow and rainfall analysis are used as inputs into a flood model to simulate future flood events. We present results from the late 21st century as this is relevant for large infrastructure projects; the design life of many infrastructure systems such as rail tracks, bridges, transmission lines, generating plants, water treatment and wastewater treatment plants, and stormwater systems usually have a 50-year or longer design lifetime (Gibson, 2017). Furthermore, many of these installations are often used beyond their design period, which means it is likely that infrastructure built in 2020 will still be in use by the late 21st century. Presenting projected flood risks in the 2071-2090 timeframe allows planners to incorporate information on future flood risks in policy choices and the chance to mitigate flood losses.

Methodology

Present and future flood risk in New Paltz is estimated using the LISFLOOD-FP flood model version 5.9 (Bates et al., 2000). LISFLOOD-FP has been tested extensively and produces comparable results to several localized and detailed flood studies conducted by the United States Geological Survey (USGS) (Neil et al., 2012; Coulthard et al., 2013). Wing et al. (2017) compared the output of a continental United States LISFLOOD-FP model run at a 30-meter resolution to USGS flood risk estimates that utilized elevation data with resolutions between 1 and 10 meters. The LISFLOOD-FP model was able to achieve a consistent hit rate of at least 80% across nine USGS flood studies that estimated the 1-in-100 year flood event.[1] The critical success index was between 60% and 90% for all but one USGS flood benchmark study. Therefore, LISFLOOD-FP was chosen to model flood risk for New Paltz because of its

[1] The hit rate measures how well the model predicted the number of wet cells in the benchmark data. Essentially, the hit rate gives an indication of how much the model underpredicted the validation data. The lower the hit rate, the greater the underprediction. The critical success index accounts for both underprediction and overprediction and so will usually be lower than the hit rate.

computational efficiency when run at high spatial resolutions and its ability to accurately estimate flood risk at large spatial scales.

As mentioned, New Paltz is vulnerable to two sources of flooding: fluvial and pluvial. To simulate the worst-case scenario, both flood sources were used as inputs to model the 24-hour compound flood event. In this context, the compound flood event is defined as the flood extent caused by the 1-in-100 year rainfall and streamflow events occurring simultaneously. As discussed below, the 1-in-100 year rainfall and streamflow values were calculated independently from each other using various data sources. However, this does not mean that the rainfall and streamflow events are probabilistically independent of each other. A storm system moving northwards through the Wallkill River watershed would result in fluvial and pluvial flooding. Therefore, in order to avoid underestimating flood risk, both fluvial and pluvial flood sources were modeled together to provide a realistic estimate of the 1-in-100 year flood event. Finally, only grid cells with a water depth greater than or equal to 0.15 meters (6 inches) are shown in the final maps. We apply this threshold because water depths above this level have the potential to cause property damage (EA, 2019).

Several inputs are required to run the model which are described in detail below:

1) *Elevation data*: The USGS 1-meter horizontal resolution Digital Elevation Model (DEM) created from LiDAR (Light Detection and Ranging) data for Ulster County was resampled to a 7-meter resolution DEM (USGS, 2015). Traditionally, during flood modeling, the bathymetry of the river is represented through cross sections in order to estimate the volume of water a river can convey within its banks. However, the bathymetry is not represented in this DEM since the DEM metadata states the DEM was hydro-flattened. Although the bathymetry of the Wallkill River was not included in this study, overestimates of flooding is not a concern because, as mentioned below, discharge is not used as an input, but rather gage height. Culverts identified through Google Maps imagery and those present in the Culvert Prioritization Project led by New York State Department of Environmental Conservation and Cornell University were burned into the final DEM (Cornell, 2020).

