Inundation Analysis Tool User Manual

About

The inundation analysis tool provides frequency and duration of inundation above a specified threshold elevation at a given location using observed data from the NOAA Center for Operational Oceanographic Products and Services (CO-OPS) water level stations. The analysis can be performed on verified six-minute data (using times and heights of high tides) or verified hourly data at most CO-OPS real-time or historic water level stations. The application was originally developed by the former CO-OPS Coastal Oceanographic Applications and Services of Tides and Lakes (COASTAL) Program for the purposes of marsh restoration and planning.

Over the past few years, CO-OPS' Coastal Hazards Branch has expanded the amount of coastal flood information available at stations through products like Coastal Inundation Dashboard and the Annual & Monthly High Tide Flood Outlooks. Historical flood day statistics are now available through these applications at select long-term stations, allowing users to understand how many days annually and seasonally that hourly water level observations exceeded a station-specific minor flood threshold. The Inundation Analysis Tool can provide a wealth of additional information for users who wish to have a deeper understanding of both flood frequency as well as duration, and how both have been impacted by sea level change. Furthermore, this tool allows users to compute inundation information on historical stations (in addition to real-time) and analyze flood frequency and duration using 6-minute water level observations providing capabilities that do not exist within other CO-OPS tools.

General Analysis Steps

1. Select a station
2. Select an existing (or enter a custom) threshold
3. Select a date range
4. Decide whether to compute an analysis on six-minute or hourly water level data
5. Run the analysis

Input

Station Selection

Inundation frequency and duration analysis can be performed on both real-time and historic stations that are tidal. Available stations can be selected on the station listing page at https://tidesandcurrents.noaa.gov/inundationanalysis/station_list.html. The list is divided into two sections, Active Stations (those that are actively measuring coastal water levels) and Active & Historic Stations, which also includes all other stations where CO-OPS has collected water level data to compute harmonic constituents on. In the future, accessing the Inundation Analysis Tool

for a station will be possible from the Tides and Currents website either through the header or footer that is present on most station products. Selecting a station will bring you to the parameter selection screen where you will select a threshold, date range and the type of analysis to run.

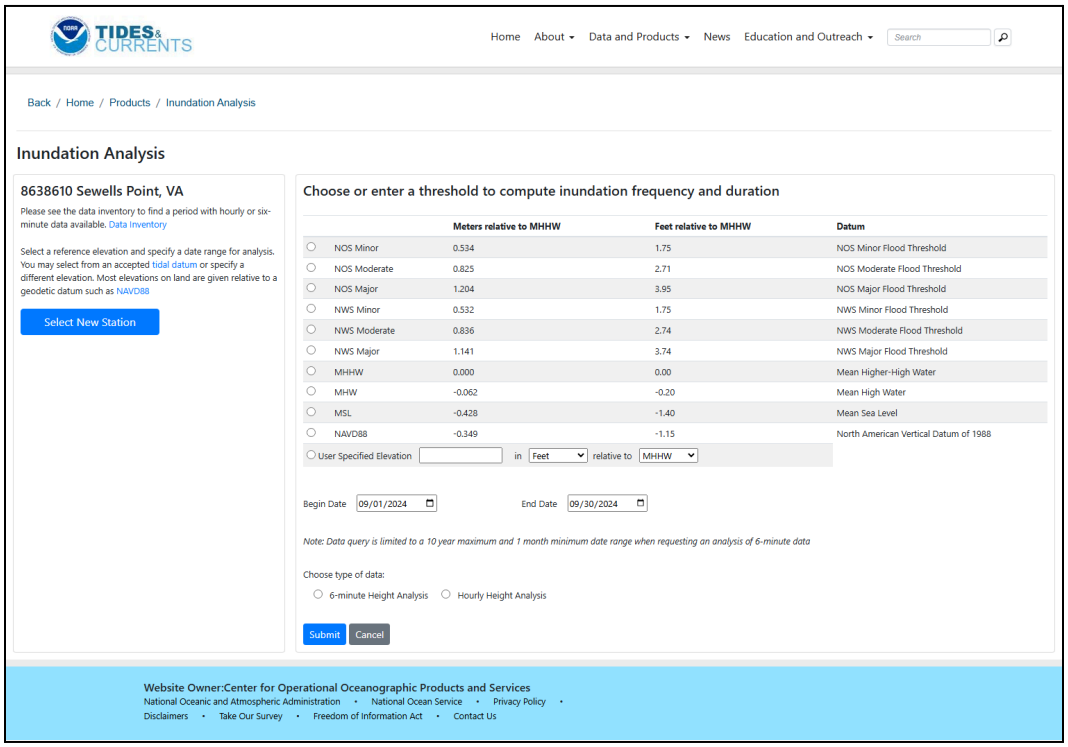


Figure: Example parameter selection screen for 8638610 Sewells Point, VA.

