APPENDIX A: METHODS

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TABLES

FIGURES

ACRONYMS

AFCEC	Air Force Civil Engineer Center
AFDD	Air Force Doctrine Documents
AOI	Area of Interest
ATP	Army Techniques Publication
CCSM	Community Climate System Model
CIP	Common Installation Picture
CMIP	Coupled Model Intercomparison Project
CN	Curve Number
CONUS	Contiguous United States
DEM	Digital elevation model
DoD	Department of Defense
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
HCCVI	Habitat Climate Change Vulnerability Index
HEC	Hydrologic Engineering Center
HMS	Hydrologic Modeling System
HUC	Hydrologic Unit Code
ICEMAP	Installation Complex Encroachment Management Plans
INRMP	Integrated Natural Resources Management Plan
IPB	Intelligence Preparation of the Battlefield
IPCC	Intergovernmental Panel on Climate Change
ISI-MIP	Inter-Sectoral Impact Model Intercomparison Project
LOCA	Localized Constructed Analogs
MC2	Dynamic Global Vegetation Model
MCRP	Marine Corps Reference Publication
MHHW	Mean Higher High Water
MRLC	Multi-Resolution Land Characteristics
NCAR	National Center for Atmospheric Research
NHD	National Hydrography Dataset
NLCD	National Land Cover Database

NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NSSDA	National Standard for Spatial Data Accuracy
OCONUS	Outside the Contiguous United States
PRECIP	Average annual precipitation
RAS	River Analysis System
RCP	Representative Concentration Pathway
SCS	Soil Conservation Service
SLR	Sea Level Rise
SS	Storm Surge
TAVE	Annual average temperature
TMAX	Annual maximum temperature
TMIN	Annual average minimum temperature
USACE	U.S. Army Corps of Engineers
USAF	U.S. Air Force
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

This appendix provides a detailed overview of the data and methods used to assess installation-specific vulnerabilities and potential impacts associated with projected changes under four climate change scenarios. The scenarios represent two global carbon emissions levels for two different target years. The **emissions scenarios** are medium emissions (RCP 4.5) and high emissions (RCP 8.5). The two **timeframes** are decades around 2030 (2026-2035) and 2050 (2046-2055). Therefore, the climate change scenarios are:

- RCP 4.5 2030
- RCP 8.5 2030
- RCP 4.5 2050
- RCP 8.5 2050

Projected climate data were then used to assess potential impacts to the installation's mission and natural resources.

A.1 Climate Projections

Climate projections are based on recent global climate model simulations developed for the Intergovernmental Panel on Climate Change (IPCC), Coupled Model Intercomparison Project Phase 5 (CMIP5) (Hibbard, Meehl, Cox, & Friedlingstein, 2007; Moss et al., 2008, 2010). Under the CMIP5 protocol, specified radiative forcing of the atmospheric warming were simulated using 32 global climate models to provide scenarios associated with emission levels at 4.5 W/m^2 and 8.5 W/m^2 (van Vuuren et al., 2011), denoted as RCP 4.5 and RCP 8.5, respectively (CMIP5 Data Search | CMIP5 | ESGF-CoG, n.d.).

A.1.1 Climate Methodology

For each US Air Force (USAF) installation assessed, historical daily temperature and precipitation data over a 30-year period were used to represent average historical conditions and generate climate projections. Future climate conditions under the RCP 4.5 and RCP 8.5 emission scenarios were projected to produce a decadal time series of daily climate values for the decades around 2030 (2026-2035) and 2050 (2046-2055).

Within the Contiguous United States (CONUS), DAYMET weather data (Thornton, Thornton, & Mayer, 2012) from 1980 to 2009 was used to represent the historical period. DAYMET provides gridded daily temperature and precipitation data at a 1-km spatial resolution. The historical climate data represent the 30-year historical reference point used by the IPCC to define climate change scenarios.

