AVERAGE ANNUAL CHANCE OF SUBSTANTIAL FLOOD DAMAGE SAMPLE CALCULATION

The FDEP Sea Level Impact Projection Study (SLIP) webtool calculates average annual chance of substantial flood damage to a coastal structure. Applying existing regional study data provided by FEMA, NOAA, and USACE, the calculations account for sea level rise as well as for storm surge and waves due to tropical cyclones. Structure-specific user input allows the webtool to identify an elevation threshold at which substantial damage would occur and calculate the average annual probability of water level reaching that elevation.

The input data must meet several requirements to return a valid result:

- The first floor elevation of the structure must exceed the terrain elevation.
- The structure placement must fall within the inundation extents defined by the FEMA 0.02% annual chance floodplain.
- The water level at which substantial damage would occur must not exceed the FEMA 0.02% annual chance water level; that is, the tool does not extrapolate water levels at frequencies lower than 0.02%.

The following example at Sand Key Park in Clearwater Beach, FL demonstrates the calculation for finding average annual chance of substantial damage:

INPUT DATA

User-defined input:

First floor elevation	7.75 ft-NAVD

Terrain:

Topographic elevation	6.99 ft-NAVD

FEMA Coastal Flood Insurance Study data:

FEMA Base Flood Elevation	12.00 ft-NAVD
FEMA 0.2% annual chance stillwater level	11.94 ft-NAVD
FEMA 1% annual chance stillwater level	8.95 ft-NAVD
FEMA 2% annual chance stillwater level	7.08 ft-NAVD
FEMA 10% annual chance stillwater level	5.28 ft-NAVD

Sea Level Rise:

End year of structure design life	2070
NOAA Intermediate-High SLR	1.60 ft

STEP 1: Fit an annual exceedance probability (AEP) curve to the FEMA stillwater elevation (SWEL) data.

- In this example, the location selected for the coastal structure falls within the 10% annual chance floodplain extent. However, the topographic elevation at the site exceeds the FEMA 10% annual chance SWEL, so the tool removes the 10% annual chance SWEL from the curve fit input data. Note that this situation can occur for high-frequency FEMA SWEL values coinciding with isolated high spots in the terrain surface.
- The tool fits FEMA 2%, 1%, and 0.2% annual chance SWEL values to a log-normal function curve: *y = m * ln(x) + b*
    - m = -2.066, b = -0.823
- Note that the tool only calculates the log-normal curve fit if the selected location falls within the 1% annual chance floodplain; if the location lies outside of the 1% annual chance floodplain but inside the 0.2% annual chance floodplain, then the tool adds SLR to the 0.2% annual chance SWEL and compares the resulting elevation with the substantial damage elevation.

STEP 2: Determine how well the curve fit represents the FEMA known SWEL values.

- Next, the tool calculates SWEL using the log-normal curve fit equation *m* and *b* values for the FEMA SWEL AEPs: *Calculated SWEL = m * ln(FEMA AEP) + b*
- The calculated SWEL values allow the tool to report R^2 value to the user as a representation of how well the curve fit *m* and *b* represent the FEMA SWEL values.
    - $R^2 = 0.99$

STEP 3: Generate arrays of SWEL and associated AEP for the full frequency space with curve fit equation.

- The tool applies the *m* and *b* curve fit values to produce an array of SWEL values corresponding to an array of AEP values that cover the frequency space from 10% to 0.2% annual chance with approximately 500 bins: *Curve SWEL = m * ln(AEP bin) + b*
- The first 50 values in both arrays (AEP and associated curve SWEL) are printed below. Note that SWEL values do not exist at the high-frequency bins; because their calculated depths are negative, the tool removes them. This can occur for high-frequency AEPs at isolated high spots in the terrain.
    - AEP(1:50) =

```
[0.1        0.09090909 0.08333333 0.07692308 0.07142857 0.06666667
0.0625     0.05882353 0.05555556 0.05263158 0.05       0.04761905
0.04545455 0.04347826 0.04166667 0.04       0.03846154 0.03703704
0.03571429 0.03448276 0.03333333 0.03225806 0.03125    0.03030303
0.02941176 0.02857143 0.02777778 0.02702703 0.02631579 0.02564103
0.025      0.02439024 0.02380952 0.02325581 0.02272727 0.02222222
0.02173913 0.0212766  0.02083333 0.02040816 0.02       0.01960784
0.01923077 0.01886792 0.01851852 0.01818182 0.01785714 0.01754386
0.01724138 0.01694915]
```