Selecting a Threshold

Each station's Parameter Selection menu allows users to select an existing threshold or enter a custom threshold. Existing thresholds include datum elevations for Mean Higher High Water (MHHW), Mean High Water (MHW), Mean Sea Level (MSL) and the North American Vertical Datum of 1988 (NAVD88).

Many newer stations, including almost all real-time stations also have pre-determined flood thresholds that can be selected. The NOS Minor, Moderate and Major flood thresholds have been established by CO-OPS for the purpose of evaluating historical and projected flood frequency both at a specific station and across a region. These thresholds are largely based on NOAA Technical Report NOS CO-OPS 086 – Patterns and Projections of High Tide Flooding and typically do not vary much across a geographical region. The NOS Minor flood threshold is primarily used to quantify historical flood days within Coastal Inundation Dashboard (https://tidesandcurrents.noaa.gov/inundationdb/) and historical and projected High Tide Flood (HTF) days within NOAA's Annual and Monthly High Tide Flood Outlooks (https://tidesandcurrents.noaa.gov/high-tide-flooding/). If looking to quantify frequency and

duration of past flood events identified by the historical flood days compiled by CO-OPS, the **NOS Minor** flood threshold should be used.

In addition to the NOS flood thresholds, the National Weather Service (NWS) has also established Minor, Moderate and Major flood thresholds at many CO-OPS stations for the purpose of coastal flood monitoring and warning through the National Water Prediction Service (NWPS) web product (https://water.noaa.gov/). These flood thresholds are largely driven by heights at which flooding becomes impactful near the specific station and could potentially vary significantly from station to station based on local geography and flood mitigation infrastructure.

The Inundation Analysis Tool also allows users to enter their own custom threshold (in feet or meters), relative to any reference datum. This is useful if the established flood thresholds do not accurately represent the height at which flood impacts may begin to be felt by the user.

Selecting a Time Period & Analysis

Inundation frequency and duration analysis can be run on verified 6-minute or hourly data. There is a **10-year limit** for running a *6-minute Height Analysis* and **no limit** for running an *Hourly Height Analysis*. A **minimum of 30 days** of data needs to be selected for either analysis. **Note that 6-minute data only dates back to the mid 1990's**. In order to determine what data is available to be analyzed, you can check the Data Inventory for the station (which is linked on the left-hand side of the station Parameter Selection menu) to see what period Verified 6-Minute or Verified Hourly Height water levels are available. Inundation frequency and duration analysis can handle any gaps that may be present in the historical record for the analysis period selected (though no inundation information will be available during those gaps).

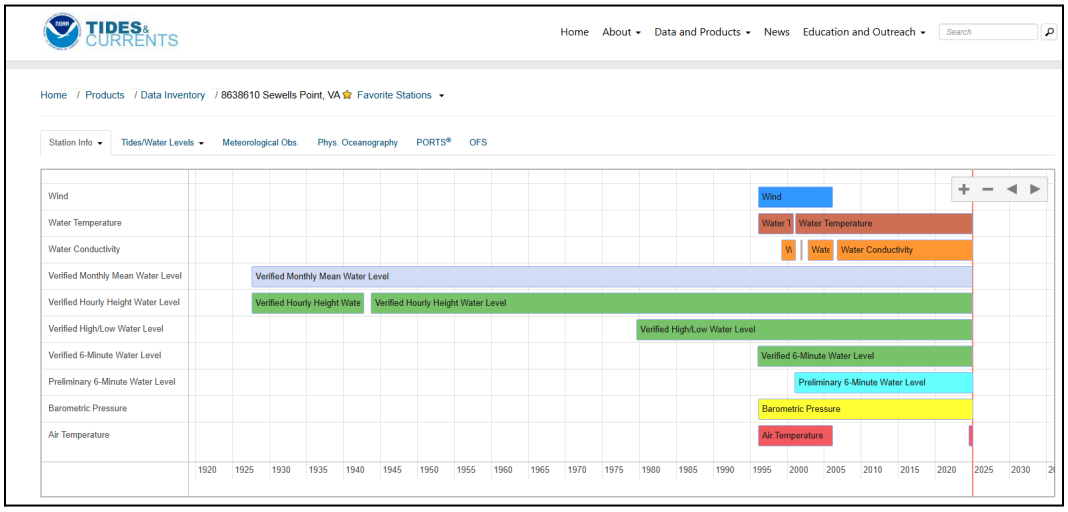


Figure: Data inventory for 8638610 Sewells Point, VA. The 6-minute height and high water analysis uses Verified 6-Minute Water Level and the Verified High/Low Water Level. The hourly height analysis uses the Verified Hourly Height Water Level.

A brief summary of each analysis is provided below.

6-minute Height Analysis

If running a frequency and duration analysis on 6-minute data, the application first identifies all high tides during the period selected based on the station's *Verified High/Low Water Level* product (see Data Inventory above) and determines if the identified high tide falls **at or above** the user-specified threshold. For all high tides where the threshold was exceeded, the application examines the 6-minute water level data before and after the peak to determine how long the period of inundation lasted.

