Coastal Flooding

Identification

1. Indicator Description

This indicator describes how the number of coastal floods exceeding local “nuisance” threshold levels has changed over time. Sea level rise related to climate change is a key driver of the increasing frequency of coastal flooding.

Components of this indicator include:

- A map that shows the change in flood days per year along U.S. coasts, comparing the first decade of record with the most recent decade (Figure 1).
- A more detailed graph that shows average flood days per year along U.S. coasts from 1950 to 2015 (Figure 2).

2. Revision History

August 2016: Indicator published.

Data Sources

3. Data Sources

Coastal flooding trends are based on measurements from permanent tide gauge stations. The original tide gauge data come from the National Water Level Observation Network (NWLON), operated by the Center for Operational Oceanographic Products and Services (CO-OPS) within the National Oceanic and Atmospheric Administration’s (NOAA’s) National Ocean Service (NOS). Daily maximum water levels are derived from the hourly data set maintained by CO-OPS. Mike Kolian of EPA developed this indicator in collaboration with William Sweet of NOAA. The analysis is adapted from Sweet and Marra (2015), which is an update to an analysis published in NOAA (2014) and Sweet and Park (2014).

4. Data Availability

Individual tide gauge measurements can be accessed through NOAA’s “Tides and Currents” website at: https://tidesandcurrents.noaa.gov/stations.html?type=Water+Levels. This website also presents an interactive map that illustrates sea level trends over different timeframes. Station-specific flood thresholds for 26 of the 27 locations presented in this indicator, as well as other locations, are identified in NOAA (2014). See also Table TD-1 in Section 6 for a complete list of the NOAA tide gauge stations and flood levels used in this indicator.

EPA obtained the 1950–2015 analysis from the authors of Sweet and Marra (2015) and NOAA (2014). Although NOAA has not published a table of the compiled results presented in this indicator, a user could reproduce these numbers by processing the individual site data available on the website listed above. Updates to this indicator are likely to coincide with NOAA's annual report, *State of Nuisance Tidal Flooding*, which is released each spring.

Methodology

5. Data Collection

This indicator presents the change in flood days, which are defined as days in which a tide gauge records water levels that exceed the National Weather Surface (NWS) "minor flooding" threshold for a given location. Thus, this indicator captures all flooding events that exceed the minor flooding threshold, including the much less frequent occurrences of moderate or major floods.

Coastal water levels have traditionally been measured using tide gauges, which are mechanical measuring devices placed along the shore. These devices measure the change in sea level relative to the land surface, which means the resulting long-term analysis reflect both changes in flood frequency occurring from changing absolute sea surface height and local land levels.

Tide gauge data for this indicator come from NWLON, which is composed of 210 long-term, continuously operating tide gauge stations along the United States coast, including the Great Lakes and islands in the Atlantic and Pacific Oceans. This indicator shows trends for a subset of stations along the ocean coasts that had sufficient data from 1950 to 2015 and had established thresholds for what constitutes a minor or "nuisance" flood (see "Indicator Derivation"). NOAA (2014) describes tide gauge data and how they were collected. Data collection methods are documented in a series of manuals and standards that can be accessed at: www.co-ops.nos.noaa.gov/pub.html#sltrends. This indicator uses hourly averages based on each tide gauge's continuous measurements.

6. Indicator Derivation

This indicator was derived by calculating each day's maximum water level based on hourly water level data, then comparing these daily maxima with established threshold levels for minor flooding at each tide gauge. Flood impact levels have been established locally by NWS weather forecasting offices based on many years of impact monitoring. Each location has a unique flooding threshold, which depends on the local land cover, topography, the built environment, and human mitigation strategies in place. For example, an area with flat topography and extensive infrastructure near sea level might have a relatively low flooding threshold, because even a small increase in water level can cause impacts to humans. All of these local thresholds have been established as objectively as possible by working with local emergency managers and reviewing impacts relative to water levels.

Of the 210 NWLON tide gauges, 75 have locally defined minor flooding thresholds. Most of these stations are located along the Atlantic and Gulf Coasts, as these areas tend to be more vulnerable to large storm surges. A total of 27 of these stations had complete records for the 1950–2015 period of study, resulting in 27 sites for this indicator. Table TD-1 identifies the NOAA tide gauges and corresponding minor ("nuisance") flood levels for the 27 sites in this indicator.

Table TD-1. Tide Gauges and Nuisance Flood Levels Used in This Indicator

Tide gauge	Nuisance flood level (meters above mean higher high water [MHHW])
Boston, Massachusetts	0.68
Providence, Rhode Island	0.66
New London, Connecticut	0.60
Montauk, New York	0.60
Kings Point, New York	0.52
Battery, New York	0.65
Sandy Hook, New Jersey	0.45
Atlantic City, New Jersey	0.43
Philadelphia, Pennsylvania	0.49
Lewes, Delaware	0.41
Baltimore, Maryland	0.41
Annapolis, Maryland	0.29
Washington, DC	0.31
Sewell Point, Virginia	0.53
Wilmington, North Carolina	0.25
Charleston, South Carolina	0.38
Fort Pulaski, Georgia	0.46
Fernandina Beach, Florida	0.59
Mayport, Florida	0.44
Key West, Florida	0.33
St. Petersburg, Florida	0.84
Galveston, Texas	0.79
Port Isabel, Texas	0.34
La Jolla, California	0.51
San Francisco, California	0.35
Seattle, Washington	0.65
Honolulu, Hawaii	0.22

The total number of days exceeding the minor flooding threshold was calculated for each tide gauge and for every calendar year. Annual totals were averaged together over multi-year periods for Figures 1 and 2. Figure 1 provides a simple comparison between the first and last decades of record: the 1950s (1950–1959) and the 2010s (2010–2015). Figure 2 covers the entire period of record by sorting the data into bins, most of which are 20 years in length.