    - Curve SWEL(1:50) =

```
[-- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
-- -- -- -- -- -- -- -- -- -- 6.996021890076962 7.042453737828759
7.087865022323944 7.132299643945352 7.175798729996781 7.218400863452832
7.260142288597747 7.301057096299749 7.341177391294016 7.380533443530911
7.419153825376911 7.4570655362260805 7.494294115883376 7.5308637479123774
7.566797353994843 7.602116680224116]
```

STEP 4: Shift curve SWEL to account for SLR.

- The tool shifts the curve SWEL vertically to account for SLR: *Curve SWEL with SLR = Curve SWEL + SLR*
- The tool again checks for negative SWEL depth values and removes them after SLR is accounted for. Note fewer nan values (--) in the shifted SWEL data compared to SWEL from Step 3:
    - Curve SWEL_with_SLR(1:50) =

```
[-- -- -- -- -- -- -- -- -- -- -- 7.067773105551828 7.163889518062552
7.255732650309534 7.3436663579823716 7.428009916583337 7.509045019279608
7.587021453362501 7.662161743868966 7.734664981980435 7.80471000413149
7.872458049646854 7.93805499629951 8.001633251759824 8.063313362602479
8.123205390018084 8.181410091679641 8.2380199416441 8.293120014215107
8.346788752976877 8.399098642448628 8.450116796791713 8.499905477566235
8.548522550557166 8.596021890076962 8.64245373782876 8.687865022323944
8.732299643945352 8.775798729996781 8.818400863452831 8.860142288597746
8.901057096299748 8.941177391294016 8.980533443530911 9.019153825376911
9.05706553622608 9.094294115883375 9.130863747912377 9.166797353994843
9.202116680224115]
```

STEP 5: Adjust wave height to SWEL depth ratio or "wave ratio" associated with FEMA Base Flood Elevation (BFE) to account for SLR.

- The FEMA BFE establishes the wave height associated with the 1% annual chance SWEL. The BFE includes the SWEL plus the contribution of the wave height that lies above the stillwater surface.
- The FEMA BFE modeling process assumes that 70% of the controlling wave height lies above the SWEL, and that waves break at condition of wave height to stillwater depth ratio of 0.78. Note that this webtool maintains these assumptions (Figure 1).
- Because FEMA models wave height only at the 1% annual chance level, the webtool applies the Wave Ratio Method (currently in testing as part of the FEMA Coastal Probabilistic Flood Risk Assessment framework) to scale the 1% annual chance wave height to other AEPs. The Wave Ratio method assumes that the ratio of wave height to SWEL depth remains constant across the frequency space.
- Adjusting the FEMA 1% annual chance wave height for SLR determines the wave ratio applied for other AEPs in the next step.
    - If the FEMA 1% annual chance wave is non-breaking, then wave height remains constant when accounting for SLR, as SLR does not impact wind wave generation. In this case, SLR acts to decrease the ratio of wave height to SWEL depth.
    - If the FEMA 1% annual chance wave is a breaking wave, then the tool assumes wave breaking for SLR condition as well; the wave height increases when accounting for SLR such that the ratio of wave height to SWEL depth remains 0.78. Notably, this case assumes that SLR does not exceed the threshold above which the breaking wave would transform to a non-breaking wave.
    - From the FEMA BFE, wave height h = (12.00 – 8.95) / 0.7 = 4.36 ft
    - Breaking wave height h_b = 0.78 * (8.95 – 6.99) = 1.53 ft
    - Because h > h_b, the FEMA BFE wave is breaking and the tool sets R = 0.78

STEP 6: Find wave heights associated with curve SWEL based on SLR-adjusted wave ratio R.