Climate projections were calculated using US National Center for Atmospheric Research (NCAR) Community Climate System Model (CCSM4) simulations prepared for the IPCC-AR5 (Gent & Danabasoglu, 2011; Hurrell et al., 2013; Moss et al., 2008, 2010). CCSM4 was chosen because it provides consistent and moderate climate representation across various climate regions. CONUS projections used Localized Constructed Analogs (LOCA) CCSM4 data with a 6-km spatial resolution (Pierce, Cayan, & Thrasher, 2014).

For installations Outside of the Contiguous United States (OCONUS), climate data for 1975-2004 from the ½ degree global degree dataset provided by the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) at the Max Planck Institute for Meteorology (Hempel, Frieler, Warszawski, Schewe, & Piontek, 2013) was used for the 30-year historical period. OCONUS climate projections used data from the HadGEM2-ES dataset, also provided by the ISI-MIP project with a spatial resolution of 50-km.

For both CONUS and OCONUS installations, historical climate data were averaged over the 30-year historical period to establish a climatological baseline for each installation. This historical baseline was then used to develop a time series of daily data for the decades around 2030 and 2050. Historical climate data gathered for each installation included average daily temperature (°C), maximum daily temperature (°C), minimum daily temperature (°C), and daily precipitation (mm). Climate data were converted to °F and inches (i.e., English units) for analysis.

For each variable of interest, a daily anomaly was computed for each emission scenario (RCP 4.5 and RCP 8.5) for each day over both 10-year periods (2026-2035 and 2046-2055). Daily data were then averaged over the 10-year period for each variable and scenario to produce annual average temperature (TAVE), average annual maximum temperature (TMAX), average annual minimum temperature (TMIN), and average annual precipitation (PRECIP) estimated for 2030 and 2050.

Daily precipitation data were used to calculate baseline and design storms used in stream channel flood modeling, as applicable (Section A.2.1).

A.1.2 Generation of Climate Summaries

Two R packages were created and used to generate the climate summary. The DaymetLOCA package produced the site-bounded projected climate data. The ClimatePrimers package generated the climate summary document for each site. Figure A-1 below shows the general workflow.