Hourly Height Analysis

If running a frequency and duration analysis on hourly water level data, the application retrieves hourly data for the entire period analyzed and identifies each instance where an hourly water level value was **equal to or greater than** the user-specified threshold. It then identifies the duration of each exceedance. **Note that if you are trying to replicate CO-OPS compiled historical flood frequency information, an Hourly Height Analysis should be performed.**

Once a threshold, date range and analysis type have been selected, click 

to perform the analysis. Depending on the length of data analyzed, the application may take up to a minute to run.

Output

Output from inundation frequency and duration analysis is divided into 4 tabs:

- Maximum Elevation vs. Duration
- Frequency of Elevations
- Frequency of Durations
- Flood Days

Each output tab will be outlined below.

Maximum Elevation vs Duration

Initially when the analysis is complete, the first set of results will display a plot comparing the maximum elevation above the selected threshold with the duration of inundation. Above the plot, any notes regarding the analysis results are displayed including whether gaps were present in the analysis period and whether 6-minute or hourly data were analyzed.

The plot header summarizes the station selected, the threshold and date range for the analysis (along with whether 6-minute or hourly data was analyzed). The last line on the header identifies how many inundations above the selected threshold were found and the total number of hours inundated, along with the percent of the entire period analyzed where water levels exceeded the threshold.

Maximum Elevation vs. Duration of Inundation at 8638610 Sewells Point, VA
Threshold 1.25 Feet above MHHW
from 2010-01-01 to 2019-12-31 (Hourly Data)
406 Inundations - Total Duration: 1346.0 Hours (1.54%)

If 6-minute data was analyzed, the percent of all high tides identified in the analysis period within verified High / Low water level data is also shown.

Maximum Elevation vs. Duration of Inundation at 8638610 Sewells Point, VA
Threshold 1.25 Feet above MHHW
from 2010-01-01 to 2019-12-31 (6-min Data)
432 Inundations out of 7057 Tides (6.12%), Inundation Duration: 1335.8 Hours (1.52%)

A sample *Maximum Elevation vs. Duration of Inundation* plot is shown below.

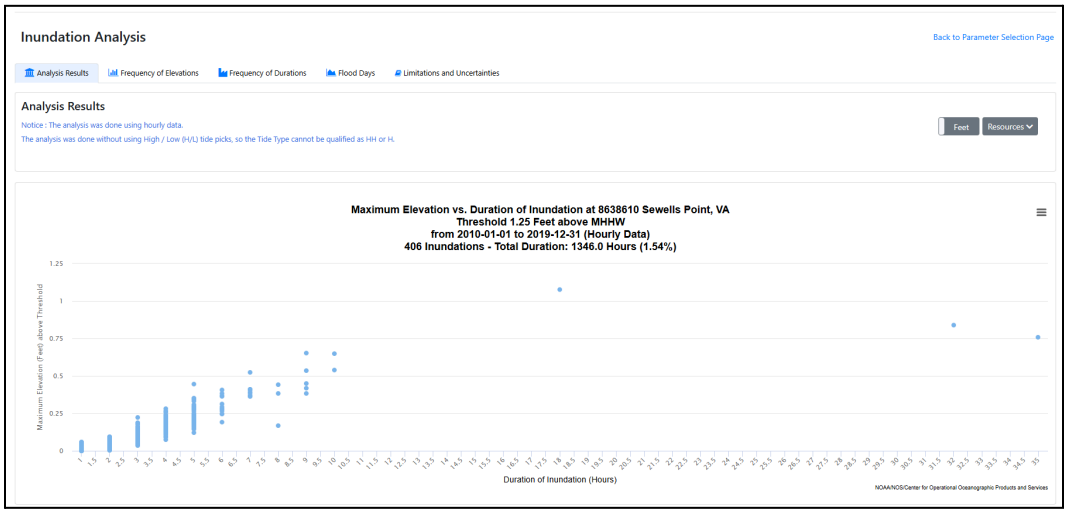


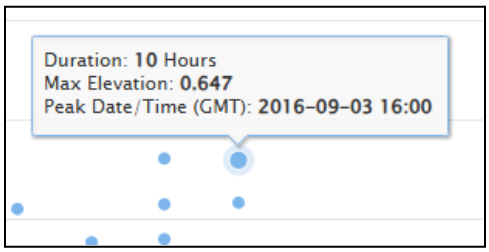
Figure: Example maximum elevation vs duration plot for 8638610 Sewells Point from an hourly height analysis.

This plot relates the inundation duration to the maximum elevation during that inundation period. Users can shift the units between **Feet** and **Meters** via a toggle in the upper-right corner above the plot.

Not surprisingly, in cases where the maximum elevation is higher, the inundation duration typically is also higher. Simply put, this is because the observed water levels exceeded the

specified threshold well before the peak water level was reached and remained above the threshold well after the peak.

On the plot, mousing over the points will display the duration, maximum elevation and the peak date/time.