- Apply the wave ratio calculated in Step 5 to find wave heights at all AEPs. Wave height = wave ratio * SWEL depth including SLR, or *H = R * (Curve SWEL with SLR – Topographic elevation)*
  - H(1:50) =

```
[-- -- -- -- -- -- -- -- -- -- -- 0.06066302233042535 0.13563382408879052
0.20727146724143658 0.27585975922624967 0.34164773493500245
0.4048551150380938 0.4656767336227509 0.5242861602177932
0.5808386859447393 0.635473803222562 0.6883172787245457
0.7394828971136175 0.7890739363726623 0.8371844228299332
0.8839002042141054 0.9292998715101201 0.9734555544823972
1.0164336110877836 1.0582952273219641 1.0990969411099298
1.138891101497536 1.1777262725016635 1.2156475894345895 1.25269707426003
1.2889139155064324 1.3243347174126763 1.358993722277374
1.3929230093974891 1.4261526734932084 1.458710985106242
1.4906245351138037 1.521918365209332 1.5526160859541105
1.5827399837939904 1.6123111182563423 1.6413494103890327
1.669873723371654 1.6979019361159775 1.72545101057481]
```

STEP 7: Find total water level (SWEL plus wave crest contribution) adjusted for SLR.

- The webtool assumes that wave crest contribution to total water level contributes to the depth of flooding (Figure 2).
- Maintain the FEMA assumption that 70% of the wave height lies above the SWEL surface to calculate total water level for all curve AEPs: *Curve TWL = Curve SWEL with SLR + (0.7 * H)*
  - TWL_with_SLR(1:50) =

```
[-- -- -- -- -- -- -- -- -- -- -- 7.110237221183126 7.20635363369385
7.298196765940832 7.38613047361367 7.470474032214635 7.551509134910906
7.6294855689937995 7.704625859500264 7.777129097611733 7.847174119762788
7.914922165278152 7.980519111930808 8.044097367391121 8.105777478233776
8.165669505649381 8.223874207310939 8.280484057275396 8.335584129846405
8.389252868608175 8.441562758079925 8.49258091242301 8.542369593197533
8.590986666188464 9.472909842058982 9.544693478683262 9.614899324512818
9.683595249539513 9.750844836575023 9.816707734898078 9.881239978172115
9.94449427087941 10.006520246940548 10.067364703698788 10.127071814032703
10.18568331900552 10.243238703155699 10.299775354272535
10.355328709276026 10.409932387626483]
```

STEP 8: Find substantial damage elevation.

- Substantial flood damage occurs when flooding results in the loss of at least 25% of the market value of the structure. USACE NACCS found that substantial damage is "most likely" associated with flood depth of 1.5 ft relative to the first floor elevation (Figure 3).
- Substantial damage elevation (SDE) is set to the first floor elevation plus an additional 1.5 ft.
  - SDE = 7.75 ft-NAVD + 1.5 ft = 9.25 ft-NAVD

STEP 9: Interpolate AEP and wave height associated with water level reaching the substantial damage elevation.

- The tool does not allow extrapolation outside of the 10% to 0.2% annual chance frequency range.

- The tool applies linear interpolation between bin values; while the log-normal curve fit equation is not linear, the bin is sufficiently small to allow linear for interpolation between adjacent bins.
    - AEP = 2.3% for inundation reaching TWL with SLR of 9.25 ft-NAVD.

STEP 10: Output information to the user.

- The tool prints AEP for substantial damage to the potential building.
- The tool also prints substantial damage elevation, the wave ratio, the wave height, and the total water level at the 10% and 0.2% annual chance bins. The latter provides the user with the range of potential flood elevations at that specific location.
- Finally, the tool generates a scatter plot (Figure 4) that overlays FEMA SWEL, FEMA BFE, curve SWEL, curve SWEL with SLR, and curve TWL with SLR as visual presentation of results.

