

Exposure Analysis

ADAPTING TO RISING TIDES PROGRAM

This guide helps with...

Conducting an efficient and effective analysis of asset exposure to impacts related to current and future flooding. The stepwise approach presented here helps pinpoint the assets and geographies that are most likely to be affected and helps identify and prioritize where further, targeted mapping, analyses or shoreline studies are needed.

Definition: Exposure

Exposure is the extent to which an asset experiences a specific climate impact. A precursor to the exposure analysis is selection of scenarios that describe the projected future conditions facilities, infrastructure and communities in the project area may face. Refer to: [How-to Guide: Selecting Climate Scenarios](#) (📄).

The scenarios set the stage for the evaluation of potential asset exposure to the selected climate impacts. Refer to: [How-to Guide: Communicating About Climate Impacts](#) (📄).

Exposure to impacts can be depicted in maps, tables, charts and summary statements. The appropriate format(s) for presenting the results of an exposure analysis depend on the type of impact being depicted, the asset, data availability and specificity, and the target audience(s).

Climate Impacts

Current and future flooding can have a number of impacts on communities, infrastructure and natural areas. In the ART Program, five impacts that could occur from either temporary or permanent coastal flooding, riverine, or localized nuisance flooding have been used to define the scope of vulnerability assessments:

- Areas that currently flood may flood more frequently
- Flooding of new areas, and more extensive, longer-duration storm event flooding in areas that currently flood
- Permanent inundation of areas currently not exposed to regular tides
- Shoreline erosion due to more extensive and longer duration flooding
- Elevated groundwater and increased salinity intrusion

Exposure Analysis Steps

1. Identify and gather information

The first step is to determine if information (data, maps or studies) is available for the selected climate scenarios to help understand the climate impacts. In the Bay Area, regional mapping is available that depicts current and future flooding during both regular daily high tide conditions (e.g., permanent inundation) and for variety of extreme tide (storm surge) conditions (e.g., temporary flooding). For some areas, locally refined sea level rise and storm event flood maps and shoreline analyses have been conducted (e.g., Alameda and San Francisco Counties). Where locally refined maps or studies are available these can be used in the exposure analysis. Check with your local flood control district, public works or planning departments to determine if refined maps or studies are available.

Publicly available mapping tools:

- NOAA Sea Level Rise Viewer
A national tool that depicts potential impacts to marshes and human communities from a range of sea level rise projection from 0 to 6 feet coupled with mean higher high water (MHHW) (i.e., the daily high tide). It also illustrates changes in flood frequency and includes visual simulations of flooding at local sites. <http://coast.noaa.gov/slr>.
- Our Coast, Our Future (OCOF)
A regional tool that provides locally relevant online maps of forty possible climate futures based on the USGS's CoSMoS Model. The tool helps users understand and visualize sea level rise and storms within San Francisco Bay and on the outer coast from Half Moon Bay to Bodega Bay. <http://data.prbo.org/apps/ocof>

What to do if data, maps or studies are not available.

In the absence of information for climate scenarios or impacts, consider using a scenario planning approach; re-purposing or re-analyzing existing data; or conducting new studies or analyses.

SCENARIO PLANNING RESOURCES

Scenario Plannin for Climate Change Adaptation: Guidance for Resource Managers

http://www.prbo.org/refs/files/12263_Moore2013.pdf

Tijuana NERR Project: Climate Understanding and Resilience Scenario Planning Workshop

<http://tnerr.org/currv>

DATA ANALYSIS AND MAPPING RESOURCES

NOAA Inundation Mapping Primer

http://coast.noaa.gov/digitalcoast/_/pdf/guidebook.pdf

- Climate Central's Surging Seas

A national tool that allows users to see maps of 0 to 10 feet of sea level rise coupled with mean higher high water (MHHW). The tool also provides statistics of population, homes and land affected by city, county and state, plus links to factsheets, data downloads, action plans, and more.

<http://sealevel.climatecentral.org/ssrf/California>

- FEMA Flood Hazards Data

A national tool that provides access to FEMA flood hazard data, including new or revised Flood Insurance Rate Maps (FIRMs) for the San Francisco Bay and outer coast.