2) *Rainfall*:
    a. *Present rainfall*: Intensity-duration-frequency rainfall data was extracted from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 (NA14) at 41.7469°N, -74.0766°E (Perica, 2019). The 24-hour 100-year and 500-year rainfall amounts were applied using a frequency-based storm rainfall distribution. This distribution consists of nested precipitation depths for different storm durations with the same return period. This rainfall distribution was selected because of its usefulness within design and engineering frameworks (USACE, 2000).
    b. *Future rainfall*: There are two steps to calculate the future rainfall amounts from the 100-year and 500-year events. The first is to estimate the change in probability of the 100-year and 500-year precipitation events in the 2041-2060 and

2071-2090 future periods in historical (2001-2020) under the Representative Concentration Pathway (RCP) 8.5 scenario. We calculate the change from future period to historical rather than historical to future so that an observed historical rainfall amount can be calculated for the future 100-year and 500-year events. We use RCP8.5, the most aggressive emissions scenario, because it most closely matches historical emissions from 2005 to 2020 (within 1% for total carbon dioxide emissions) compared to other pathways (Schwalm et al., 2020). We use output from a regional 0.22º resolution climate model, REMO2015, which was forced by 3 general circulation models (GCMs) to calculate the change in probability (Remedio et al., 2019). A regional frequency analysis method was used to fit a generalized extreme value (GEV) distribution by the method of L-moments to the full model ensemble output using the Bukovsky regions (Hosking et al., 2005; Bukovsky, 2011). The full ensemble was used to maintain consistency with the streamflow analysis discussed below. The second step is to assign a rainfall amount to the change in probability. The future percentile value for the pixel containing the New Paltz watershed for the historical (2001-2020) 100-year and 500-year precipitation events were then assigned a precipitation amount based on the NA14 Intensity-Duration-Frequency curves. While precipitation biases may exist in the raw model output, assessing the extreme rainfall probability change through a percentile-based method and then assigning a precipitation amount based on the observational record should reduce the impact of those biases on estimated changes in future extreme precipitation. Finally, while there is temporal variation of the rainfall input, the flood model only allows for a spatially constant rainfall rate.

3) *Streamflow*:
   a. *Present streamflow*: Gage height is used as an input for the flood model and not discharge to avoid overestimates of flood extent given a lack of bathymetry data for the Wallkill River. The present 100-year and 500-year gage heights were estimated using the peak gage height data available at the Wallkill River USGS stream gage station (ID: 01371500) (USGS, 2016). Peak river stage data for 95 water years (1925-2019) were fitted to a Gumbel distribution using the maximum likelihood estimator (MLE) method. The Gumbel and MLE method were chosen based on the lowest calculated Bayesian Information Criterion (BIC) and Akaike Information Criterion (AIC) for the GEV, Gumbel, and Pearson Log III distributions estimated using the L-moments and MLE method. The stream gage location was used as the upstream boundary point for the flood model. The hydrograph input was created by using the most recent extreme flooding event, Hurricane Irene which occurred on August 28th, 2011. The difference between the peak and 12 hours before and 12 hours after were used to estimate the starting and ending river stage heights, respectively, for the 100-year and 500-year events. The starting height was lowered further to avoid numerical instabilities in the flood model. The hydrograph peaks for 7 hours similar to the 2011 flood event.

b. *Future streamflow*: As was done for future rainfall estimates, all future streamflow analyses were completed assuming the RCP8.5 scenario. To calculate the change in probability of the historical 100-year and 500-year streamflow events, river reach streamflow data from Wobus et al. (2017) modeled through 2100 was used. The full model ensemble (29 GCMs) data for the Wallkill River reach closest to New Paltz was fit to a GEV distribution (as was done in Wobus et al.) using the MLE method, justified through a BIC and AIC analysis. The future streamflow amount was then assigned to the future 100-year and 500-year events using the historical Gumbel distribution discussed previously.

4) *Floodplain friction values or Manning's n values*: Each pixel in the model domain was assigned a friction value based on land cover from the National Land Cover Database 2016 (Yang et al., 2018). The friction values come from an analysis completed by the United States Department of Agriculture (NRCS, 2016).