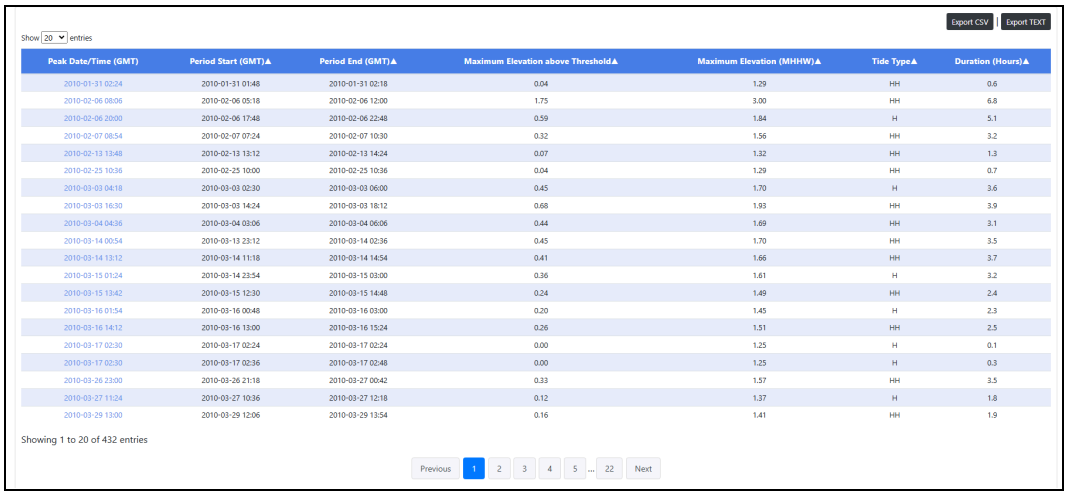


Below the plot will be a sortable table, listing each inundation identified by the analysis. For each exceedance, the following information is listed:

- **Peak Date/Time** - For Hourly Height Analysis this is the date/time of the peak hourly observation. For 6-minute Height Analysis, this is the date/time of the identified high tide.
- **Period Start**
- **Period End**
- **Maximum Elevation above Threshold**
- **Maximum Elevation above Datum*** - The datum shown is MHHW unless the user selected a custom threshold relative to another datum or the MHW, MSL or NAVD88 datum options as the threshold, in which case the selected datum is used.
- **Tide Type** (6-min analysis only) - Whether the tide was a High (H) or Higher-High (HH).
- **Duration**

All times are on GMT.

***Note**: The maximum elevation above datum for the hourly height analysis represents the peak hourly value. For 6-minute height analysis, this value represents the value of the high tide pick, which may differ slightly from the highest 6-minute observation during the inundation period.



Export CSV | Export TEXT

Show 20 entries

Peak Date/Time (GMT)	Period Start (GMT)▲	Period End (GMT)▲	Maximum Elevation above Threshold▲	Maximum Elevation (MHHW)▲	Tide Type▲	Duration (Hours)▲
2010-01-31 02:24	2010-01-31 01:48	2010-01-31 02:18	0.04	1.29	HH	0.6
2010-02-06 08:06	2010-02-06 05:18	2010-02-06 12:00	1.75	3.00	HH	6.8
2010-02-06 20:00	2010-02-06 17:48	2010-02-06 22:48	0.59	1.84	H	5.1
2010-02-07 08:54	2010-02-07 07:24	2010-02-07 10:30	0.32	1.56	HH	3.2
2010-02-13 13:48	2010-02-13 13:12	2010-02-13 14:24	0.07	1.32	HH	1.3
2010-02-25 10:36	2010-02-25 10:00	2010-02-25 10:36	0.04	1.29	HH	0.7
2010-03-03 04:18	2010-03-03 02:30	2010-03-03 06:00	0.45	1.70	H	3.6
2010-03-03 16:30	2010-03-03 14:24	2010-03-03 18:12	0.68	1.93	HH	3.9
2010-03-04 04:36	2010-03-04 03:06	2010-03-04 06:06	0.44	1.69	HH	3.1
2010-03-14 00:54	2010-03-13 23:12	2010-03-14 02:36	0.45	1.70	HH	3.5
2010-03-14 13:12	2010-03-14 11:18	2010-03-14 14:54	0.41	1.66	HH	3.7
2010-03-15 01:24	2010-03-14 23:54	2010-03-15 03:00	0.36	1.61	H	3.2
2010-03-15 13:42	2010-03-15 12:30	2010-03-15 14:48	0.24	1.49	HH	2.4
2010-03-16 01:54	2010-03-16 00:48	2010-03-16 03:00	0.20	1.45	H	2.3
2010-03-16 14:12	2010-03-16 13:00	2010-03-16 15:24	0.26	1.51	HH	2.5
2010-03-17 02:30	2010-03-17 02:24	2010-03-17 02:24	0.00	1.25	H	0.1
2010-03-17 02:30	2010-03-17 02:36	2010-03-17 02:48	0.00	1.25	H	0.3
2010-03-26 23:00	2010-03-26 21:18	2010-03-27 00:42	0.33	1.57	HH	3.5
2010-03-27 11:24	2010-03-27 10:36	2010-03-27 12:18	0.12	1.37	H	1.8
2010-03-29 13:00	2010-03-29 12:06	2010-03-29 13:54	0.16	1.41	HH	1.9

Showing 1 to 20 of 432 entries

Previous 1 2 3 4 5 ... 22 Next

Figure: Example tabular output from a 6-minute height analysis.