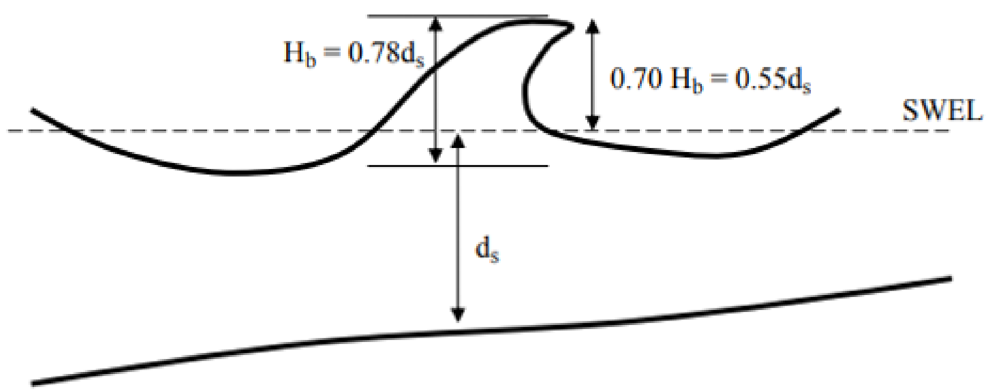

Figure 1. FEMA wave breaking relationships, where H_b = breaking wave height and d_s = SWEL depth.

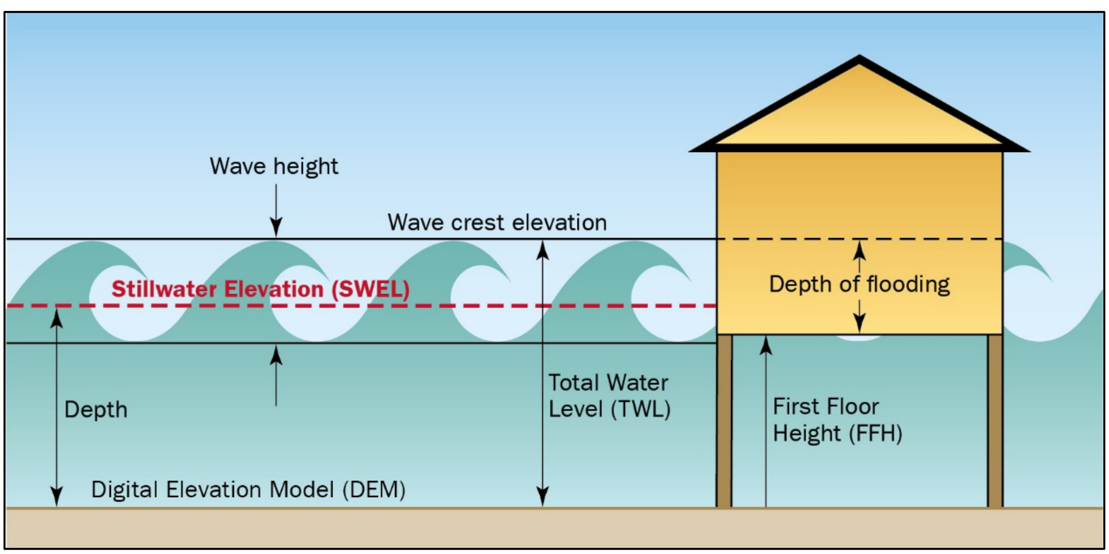

Figure 2. FEMA depth of flooding diagram.

North Atlantic Coast Comprehensive Study (NACCS)

United States Army Corps of Engineers

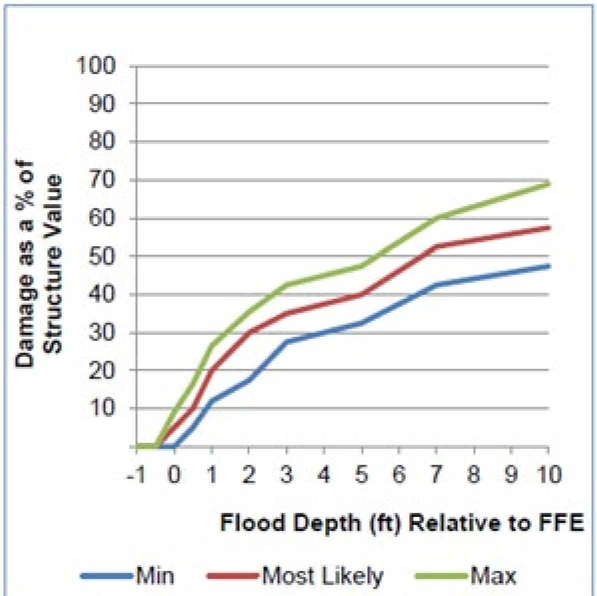

Figure 49. Prototype 2: Commercial Engineered, Inundation Damage – Structure

Table 25. Prototype 2: Commercial Engineered, Inundation Damage – Structure

Flood Depth	Min	Most Likely	Max
-1.0	0	0	0
-0.5	0	0	0
0.0	0	5	9
0.5	5	10	17
1.0	12	20	27
2.0	18	30	36
3.0	28	35	43
5.0	33	40	48
7.0	43	53	60
10.0	48	58	69

Figure 3. USACE depth-damage function (NACCS).