<http://www.r9map.org/Pages/California.asp>

- Point Blue Future San Francisco Bay Tidal Marshes Climate Smart Planning Tool

A regional tool that provides spatially explicit projections of marsh elevation and bird distributions for a range of sea level rise projections, allowing for the uncertainty in future rates of sea-level rise and suspended sediment availability to be considered. <http://data.prbo.org/apps/sfbslr/>

2. Analyze exposure

The second step is to analyze which assets are potentially exposed. It is often helpful to first conduct a visual inspection of hard copy (printed) maps or online mapping tools to gain an understanding of the assets and geographic areas that may be exposed to different scenarios and selected. The visual inspection approach works well for asset categories or sectors that have few assets or where assets have a large footprint, e.g., wastewater treatment plants, shoreline parks, airports/seaports or landfills. For asset categories or sectors where there is a large number of assets such as schools, homes, hazardous materials sites, or for linear interconnected assets such as pipelines, roadways, rail lines and utility networks, it is generally necessary to evaluate exposure using geospatial analysis, i.e., GIS.

For information about gathering data and conducting a GIS exposure analysis see the

ART Subregional Project GIS Appendix (📎).

Flood recurrence intervals

The magnitude of flooding used as the standard for floodplain management in the United States is a flood having a probability of occurrence of 1 percent in any given year, also known as the 100-year flood or base flood. The most readily available source of information for the 100-year flood is the system of Flood Insurance Rate Maps (FIRMs) prepared by FEMA.

Other floods referenced in this guide include:

Recurrence interval, in years	Probability of occurrence in any given year	Percent chance of occurrences in any given year
2	1 in 2	50
5	1 in 5	20
10	1 in 10	10
25	1 in 25	4
50	1 in 50	2
100	1 in 100	1

The following subsections provide additional detail for analyzing exposure to specific climate impacts.

Temporary Flooding and Permanent Inundation

Temporary flooding is generally short in duration but can have long lasting consequences. Some areas along the Bay shoreline or along creeks and rivers already experience temporary flooding. This temporary flooding usually occurs when there are storms over the Pacific Ocean during the winter, when high tide coincides with strong winds or when significant rainfall causes creeks and rivers to rise over their banks. While some assets and areas can maintain their function after the water recedes, other assets can suffer irreversible damage if exposed to any amount of water, even temporarily. Permanent inundation occurs if an area is exposed to regular daily inundation.

As sea level rises, higher water levels will become more frequent, increasing the extent, depth, and duration of temporary flooding and extending the area that is permanently inundated. These impacts will not be confined to the shoreline as sea level rise will also affect tidal creeks. As the Bay rises, water levels in tidal creeks will also rise, pushing the extent of tidal influence further upstream, potentially making riverine flooding that already occurs worse in some locations.

Current coastal and riverine flood is evaluated for the 100-year flood as depicted in FEMA's Effective Flood Insurance Rate Maps. For future flooding, sea level rise inundation maps help visualize under what conditions assets or specific geographic areas may be affected by temporary flooding during storm events or permanent inundation during a daily high tide. The total water level approach presented below simplifies this process and reduces the number of maps needed. In this approach each inundation map represents a number of different unique combinations of sea level rise and extreme tide (storm surge) conditions.¹

For example, a total water level of 36 inches above mean higher high water (MHHW)² can represent:

- A new “daily” high tide with 36 inches of sea level rise. This amount of sea level rise, which is a likely projection for 2100, could result in regular, e.g., permanent, tidal inundation.

The same total water level (i.e., 36 inches above MHHW) also represents:

- Today's 50-year extreme tide level
- A new 1-year extreme tide level with 24 inches of sea level rise. Extreme tide events that are larger than daily high tide levels can result in episodic, short duration, or temporary, flooding.
- A new 5-year extreme tide level with 12 inches of sea level rise, which is a likely 2050 projection.

The matrix of numbers presented in Table 1 can be used to understand a range of total water levels, from 0 to 95 inches above MHHW, represented both in terms of today's tides and future tides as sea level rises. Each total water level represent a combination of sea level rise (0 to 60”) and tide levels (MHHW to a 100-year extreme event). The example above is indicated in green in the table. Another example is indicated in red; the likely mid-century daily high tide is projected to be 12” above today's high tide, or 12”+MHHW. This total water level also approximates the level currently observed during King Tide, which is an astronomical

¹ Extreme tides are the maximum high tide level that has occurred over a specific return period (recurrence interval) that correlates to specific occurrence probability. For example a 100-year extreme tide has a return period of 100 years, and therefore a 1% chance of occurring in any given year

² Mean higher high water (MHHW) is calculated as the average of the higher of the two daily high tides over a 19-year tidal epoch.

tide that occurs approximately twice per year when the Moon and the Sun simultaneously exert their gravitational influence on the Earth.