Clicking on the column headers will sort the results. Clicking on the *Peak Date/Time* will take you to the observed water levels during that period. You can change the number of entries per page using the drop-down above the table (20 are shown by default). The table can be exported in CSV or text format using the buttons above the table on the right-hand side.

Frequency of Elevations

The Frequency of Elevations tab displays a plot relating the number of inundations to the maximum water level elevation. The plot displays the number of inundations (exceedances) that fall within a specified range of peak water level heights as blue bars and the percentage of all inundations that exceed the lower bound of each range displayed as a red-dotted line.

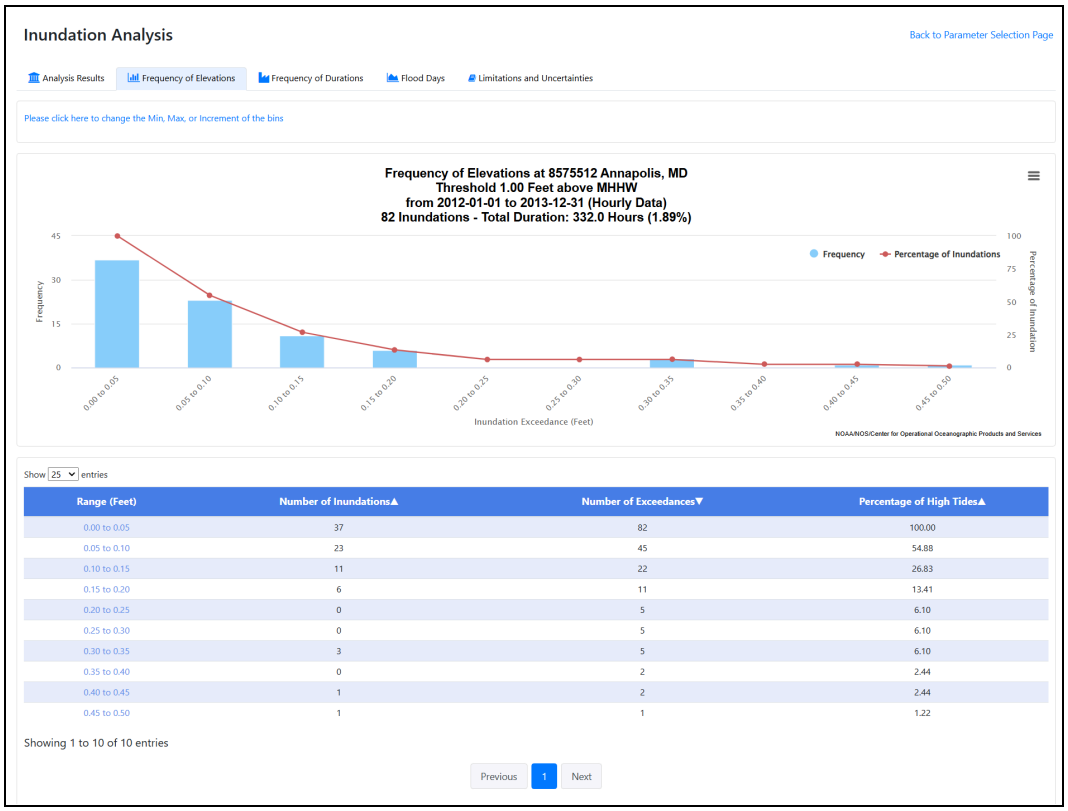


Figure: Frequency of Elevations plot for 8575512 Annapolis, MD for the period of January 2012 to Dec 2013.

Below the plot the data is displayed in tabular form showing:

- Duration range
- Number of Inundations within each range
- Number of Exceedances above the lower bound of the range
- Percentage of Inundations exceeding the lower bound of the range

The application will automatically determine the range based on the data, however users can click *Please click here to change the Min, Max, or Increment of the bins* above the plot to set custom bounds and a custom increment for the range to suit their needs. In the above example, the application automatically set the range to 0.05 feet increments (e.g. 0.00 to 0.05 feet, 0.05 to 0.10 feet, etc).