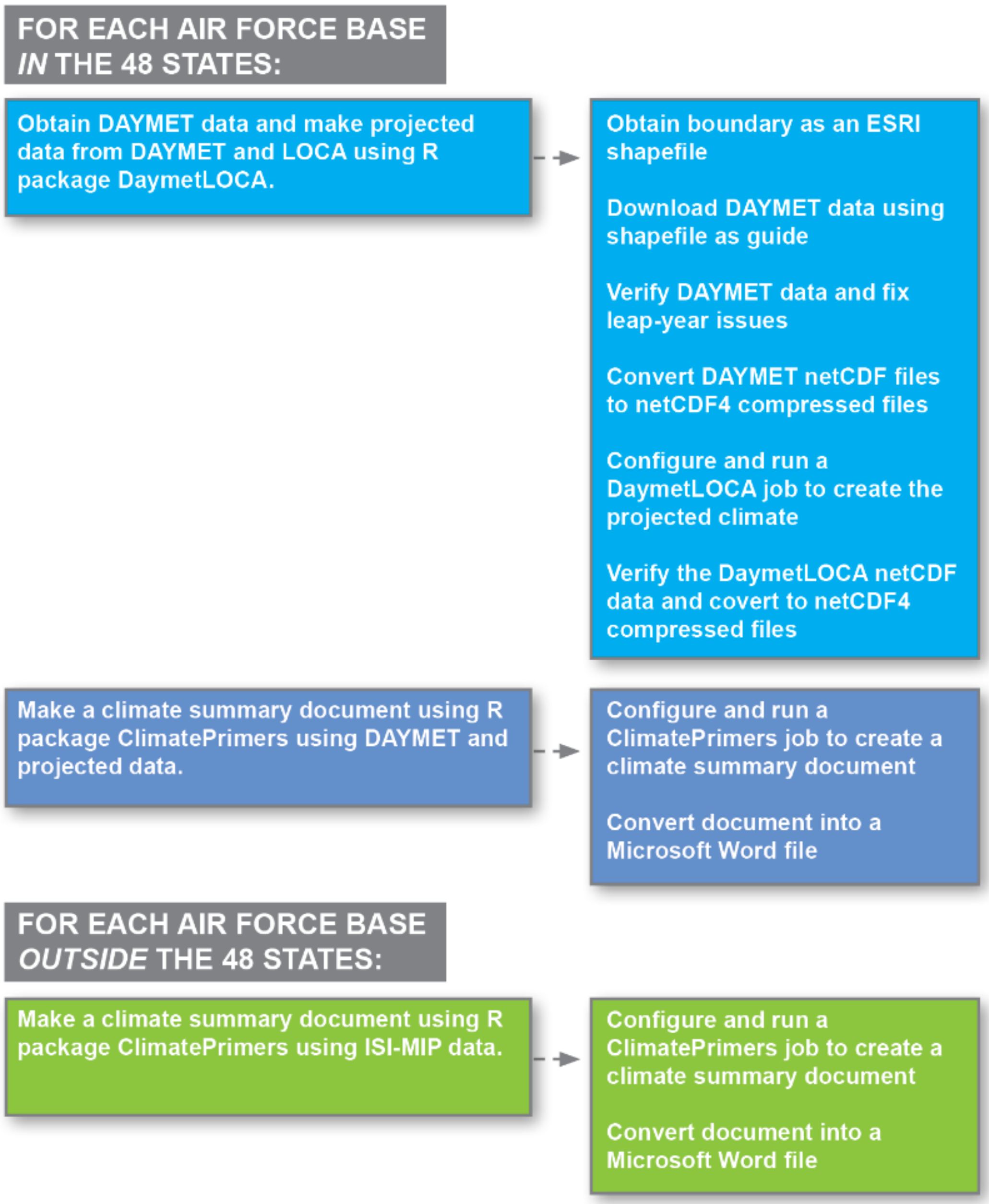

Figure A-1. Climate analysis workflow.

A.1.3 Walter & Lieth Climate Diagrams

The ClimatePrimers package in R also generated Walter & Lieth climate diagrams (Walter & Lieth, 1960), which display average monthly precipitation and temperature patterns throughout a year. The diagrams were developed by averaging temperature and precipitation data by month for each year of the 10-year period for each scenario. Resulting monthly values were then averaged across the 10-year period to generate the Walter & Lieth climate diagrams. An annotated Walter & Leith diagram example is shown in Figure A-2.

The diagrams were developed using R functions derived from the “diagwl” function in the climatol R package (Climatol Climate Tools, n.d.). The original function was modified to display values in English units (°F and inches) for CONUS locations.