Because of the uncertainties associated with modeling and mapping sea level rise it is reasonable to allow for a +/- 3-inch range when interpreting the total waters in Figure 1 (see the Key to matrix). As an example, the likely end-of-century high tide is projected to be 36 inches above today's high tide, or 36"+ MHHW. Water levels ranging from 33 to 39 inches can be used to understand what other combination of tides and sea level rise that may result in the same amount of flooding or inundation as 36"+ MHHW.

The values presented in Figure 1 are generally applicable to central San Francisco Bay and are therefore appropriate for local and regional scale climate adaptation planning, although it may not be as precise for some areas of the South and North Bay. Because tide levels do vary around the Bay, additional information about tide levels should be used for site-scale planning. (See [ART Portfolio: ART Supplies > Supporting Information: Tidal Datums and Technical Memo](#) (📄)). Additionally, the values in Figure 1 are based on an analysis that does not include the effects of locally-generated wind waves and assumes that future storms will behave like past storms.


FIGURE 1. MATRIX OF TOTAL WATER LEVELS

Sea Level Rise	MHHW (≈ daily high tide)	Total water level above today's daily high tide, MHHW (inches NAVD88), by tide recurrence interval						
		1-yr (≈ King Tide)	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr (1% annual chance)
+0	0	12	19	23	27	32	36	41
+6	6	18	25	29	33	38	42	47
+12	12	24	31	35	39	44	48	53
+18	18	30	37	41	45	50	54	59
+24	24	36	43	47	51	56	60	65
+30	30	42	49	53	57	62	66	71
+36	36	48	55	59	63	68	72	77
+42	42	54	61	65	69	74	78	83
+48	48	60	67	71	75	80	84	89
+54	54	66	73	77	81	86	90	95
+60	60	72	79	83	87	92	96	101

Key to matrix

Color Code	Inches above MHHW	Applicable water level range (+/- 3 inches)
12	12	9 - 15
24	24	21 - 27
36	36	33 - 39
48	48	45 - 51
60	60	57 - 63
72	72	69 - 75

Shoreline Overtopping and Erosion

To understand shoreline overtopping and when and where erosion may occur, an overtopping analysis can be conducted. “Overtopping potential” refers to the condition where the water surface elevation from a particular inundation scenario exceeds the elevation of the existing shoreline, potentially causing flooding of inland low-lying areas. The analysis of overtopping potential can identify where the shoreline may not be high enough to control inland inundation relative to the climate scenarios selected. Typically, this kind of analysis does not account for the physics of wave “setup” and “run up”, the condition of the shoreline, or the potential for the shoreline to fail as flood protection due to damage (e.g., scour or undermining), or a breach caused by the initial overtopping. See [ART Portfolio: ART Supplies > ART Vulnerability and Risk Report, Chapter 2. Sea Level Rise Mapping and Shoreline Potential Overtopping Analysis](#) .

Different overtopping potential metrics can be calculated, including length of the shoreline overtopped, the percent of the shoreline length overtopped, and the average and maximum depth of overtopping.

While the analysis of overtopping potential provides some understanding of relative vulnerability, it should not be used as a direct indicator of the risk of inundation. Rather, it should serve as a screening level tool to help direct resources to specific shoreline areas where further study is necessary. As an example of why this is important, even small areas of shoreline overtopping could lead to flooding of large inland areas. And, if the overtopping leads to a structural failure, then even larger areas could be inundated at greater depths. Further analysis would be needed to determine this type of risk.

Higher Groundwater and Salt Water Intrusion

Groundwater levels fluctuate considerably in time and space. They rise due to recharge from rain or snowmelt, and can vary substantially over short distances depending on aquifer characteristics. Sea level rise may cause groundwater levels to rise, flooding underground infrastructure such as utilities and basements. Higher salinity may corrode pipelines and pumping equipment not typically designed for saltwater exposure. Due to the variability of groundwater levels and the lack of detailed studies of the extent that groundwater and salinity conditions will be impacted by rising sea levels, the evaluation of groundwater impacts on asset exposure has been qualitative.