5) *Infiltration Rates*: Soil infiltration rates were assigned using the hydrologic group attribute in the SSURGO database and the infiltration rates from the Minnesota Stormwater Manual (Soil Survey Staff; MSSC, 2020). While the stormwater system is important for estimating pluvial flooding, the New Paltz stormwater system has not been fully mapped nor the capacity analyzed and therefore it is not possible to incorporate the stormwater system in the flood model. Discussions with local officials and engineering firms have revealed that the stormwater system was installed decades ago and the capacity has never been measured.

Finally, we note sources of uncertainty in this study that have not been previously mentioned. The first being that the uncertainty in climate model output increases with spatial resolution since climate models are estimating some atmospheric processes that occur at spatial resolutions higher than the model resolution. Within a flood model, there is some uncertainty regarding antecedent moisture conditions as these can impact the ability of soils to infiltrate rainfall and thus flooding. Sensitivity tests regarding antecedent moisture conditions were not completed as part of this study. Additionally, there is uncertainty in pluvial flood estimates in urban areas where stormwater systems are not adequately represented.

Results

A. Present Flood Risk and Comparison to FEMA Flood Maps

The present 1-in-100 year flood extent generated in this study is compared to the FEMA 100-year flood extent in Figure 1 within the boundaries of the Town of New Paltz. The two flood extents agree quite well along the Wallkill River; however, the flood extent generated by Woodwell is overall greater than FEMA's. This result can be clearly seen in the eastern areas of New Paltz. These discrepancies mainly occur because FEMA does not consider pluvial flooding and focuses on riverine events (Wing et al., 2017). Small streams are not modeled by FEMA and so FEMA maps likely show underestimates of total flood risk within a community. Additionally, while the current effective flood maps from FEMA for Ulster County were published in 2016, the hydrologic analysis used in the creation of the maps dates from 1984 and has not been updated. FEMA also only shows historical flood risk and does not incorporate future changes in the climate (Pralle, 2019).