Sweet and Marra (2015) provide more information about station selection, data compilation, and calculation methods.

7. Quality Assurance and Quality Control

Quality assurance and quality control procedures for U.S. tide gauge data are described in various publications available at: www.co-ops.nos.noaa.gov/pub.html#sltrends.

Analysis

8. Comparability Over Time and Space

All of the tide gauges included in this indicator have used the same methods for determining hourly water levels. These methods remained constant over time and across gauges, except as documented in NOAA (2014). Tide gauge measurements at specific locations are not indicative of broader changes over space, however, and the network is not designed to achieve uniform spatial coverage. Rather, the gauges tend to be located at major port areas along the coast, and measurements tend to be more clustered in heavily populated areas like the Mid-Atlantic coast. Nevertheless, in many areas it is possible to see consistent patterns across numerous gauging locations—for example, increases in the frequency of flooding along the Atlantic and Gulf Coasts.

Flooding thresholds are established on a local basis, accounting for site-specific characteristics such as topography. Thus, thresholds are not exactly the same across space. For example, minor flood levels are 0.25 meters above the MHHW datum in Wilmington, North Carolina, compared with 0.79 meters in Galveston, Texas. This degree of variation is appropriate, as the indicator is designed to characterize an impact rather than just a physical condition, and thresholds for that impact naturally vary from one location to another. Thus, this indicator focuses more on comparing change over time at individual locations rather than comparing different locations over space. Each location's flood threshold has been applied consistently throughout the period of record, which supports this analysis of trends over time.

9. Data Limitations

Factors that may impact the confidence, application, or conclusions drawn from this indicator are as follows:

1. Coastal flooding relates to relative sea level change, which is the height of the sea relative to the height of the land. Changes in coastal flooding frequency cannot be solely attributed to absolute sea level change, but instead may reflect some degree of local changes in land elevation (e.g., subsidence). Tide gauge measurements generally cannot distinguish between these two influences without an accurate measurement of vertical land motion nearby.

2. Some changes in coastal flooding may be due to multiyear cycles such as El Niño/La Niña and the Pacific Decadal Oscillation, which affect coastal ocean temperatures, water density (due to salt content), winds, atmospheric pressure, and currents.

3. As described in "Comparability Over Time and Space," local flooding thresholds vary according to land cover, topography, and human mitigation strategies in place. This variation complicates regional frequency-change comparisons.

4. Not all tide gauges have NWS-defined flooding levels. This indicator only includes tide gauges with NWS flood levels and with hourly data since 1950, which results in sparse coverage on the Pacific and Gulf Coasts and no coverage of Alaska and Hawaii.

5. Impacts are localized and not necessarily readily observable. When water levels are expected to exceed the flooding threshold, coastal flood advisories are typically issued. Minor impacts typically, but not always, manifest.

6. Local topography may affect the relative influences of various environmental processes on a specific site's flooding. For example, offshore barriers such as coral reefs or barrier islands may help to buffer certain contributing effects, such as wind. By contrast, other areas may have topographical features that amplify the flooding caused by slight changes in the environment. Although these differences do not negate the site-specific trends observed, they do contribute to differences between stations.

10. Sources of Uncertainty

Error measurements for each tide gauge station are described in NOAA (2009), but many of the estimates in that publication pertain to longer-term time series (i.e., the entire period of record at each station, not the exact period covered by this indicator). Uncertainties in the data do not impact the overall conclusions. Tide gauges provide precise, reliable water level data for the locations where they are installed.

11. Sources of Variability

Changes in sea level and corresponding changes in coastal flooding can be influenced by multi-year cycles such as El Niño/La Niña and the Pacific Decadal Oscillation, which affect coastal ocean temperatures, salt content, winds, atmospheric pressure, and currents.

12. Statistical/Trend Analysis

This indicator does not report on the slope of the apparent trends in flood frequency, nor does it calculate the statistical significance of these trends. Separately, NOAA (Sweet and Park, 2014) analyzed trends in the annual number of flood days from 1950 to 2013 using quadratic and linear fits, and reported those with statistically significant fits above a 90% level. Of the 27 stations presented in this indicator, 19 had significant quadratic fits and four had significant linear fits. There were four stations, whose "nuisance-level" thresholds were quite high, that did not have a significant fit of any sort.

References

NOAA (National Oceanic and Atmospheric Administration). 2009. Sea level variations of the United States 1854–2006. NOAA Technical Report NOS CO-OPS 053. www.tidesandcurrents.noaa.gov/publications/Tech_rpt_53.pdf.

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Sweet, W.V., and J. Park. 2014. From the extreme to the mean: Acceleration and tipping points of coastal inundation from sea level rise. Earth's Future 2(12):579–600. http://onlinelibrary.wiley.com/doi/10.1002/2014EF000272/full.

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