Areas that already experience high groundwater levels and salinity intrusion may be more at risk of higher, more saline groundwater levels as sea level rises. As an indication of exposure to higher groundwater or salinity intrusion, information about the current groundwater condition can be used for assets with below-ground components, such as pipelines, pumps, septic systems, wells, and homes with below-ground living space. For example Lake Merritt BART station in Oakland, CA already has to accommodate high groundwater, and relies on pumping to keep the station operating.

3. Summarize findings

The third step is summarizing findings as maps, tables, charts or summary statements that describe exposure and can be shared with local stakeholders or other experts. Remember that different audiences respond differently to how information is presented. In deciding how to summarize exposure findings make sure to consider to whom the information will be presented to and what outcomes you are trying to achieve, e.g., obtaining review and feedback on the validity of the mapping and analysis, or helping your stakeholders communicate the potential exposure to their own stakeholders, other groups or the public.

Maps

These highly visible depictions of potential exposure can provide a broader-than-asset perspective as well as context for understanding connected vulnerabilities and consequences.

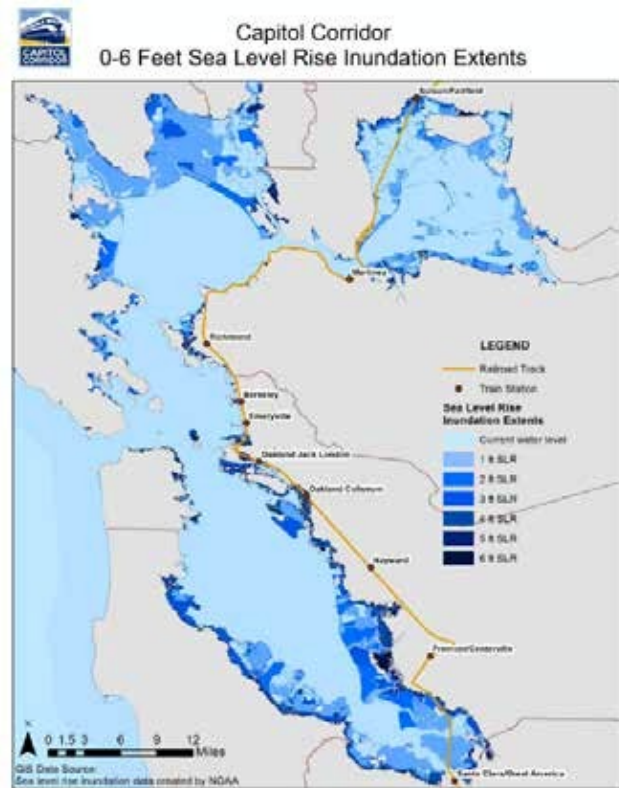
FIGURE 2. EXPOSURE MAPS

Top: Regional, Single-Sector, Multiple Water Levels

This example shows the inundation extents, but not depths for six sea level rise amounts – shown in gradations of blue – for the San Francisco Bay Region, with passenger rail infrastructure indicated.

Bottom: Local/Community-Scale, One Water Level

Inundation extent and depths for a total water level analysis (of 36" of sea level rise over current MHHW) are shown in the map of the ART Hayward Resilience Study area below as gradations of blue. Darker blues are greater depths of inundation. Green indicates a low-lying area that is disconnected, for instance by levees, tidegates or other shoreline structures from surrounding areas. The map also shows the results of a shoreline protection overtopping analysis, indicating the normalized height of shoreline protection (i.e., the shoreline protection height relative to the MHHW elevation with sea level rise.



Tables and Charts

These highly visible depictions of potential exposure can provide a broader-than-asset perspective as well as context for understanding connected vulnerabilities and consequences.

FIGURE 3. QUANTITATIVE EXPOSURE ANALYSIS FINDINGS FOR ROADWAYS AND RAIL LINE IN THE ART SUBREGIONAL PROJECT AREA IN ALAMEDA COUNTY

The presentation of quantitative exposure findings of sea level rise exposure for roadways and rail line within a project area can be useful in communicating potential vulnerability to transportation asset managers. In general, transportation asset managers are aware of costs to repair and replace different types of roadways and related infrastructure, and are comfortable prioritizing work (e.g., further analyses, retrofits) based on type and cost. This quantitative exposure table is likely to be less helpful for community and land use planners who need site- and asset-specific information to understand the vulnerabilities of community assets that rely upon these transportation assets.