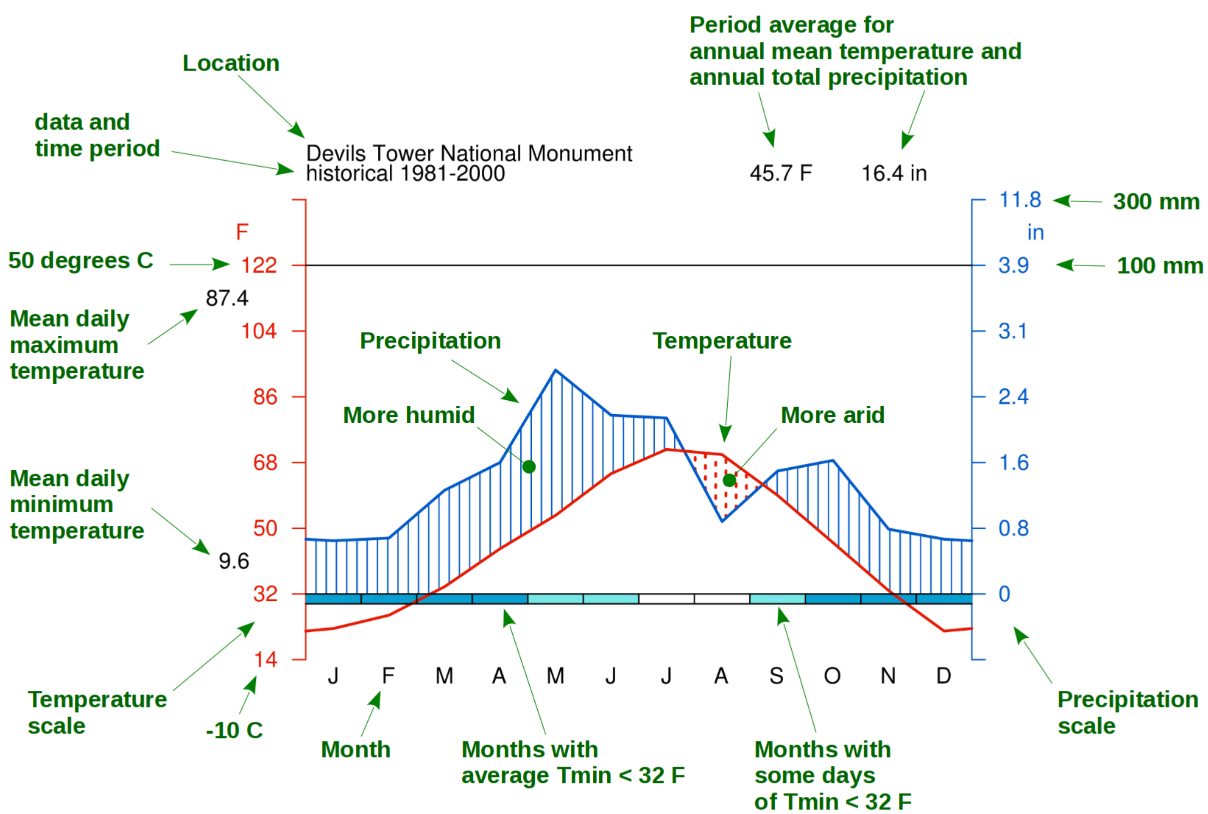

Figure A-2. Example Walter & Leith climate diagram.

A.2 Hydrology

Flooding associated with (1) precipitation induced stream channel overflow and (2) coastal sea level rise (SLR) and storm surges (SS) was assessed for USAF installations as applicable.

A.2.1 Stream Channel Modeling

Modeling of stream channel overflow (or flood modeling) was conducted using climate projection data for RCP 4.5 and RCP 8.5 emission scenarios in 2030 and 2050. The scope of flood modeling was limited to stream channel networks and did not consider flooding of independent surface bodies, stormwater systems, or surface ponding.

Floodplain modeling was not conducted for installations under the following conditions:

1. No stream channels exist within or around the installation boundary. Standing water bodies (if present) are not integrated into a stream network.
2. Installation is outside of the 100-year floodplain of nearby stream channels. Design storms are expected to be less likely than a 100-year storm due to projection methods.
3. Flooding has not been documented as a historical issue and design storm projections do not estimate increased storm intensities under climate change scenarios.
4. Storm water management infrastructure exists on the installation or is integrated into the contributing drainage network; modeling could not be conducted without storm water infrastructure data.
5. Available data were not sufficient to conduct a reliable evaluation.

A.2.1.1 Design Storm Development

A design storm is a hypothetical storm used to design infrastructure, evaluate flood hazards, and/or inform land use planning and resource management. Daily precipitation data from 1996-2005 were used to estimate baseline design storms for the year 2000. Projected daily precipitation data from 2026-2035 and 2046-2055 were used to estimate design storms for emission scenarios in 2030 and 2050, respectively.

Projection methods did not allow for determination of design storm probability. Design storms were based ten years of data and therefore do not represent extreme weather events (e.g., hurricanes, extraordinary storm fronts) and are expected to be smaller than current 100-year storms.

Initially, each 10-year dataset was averaged, however it was determined that averaging daily precipitation data across a 10-year period resulted in decreased variance from day-to-day and, therefore, obscured potentially significant storm events. As a result, algorithms were developed to screen the raw data and identify the biggest three-day storm in each year (defined as the maximum annual precipitation over a three-day period where precipitation occurs each day). Daily totals were then averaged across the 10 selected storms (1 storm per year), omitting values below the 50th percentage. Three-day storm events were used as design storms for flood modeling because rainfall occurring over consecutive days can cause soil saturation, overland flow, and compounding runoff.