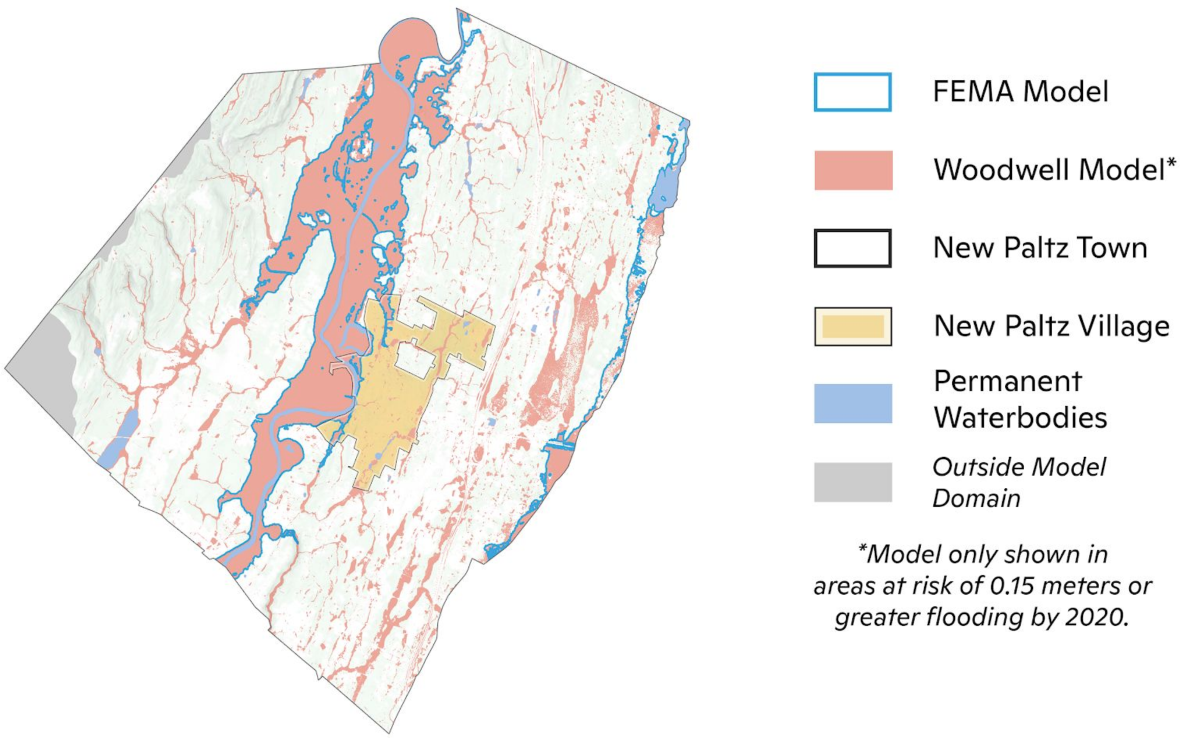

Figure 1. The 1-in-100 year flood extent for New Paltz generated by Woodwell and FEMA.

B. *Shifting Return Periods of Extreme Rainfall and Streamflow*

To give an initial indication of how the frequency of historical extreme rainfall and streamflow events will change in the 21st century, the future return periods of the historical (2001-2020) 100-year and 500-year in the 2041-2060 and 2071-2090 time frames are shown in Tables 1 and 2. The historical 100-year rainfall event is 1.5x and 4x as likely in 2041-2060 and 2071-2090, respectively. The historical 500-year rainfall event is 1.8x and 5.8x as likely in 2041-2060 and 2071-2090, respectively. The historical 100-year river stage event is 2x and 3.7x as likely in 2041-2060 and 2071-2090, respectively. The historical 500-year river stage event is 3.5x and 7.6x as likely in 2041-2060 and 2071-2090, respectively. We note that while the direction of probability change is consistent between rainfall and streamflow, the magnitude of the change varies. This difference becomes more apparent the rarer the event (100-year vs 500-year) and the further we go into the future. There are several possible reasons for this phenomenon. The first is that we use different models to analyze changes in rainfall versus streamflow. The second is that we are using a 20-year time period to estimate extreme events with return periods several times greater than the time period length (e.g. 100-year). While using the full ensemble of models allows for robust statistical estimates, there are still uncertainties in the model output.

Table 1. Historical (2001-2020) return period of future rainfall events.

	2041-2060	2071-2090
1-in-100 year	1-in-67 year	1-in-25 year
1-in-500 year	1-in-285 year	1-in-86 year

Table 2. Historical (2001-2020) return period of future streamflow events.

	2041-2060	2071-2090
1-in-100 year	1-in-51 year	1-in-27 year
1-in-500 year	1-in-144 year	1-in-66 year

C. Future Flood Extents and Building Damage Assessment

Using the future return periods shown in Tables 1 and 2 as inputs into the flood model, future flood extents are generated for the 100-year and 500-year events in 2041-2060 and 2071-2090. The percent change in flood depth is then calculated from the baseline period. These results are shown in Figures 2, 3, 4, and 5. Changes in flood extent in these maps can be identified in dark orange areas where the percent change in flood depth approaches 100%. New Paltz will experience not only increases in flood extent but also significant increases in flood depth by the mid and late 21st century. Flood extents do not shift dramatically at the New Paltz Town-scale between the present and future time periods mainly because the topography rises rather rapidly at the edges of the Wallkill River floodplain. However, with higher flood waters come greater flood damages. Even buildings with flood defenses in place and elevated structures may be at risk of flooding in the future because of these higher water levels. Changes in total inundated area and average water depth within the flood model domain are shown in Table 3 to provide a high-level view of the changes in flood risk.

Table 3. Changes in flood extent and average flood depth from present period.