Depending on the sea level rise scenarios that are used, this type of table can help also help identify thresholds for exposure. Note that in this example table, exposure information for intermediate scenarios (between 16" and 55") would be needed to allow for identifying thresholds.

	16" SLR			55" SLR		
	Daily High Tide	Storm Event		Daily High Tide	Storm Event	
System Category	Miles exposed	Miles exposed	Miles exposed to wind waves only	Miles exposed	Miles exposed	Miles exposed to wind waves only
Roadways: Limited-Access Highways (FRC 0)	0	4	25	16	29	16
Roadways: Major Roads (FRC 1)	0	0	3	1	3	1
Roadways: Regional Connectors (FRC 2)	0	0	0	0	0	0
Roadways: Secondary Roads (FRC 3)	0	7	5	8	12	2
Roadways: Local Connectors (FRC 4)	0	8	50	24	58	23
Roadways: Local Roads of High Importance (FRC 5)	5	27	64	48	91	26
Total length of roadways exposed	5	45	149	98	194	68
Regional Railroads: System-Wide	0	5	55	22	61	22

FIGURE 4. QUALITATIVE EXPOSURE ANALYSIS FINDINGS FOR RECREATION ASSETS

The exposure of recreation assets in 16 parks (numbered columns) in the ART Subregional Project in Alameda County was assessed for two water levels with 16” of sea level rise: high tide and a 100-year storm event water level. Recreation activities that are offered at each park are shown with icons that are colored red, yellow and green to indicate high, medium and low level of exposure of the facilities on which those activities rely. Exposure maps were made for each park and visually compared with maps of park facilities to qualitatively determine exposure levels for the activities: low = little or no exposure such that the activity can be maintained at current levels; medium = partial exposure that reduces the activity; high = exposure that severely limits or eliminates the activity. As an example, for park #1, a high tide would partially cover the beach whereas the storm event water level would fully inundate the beach, eliminating all swimming and launching for paddleboaters and sailboarders. Presentation of the findings in this format helped identify highly vulnerable parks as well as recreation activities that are vulnerable across the entire project area.

16" HIGH TIDE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
walk / run / hike / bike																
passive recreation																
group / event facilities																
sports fields / courts																
golf course																
nature / wildlife viewing																
interpretation & education																
swimming																
paddleboating																
rowing																
sailboarding																
motorboat launch																
fishing pier																
dog recreation																
parking																
restrooms																
16" STORM EVENT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
walk / run / hike / bike																
passive recreation																
group / event facilities																
sports fields / courts																
golf course																
nature / wildlife viewing																
interpretation & education																
swimming																
paddleboating																
rowing																
sailboarding																
motorboat launch																
fishing pier																
dog recreation																
parking																
restrooms																

FIGURE 5. QUANTITATIVE EXPOSURE ANALYSIS RESULTS FOR WASTEWATER FACILITIES IN THE ART SUBREGIONAL PROJECT AREA IN ALAMEDA COUNTY

Asset	55 "SLR			
	Daily High Tide		Storm Event	
	% Exposed	Average depth (ft)	% Exposed	Average depth (ft)
Treatment Plants				
EBMUD Main WWTP	26	1	83	2
Hayward			25	2
OLSD	81	3	100	4
San Leandro	90	2	96	5
USD Alvarado	99	3	100	6
Ancillary Facilities				
Hayward Oxidation Ponds	94	7	100	9
San Leandro Pond & Drying Beds	41	8	46	9
OLSD Sludge Drying Beds	72	3	72	3
Wet Weather Facilities				
EBMUD Oakport			98	5
EBMUD San Antonio Creek	63	1	100	3

Summary Statements

Descriptions or narratives of exposure that can be integrated into vulnerability and consequence statements and used to develop issue statements.