A design storm hyetograph was produced for each climate scenario representing simulated precipitation intensity over the 72-hour period. The National Oceanic and Atmospheric Administration (NOAA) Atlas 14 was used to develop the synthetic distribution for each design storm. The late-peaking storm distribution was selected for all installations.

A.2.1.2 Watershed Delineation

The watershed boundary was delineated for each drainage basin that was to be modeled. Most CONUS watersheds were delineated using the United States Geological Survey (USGS) online StreamStats application. If StreamStats watershed data were not available for CONUS locations, then Hydrologic Unit Code (HUC) shapefiles were accessed from the Natural Resources Conservation Service (NRCS) database. The watershed boundary was determined using the Digital Elevation Model (DEM), aerial imagery and/or a topographic map to establish the perimeter of area that would continuously contribute drainage to the installation.

For OCONUS locations, watersheds were delineated with the ArcHydro tools package in ArcGIS using available DEM. This tool uses a point shapefile (point of interest) and the DEM of the area to delineate the contributing runoff area upstream of the selected point. Alternatively, the Spatial Analyst toolbox called “Watershed” in ArcGIS could also be used to delineate the watershed using the DEM, point of interest, and flow direction raster.

A.2.1.3 Flood Modeling

U.S. Army Corps of Engineers’ (USACE) Hydrologic Engineering Center (HEC) Hydrologic Modeling System (HMS) software was used to simulate runoff and estimate discharge over the contributing watershed following design storms. HEC–River Analysis System (RAS) 2D software was used for hydraulic modeling to evaluate potential stream channel overflow at the installation. ESRI ArcGIS tools, such as ArcHydro, were used for preprocessing geospatial data used in hydrologic and hydraulic modeling. Figure A-3 shows the workflow for flood modeling.