	% Change in Flood Area	Change in Average Water Depth in cm (ft)
2041-2060 100-Year	7.2	13 (0.43)
2071-2090 100-Year	20.2	35 (1.14)
2041-2060 500-Year	4.8	30 (0.99)
2071-2090 500-Year	14.1	45 (1.47)

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Many neighborhoods are projected to see significant increases in flood risk. For example, the area north of downtown New Paltz adjacent to the New Paltz Golf Course and along New York State Route 32 will see moderate increases in flood extent by 2041-2060 and even greater changes by 2071-2090. Flood depths for the 100-year event will rise approximately 20 cm (8 inches) and 60 cm (2 ft) by mid and late 21st century, respectively. The wastewater treatment plant, a critical piece of infrastructure, is currently within the 100-year flood extent and with higher flood waters may be offline for longer periods of time in the future due to greater than anticipated flood damage based solely on historical estimates. The 100-year water depth is projected to increase by more than 60 cm (2 ft) in this section of the Wallkill by 2071-2090. The intersection at South St and New York State Route 299 in eastern New Paltz is already vulnerable to the 100-year event and will experience even greater risk by the late 21st century. Poor drainage and conveyance in the Swarte Kill will cause water depths to rise 20 cm (8 inches) and 30 cm (12 inches) by 2041-2060 and 2071-2090, respectively, for the 100-year event.

An additional analysis was completed to estimate the number of buildings in the model domain affected by at least 15 cm (6 inches) of flooding. Building outlines were taken from the New York State Building Footprints with Flood Analysis completed by the Center for International Earth Science Information Network at Columbia University (CIESIN, 2019). The results are shown in Table 4 for both the 100 and 500 year events and each time period. Percent changes for future periods compared to the present are shown in parenthesis. High risk areas include along Springtown Rd in northern New Paltz which runs adjacent to the Wallkill River and in the northern section of the Village of New Paltz close to the New Paltz Golf Course. The downtown area begins to see greater pluvial flood risk later into the 21st century.

Table 4. Number of buildings (% change) in model domain flooded (water depth greater than 15 cm).

	Present	2041-2060	2071-2090
1-in-100 Year	957	1,071 (+12%)	1,282 (+34%)
1-in-500 Year	1,295	1,394 (+8%)	1,589 (+23%)

The urban space will not be the only area affected by increased flood risk. Agricultural lands will face more flooding in the future as well. Several farms, identified by the New York State Agricultural Districts[2], currently reside in the 100-year and 500-year floodplains. Flood extent changes in the future are greater in these areas of the floodplain than in urban spaces, especially at the northern edge of the Town boundary, which will lead to more agricultural losses than experienced historically. Several farms in the area experienced severe losses during Hurricane Irene in 2011 (Kemble, 2011).

[2] Available at the Cornell University Geospatial Information Repository (https://cugir.library.cornell.edu/catalog/cugir-007995)