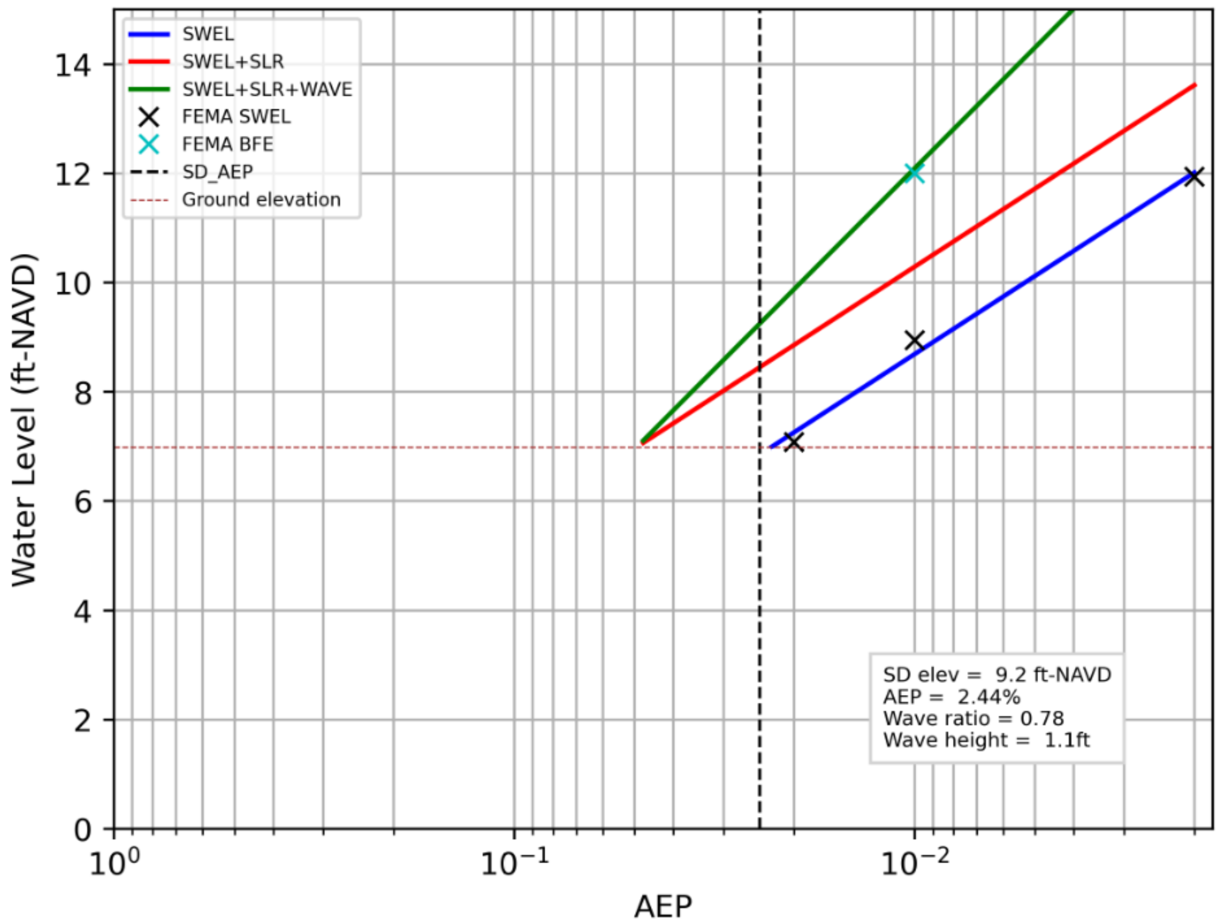

Figure 4. Webtool Internal Output.