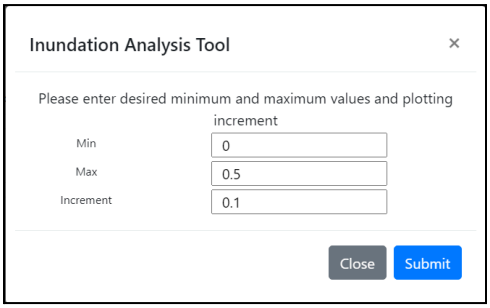


Figure: Pop-up for setting the minimum, maximum and increment for the maximum water level height within the Frequency of Elevation plot.

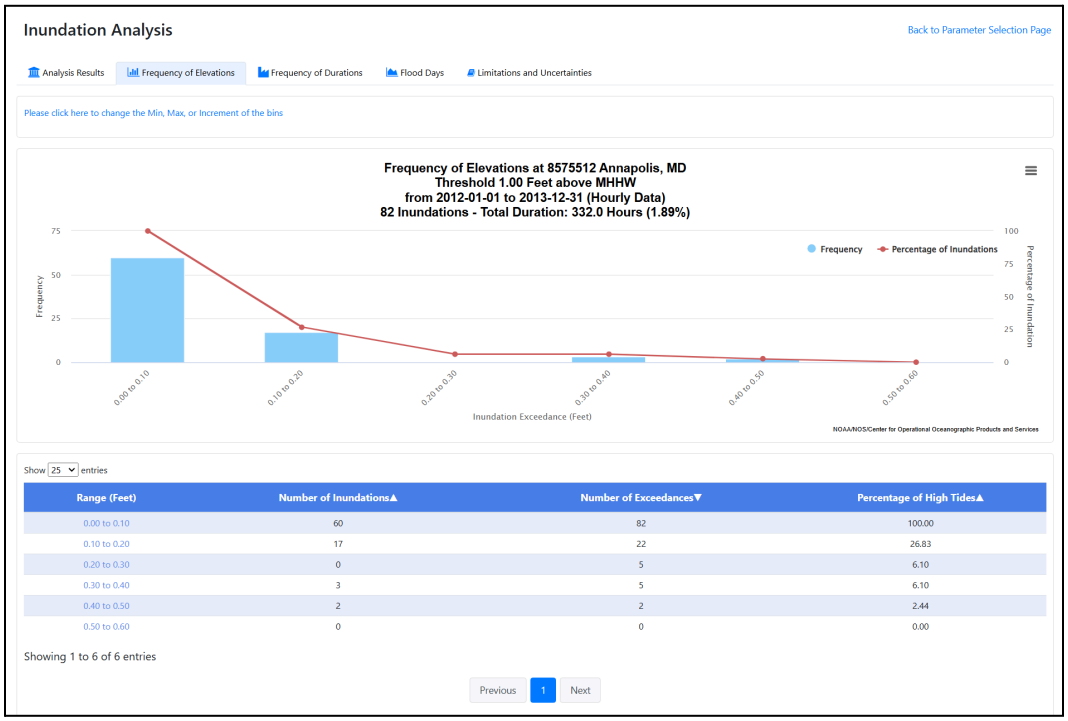


Figure: Frequency of Elevations plot after the range was adjusted from 0.05 feet to 0.1 feet.

In the above example, the range has been changed to 0.1 feet, so the increment bins are now 0.00 to 0.1 feet, 0.10 feet to 0.20 feet, etc. This provides more detail than the default view.

Both the plot and the table data can be exported by clicking the ☰ in the upper-right corner of the plot. Download options for the plot are PNG, JPEG, PDF & SVG. The tabular data can be downloaded in either text or CSV format.

Frequency of Durations

Similar to the previous tab, the Frequency of Elevations tab examines the number of inundations, but relates it to the duration of inundation instead of the peak water level height. The plot displays the number of inundations (exceedances) that fall within a specified duration range as blue bars and the percentage of all inundations that exceed the lower bound of each range displayed as a red-dotted line.

Below the plot the data is displayed in tabular form showing:

- Duration range
- Number of Inundations within each range
- Number of Exceedances above the lower bound of the range
- Percentage of Inundations exceeding the lower bound of the range

Figure: Frequency of Durations plot for 8575512 Annapolis, MD for the period January 2012 to Dec 2013.

The application will automatically determine the range based on the data, however users can click *Please click here to change the Min, Max, or Increment of the bins* above the plot to set custom bounds and a custom increment for the range to suit their needs. In the above example, the application automatically set the range to 1 hour increments (e.g. 0.0 to 1.0, 1.0 to 2.0t, etc).

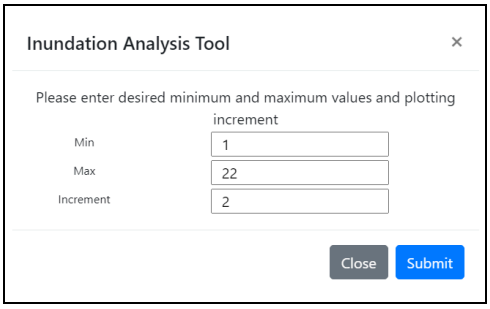


Figure: Pop-up for setting the minimum, maximum and increment for the duration within the Frequency of Duration plot.