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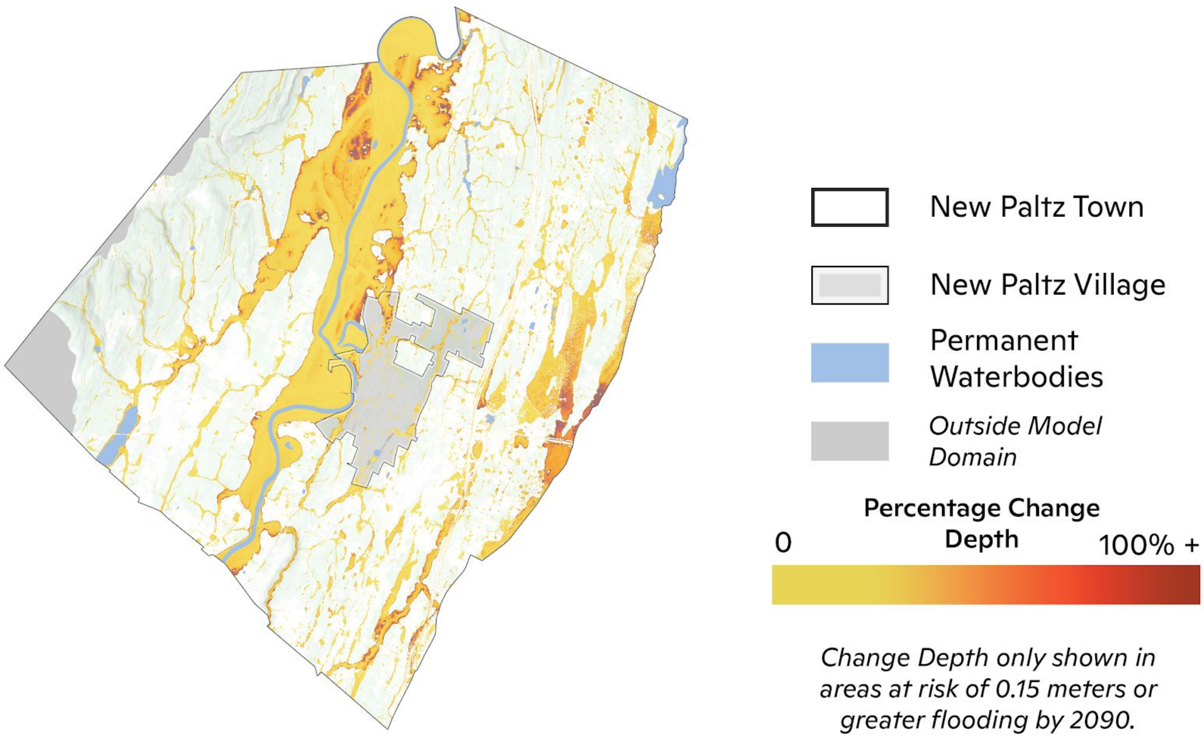

Figure 2. Percent change in water depth between 2041-2060 and present 1-in-100 year event.