EXAMPLE SUMMARY STATEMENTS

“The presence of residential housing units within areas potentially exposed to tidal inundation, storm event flooding and rising groundwater levels is of particular concern. Past experience with coastal flooding hazards, such as significant winter storms, hurricanes and tsunamis has demonstrated that residential neighborhoods are not only extremely vulnerable to these events, but also tend to be the slowest to recover and have the greatest difficulty in doing so.” (ART Vulnerability and Risk Report: Community Facilities)

“Permanent inundation becomes a serious risk for the station and the tracks in Martinez starting at 4 feet, or 48 inches, of sea level rise. Temporary flooding of 4 feet of water above MHHW is expected to occur with a 100-year extreme storm tide level with no sea level rise and could also occur with a 50-year extreme storm tide level with 6 inches of sea level rise.” (Capitol Corridor Joint Powers Authority Vulnerability & Risk Report)

“Inundation of the residential areas adjacent to the lagoon will begin at 36 inches of SLR. Inundation will occur from overtopping of the tide gate seawall and also via pathways originating from the adjacent Corica Golf Course that is also flooded during this scenario. Residential neighborhoods located more inland will be protected from 36 inches of SLR but will begin to experience inundation at 48 inches of SLR.” (Bay Farm Island Technical Memo)

4. Check your work

The fourth step is to ground truth findings with stakeholders or other experts that have local knowledge of the project area and/or assets. The goal is to have them help you flag trouble spots where additional studies, field verification, re-mapping or re-analysis is needed. There are a number of different ways to ground truth the exposure analysis including:

- Visit key locations and assets in the project area with asset managers and experts to identify on-the-ground conditions and determine where mapping and analysis results do not align with local knowledge. **ART Engagement Exercise: Field Trip** (📎)
- Engage stakeholders in a participatory mapping process to identify their resources, perspectives, and priorities. NOAA's Participatory Mapping guide provides simple strategies for facilitators leading a participatory mapping process. coast.noaa.gov/digitalcoast/publications/participatory-mapping
- Hire a coastal engineering consultant to field-verify the topographic and water level data used to create the mapping and data used in the exposure analysis. **Case Studies: Hayward Shoreline, Bay Farm Island, Coliseum and Bay Bridge Touchdown** (📎).



FIGURE 6. FIELD VERIFICATION AND UPDATED MAPPING

For an adaptation planning effort on Bay Farm Island in San Francisco Bay, the initial exposure mapping indicated extensive inundation, but not the pathway of this flooding. A coastal engineering consultant conducted additional, focused mapping analysis and fieldwork to accurately depict local conditions and pinpoint where overtopping could occur

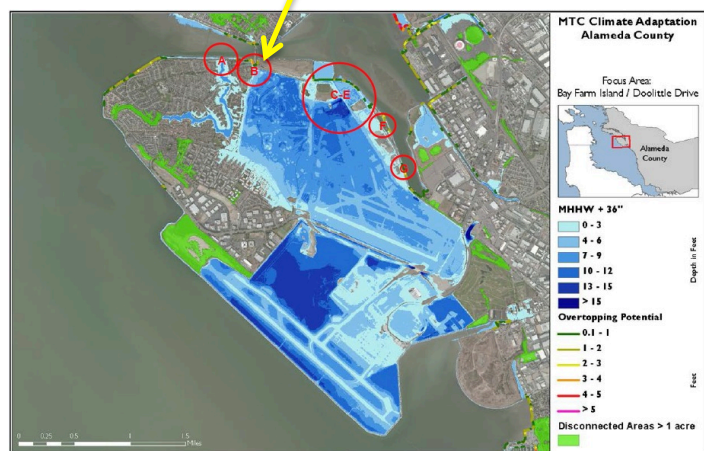


Figure 12. Updated Inundation and Flooding Analysis Using the Modified DEM

5. Identify gaps

The final step is to cross-reference the exposure analysis with other assessment information (see box) to determine what further (additional) exposure analyses, mapping or investigation is needed for the assets to help complete the understanding of vulnerability and consequences, and to support development of adaptation responses. Pinpointing these gaps will help you make efficient use of available resources for further analysis. It can also highlight information vulnerabilities that need to be addressed prior to further adaptation planning and decision-making.

Review collected assessment information and consider which assets or sites could benefit from additional analyses, mapping or investigation. For example, determine if the picture of vulnerability and consequence would change if the extent, depth or duration of flooding was better understood, or if the asset was to be exposed earlier, either with lower amounts of sea level rise or smaller storm events.

Other assessment pieces

The analysis of exposure of assets to climate change impacts is just one piece of understanding vulnerability. To help planners gather and organize other information relevant to understanding vulnerability and consequences, the ART Portfolio includes assessment questions and information on how and when to use them:

- [How-to Guide: ART Assessment Questions](#) (📄)
- [How-to Guide: Vulnerability and Consequence Statements](#) (📄)
- [How-to Guide: Profile Sheets](#) (📄)