Below, the range has been changed to 2 hours, so the increment bins are now 0.0 to 2.0 hours, 2.0 to 4.0 hours, etc.

Both the plot and the table data can be exported by clicking the ☰ in the upper-right corner of the plot. Download options for the plot are PNG, JPEG, PDF & SVG. The tabular data can be downloaded in either text or CSV format.

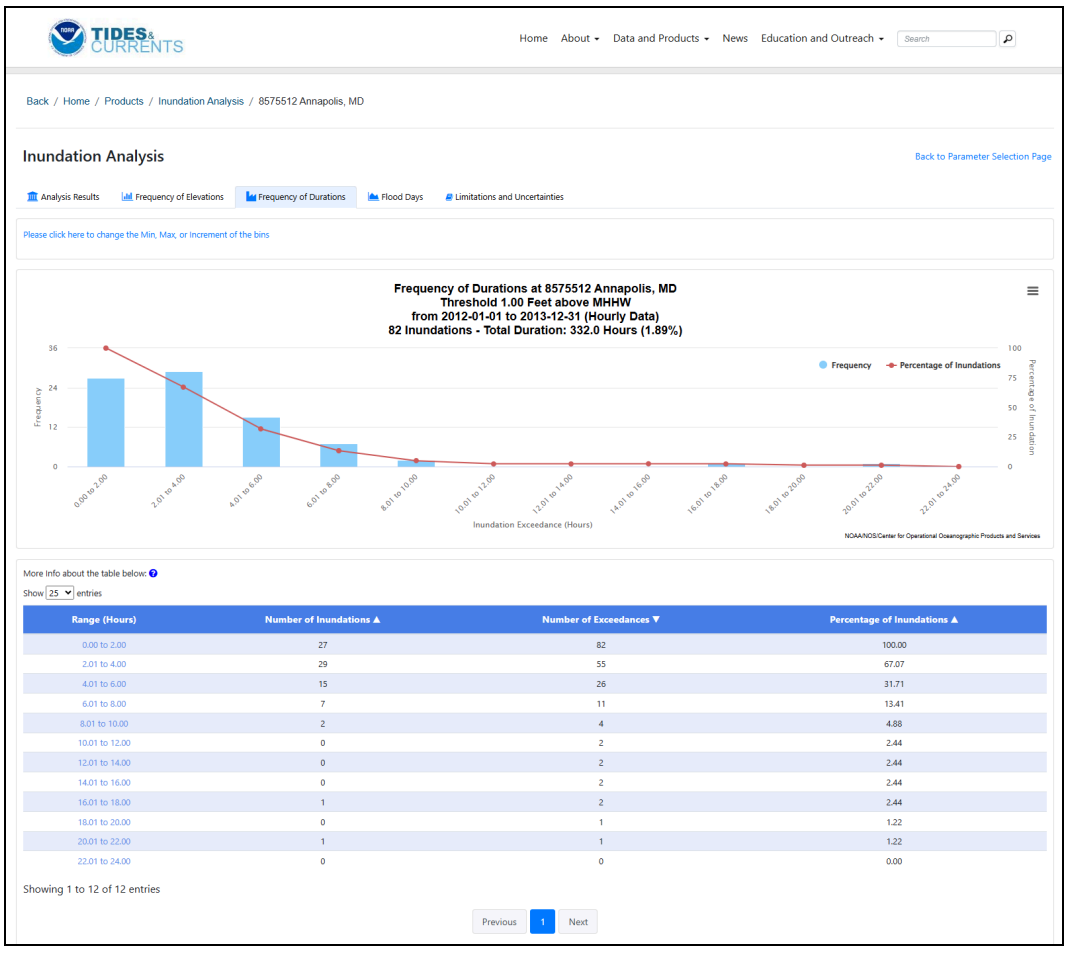


Figure: Frequency of Durations plot for 8575512 Annapolis, MD after the duration range was increased from 1 to 2 hours.

Flood Days

CO-OPS compiles the number of historical flood days for long-term stations based on days where at least one hourly water level measurement exceeds the NOS minor flood threshold. This same logic is used within the Inundation Analysis Tool for tallying the number of flood days based on the analysis output. Data are presented in the same fashion as flood days within CO-OPS Coastal Inundation Dashboard, with an annual bar-chart at the top and 4 bar charts depicting flood days for each of the meteorological seasons:

Winter - December, January, February
Spring - March, April, May
Summer - June, July, August
Autumn - September, October, November

This allows easy comparison between the “official” NOAA flood days and flood days compiled by the Inundation Analysis Tool. It also allows users to easily track which season flooding has occurred most frequently. Since meteorological winter begins during the prior year (e.g. Winter 2023 = Dec 2022 + Jan 2023 + Feb 2023), but the number of annual flood days represents the cumulative total from January - December of that year, the annual value will differ slightly from the sum total of all 4 seasons for that year.