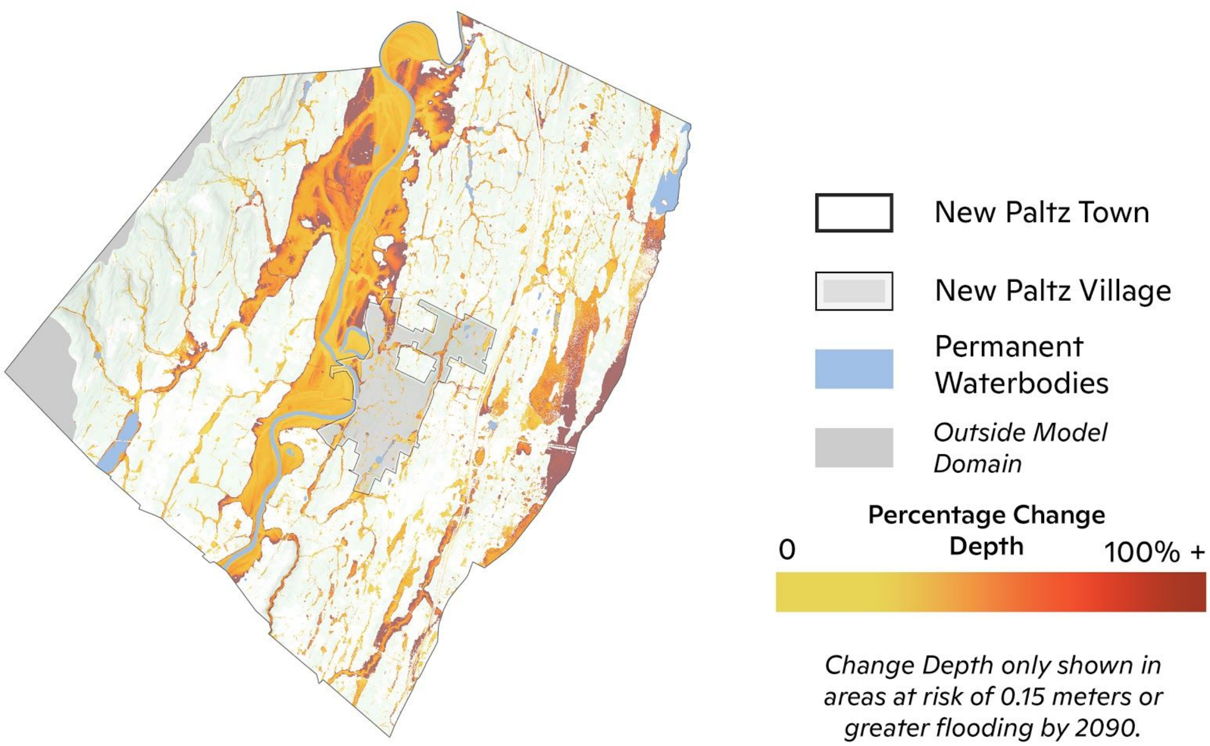

Figure 3. Percent change in water depth between 2071-2090 and present 1-in-100 year event.

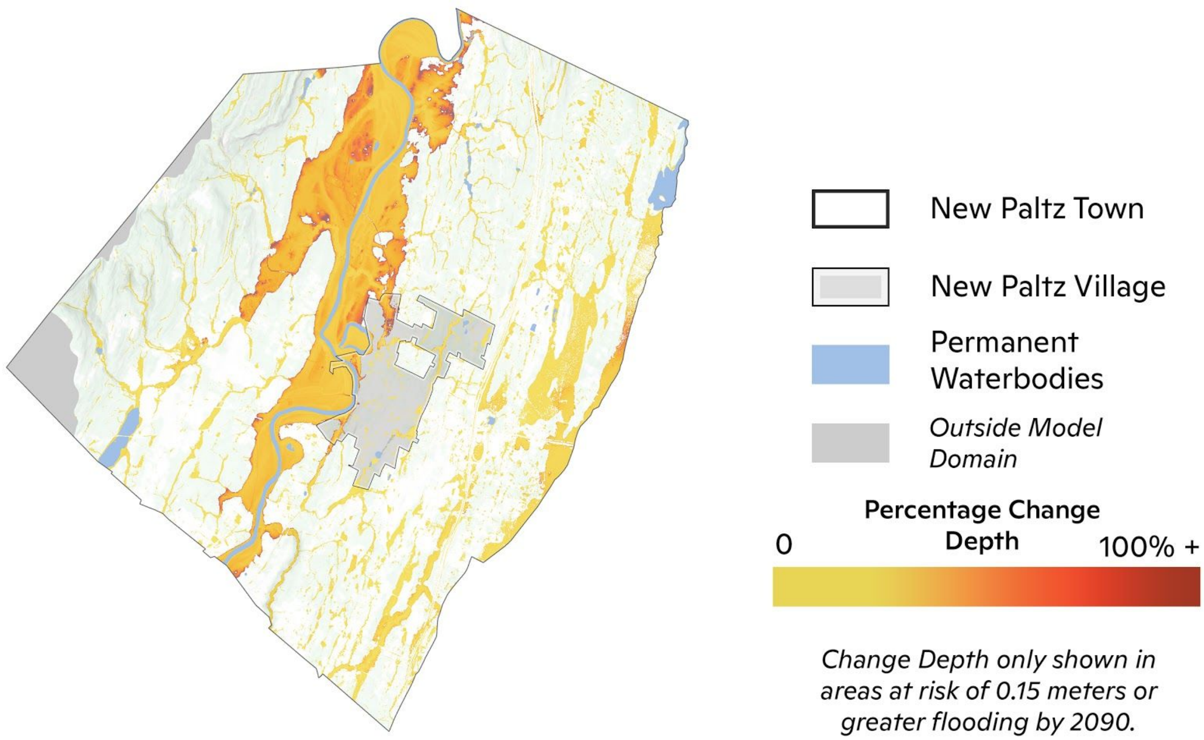

Figure 4. Percent change in water depth between 2041-2060 and present 1-in-500 year event.