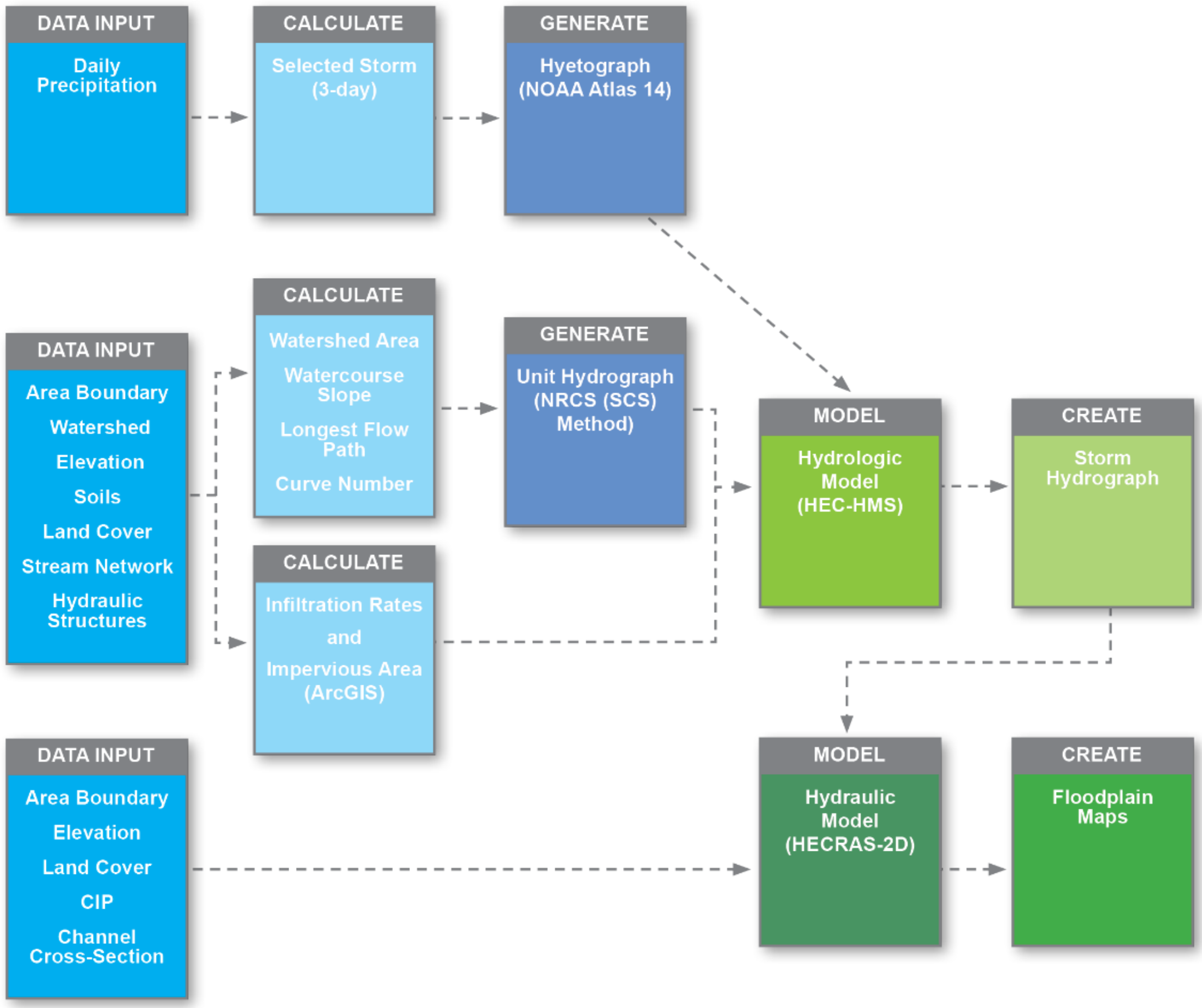

Figure A-3. Flood modeling workflow.

A.2.1.4 Hydrologic Modeling

A HEC-HMS hydrologic model was created for each watershed to represent how tributaries and sub-basins upstream of the installation are interconnected. Junctions were included where tributaries from sub-basins join a river or where two or more sub-basins drain. River routing was based on available data. Both the kinematic wave and lag routing methods were used to simulate flow.

The amount and timing of storm runoff also depends on physical characteristics of the watershed. A unit hydrograph characterizes how the watershed is expected to respond to a unit of rainfall. Unit hydrographs were developed according to the Soil Conservation Service (SCS), now the NRCS, method as described in the NRCS National Engineering Handbook (NRCS, 2009).

The SCS method requires the following parameters:

- Watershed area (above the point where the hydrograph is to be developed)
- Longest flow path using watershed and stream network data
- Average watershed slope using elevation and watershed data
- Curve Number (CN) determined from soils, land cover, and watershed data

Additional inputs into the model included land cover, soil type, depth to water table, and percent imperviousness. Infiltration losses were calculated using the initial and constant method. The NRCS National Engineering Handbook (NRCS, 2009) provides a range of infiltration rates for each type of soil group according to water table depth. Soils data were used to determine infiltration rates for each portion of the land in the sub-basin. The constant infiltration rate was then calculated using a weighted area analysis. Impervious land area was calculated using land cover data. After identifying the imperviousness for each portion of the land in the sub-basin, the total percent imperviousness was calculated using a weighted area analysis.

When available, projected land cover data over the delineated watershed was used as a variable input for modeling future climate scenarios. MC2 data were available for most CONUS installations at a spatial resolution of 4-km. Other model parameters including soil type and impervious area were held constant in projection models. Land cover was held constant for OCONUS installations.

The HEC-HMS model generated a hydrograph for each design storm estimating discharge in cubic feet per second.

A.2.1.5 Hydraulic Modeling

A hydraulic model was used to simulate channelized flow and stream channel overflow at the installation. Inputs to the hydraulic model included hydrographs produced from hydrologic modeling, elevation data, land cover data, environmental data, and Common Installation Picture (CIP) data.

A 2D mesh digital representation of the channel and physical terrain adjacent to the channel. Elevation data was imported into the HEC-RAS 2D model to represent terrain and water surface elevations. If the channel bathymetry data was not captured within the elevation data, channel area was mapped and elevation within the channel was dropped to account for channel depth/capacity. Based on the spatial resolution, elevation data were further manipulated to account for hydraulic structures like culverts, bridges, and dams. Stream network data and road network data were imported into the model and assigned as breaklines. Breaklines stabilize the model by refining the cell sizes within the 2D mesh.