Note: Flood Days are only available for the hourly height analysis.

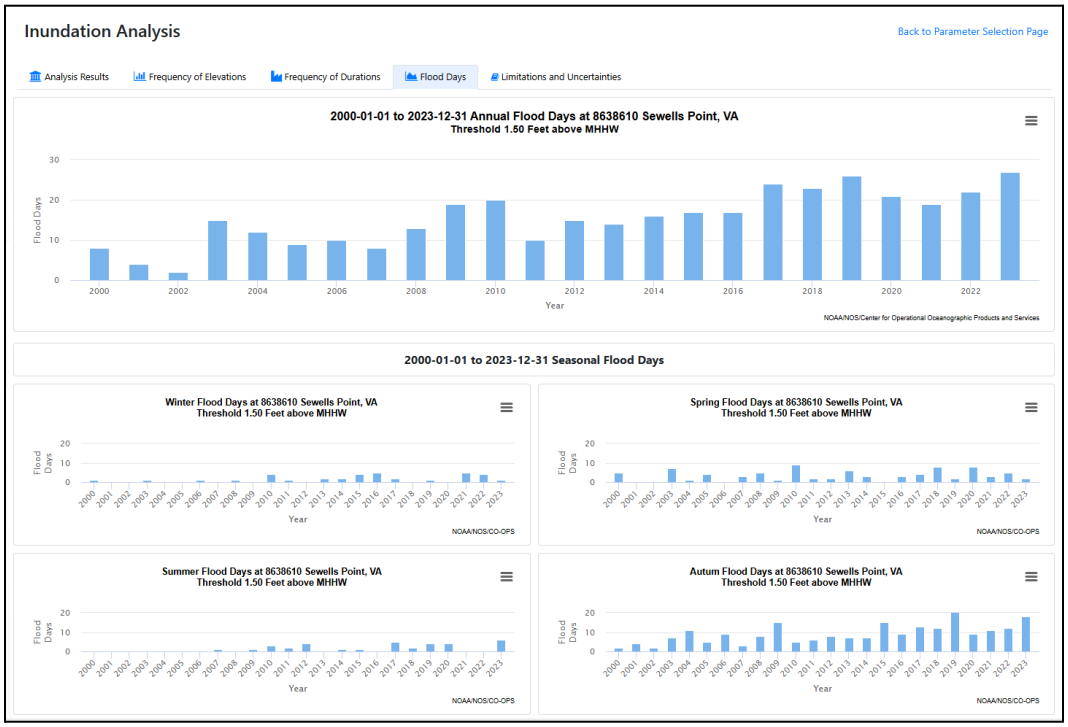


Figure: Flood Day plot for 8638610 Sewell’s Point, VA using a threshold of 1.50 feet above MHHW. Since this threshold is lower than the NOS threshold of 1.75 feet above MHHW, the number of flood days is higher than the “official” NOS flood day count for this station.

In the above example, flood days for 8638610 Sewell's Point, VA are displayed using a threshold of 1.50 feet above MHHW. The annual number of flood days for this station shows a general upward trend for the period of 2000 - 2023. The seasonal plots below the annual plot show that Autumn experiences the most flood days of any meteorological season.

While the Flood Day plot will be available for analysis periods of less than 1 year, some seasons may not be included. An example would be if the period of March to November 2023 is analyzed, there would be no data to display for Winter 2023 since this meteorological season comprises Dec 2022, Jan 2023 & Feb 2023. In these cases, a message will be displayed for the corresponding seasonal plot. **In general, the Flood Days information is most relevant when longer periods of data are analyzed (a decade or more).**

Limitations & Considerations

Below are some items to consider when using this tool.

- Up to **10 years** of **six-minute** data can be analyzed by the application. There is **no limit** to the amount of **hourly** data that can be analyzed.
- NOS and NWS minor, moderate and major flood thresholds are only available for select stations.
    - NWS thresholds are available for a subset of (mostly) active real-time stations.
    - NOS thresholds are available for long-term stations that are part of NOAA's High Tide Flood Outlooks.
- In order to capture inundations, the algorithm used by the tool requires water levels to cross the threshold within the analysis period chosen. As a result, **if there is an active inundation at the beginning or end of the analysis period chosen, it will not be part of the overall inundation count**.
    - In these cases, it is recommended to extend the analysis period to fully encompass the inundation event.
- If gaps are present in the data and water levels are above the user-submitted threshold either at the beginning or end of this gap, the inundation will not be counted by the algorithm.
- When six minute data is analyzed, the maximum water elevation may differ from the peak six-minute observed water level value during the identified inundation period. This is because the maximum elevation data is taken from the high tide pick within the verified High / Low water level data.
- When viewing flood days annually, the Annual Flood Days value for a given year will differ slightly from the sum of the 4 seasonal values for the same year. This is due to the fact that meteorological winter for a given year includes December of the prior year (e.g. Winter 2023 = Dec 2022 + Jan 2023 + Feb 2023).