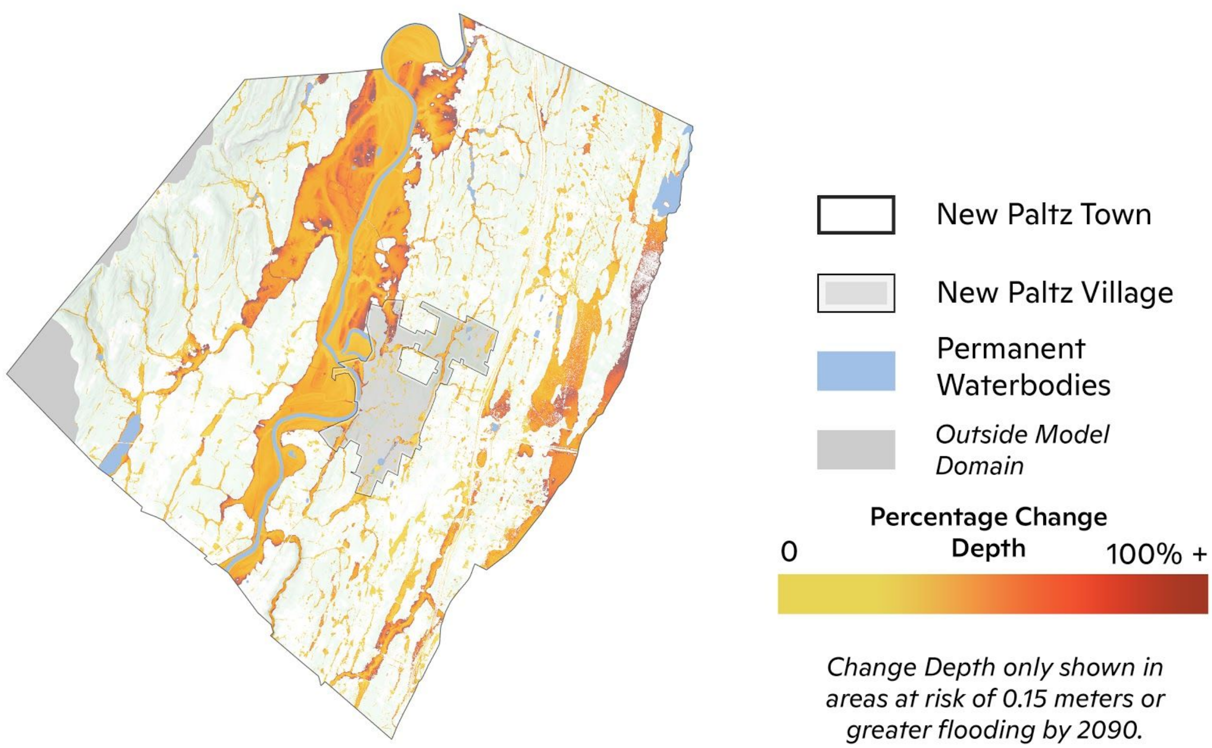

Figure 5. Percent change in water depth between 2071-2090 and present 1-in-500 year event.

About Woodwell Climate Research Center

Woodwell Climate Research Center ("Woodwell") is an organization of researchers who work with a worldwide network of partners to understand and combat climate change. We bring together hands-on experience and 35 years of policy impact to find societal-scale solutions that can be put into immediate action, including with municipalities that are so often on the front lines of the climate crisis.

We were founded in 1985 as the Woods Hole Research Center by George Woodwell, a visionary ecologist. Today, we work around the globe, conducting research in collaboration with policymakers and decision makers in more than 20 countries. We conduct research on a range of strategies to immediately address climate change, from carbon sequestration solutions using Earth's forests and soils, to climate risk assessments that seek to shift public perception and corporate behavior. Our scientists are widely published in leading scientific journals, testify to lawmakers around the world, and are regularly quoted in media outlets from *The New York Times* to *CBS Evening News*. They have contributed to every Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), and shared the 2007 Nobel Prize awarded to the IPCC.

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