CIP data were imported into the model to assign buildings and structures as obstructions within the 2D mesh area. Land cover data were imported into the model and Manning’s n roughness coefficients were assigned to each land cover classification (Table A-1). Roughness coefficients define the resistance for the terrain in the 2D flow area and have a large impact on the model results.

Once the 2D mesh was created, the boundary conditions were established at upstream (inflow) and downstream (outflow) ends of the channel. The inflow boundary condition was used to load the hydrologic information using the flow hydrograph. Since the flood modeling was conducted based on a projected three-day design storm, the inflow boundary conditions were set to unsteady flow data. The outflow boundary condition was used to define the outflow discharge information in the form of water surface elevation (typically set as ‘normal’ depth). The simulations were computed using full momentum equations for higher accuracy, compared to diffusion wave equations. A computational time interval of 6 seconds was used to generate stable results. Flood maps were created based on resulting inundation to display the spatial extent of projected inundation.

Table A-1. USACE recommended Manning’s n roughness coefficients based on NLCD land cover type.

NLCD ‘Code’ 2011	NLCD ‘Type’ 2011	USACE ‘n’ 2016
11	Open Water	0.035
21	Developed, Open Space	0.040
22	Developed, Low Intensity	0.100
23	Developed, Medium Intensity	0.080
24	Developed, High Intensity	0.150
31	Barren Land Rock/Sand/Clay	0.040
41	Deciduous Forest	0.100
42	Evergreen Forest	0.120
43	Mixed Forest	0.080
52	Shrub/Scrub	0.080
71	Grassland/Herbaceous	0.045
81	Pasture/Hay	0.060
82	Cultivated Crops	0.060
90	Woody Wetlands	0.120
95	Emergent Herbaceous Wetlands	0.080

A.2.2 Coastal Zone Modeling

SLR and SS exposure was assessed using a Department of Defense (DoD) site specific scenario database. Details on the development and use of this database are described in Hall et al. (2016). Because of the methods used in that database, scenarios modeled for SLR/SS vary slightly from the scenarios used in other sections of this report. The DoD assessed regionalized sea level and extreme water level timeframes surrounding the years 2035 and 2065. That assessment determined scenarios based on change in sea level rather than on emissions scenarios. However, RCP 4.5 climate change scenarios were determined to align with projection data from the 1.6 ft. (0.5 m) SLR scenario. RCP 8.5 climate change scenarios were determined to align with projection data from the 3.3 ft. (1.0 m) SLR scenario.

In addition, the DoD report analyzes extreme water level scenarios in which SLR is compounded by SS. Extreme water level scenarios were based on regional frequency analysis estimates of 20-year and 100-year storm surges. The SLR/SS scenarios presented are:

RCP 4.5 2035 no SS	RCP 4.5 2065 no SS
RCP 8.5 2035 no SS	RCP 8.5 2065 no SS
RCP 4.5 2035 20-year SS	RCP 4.5 2065 20-year SS
RCP 8.5 2035 20-year SS	RCP 8.5 2065 20-year SS
RCP 4.5 2035 100-year SS	RCP 4.5 2065 100-year SS
RCP 8.5 2035 100-year SS	RCP 8.5 2065 100-year SS

To account for impacts from tides, the Mean Higher High Water (MHHW) tide data for each location was added to SLR and SS projections. MHHW is the average height of the highest tide recorded at a tide station each day observed over a period of several years. In the United States this period spans 19 years and is referred to as the National Tidal Datum Epoch. The projected SLR inundation estimates the new permanent coastline for each SLR scenario and year. Projected SS inundation represents short-term flooding that is expected to recede after the storm.

ESRI’s ArcGIS was used to evaluate how SLR and SS projections were likely to impact an installation. The spatial extent of flooding due to SLR and SS was assessed for installations within a 20-km buffer from shoreline. DEM data were used to represent digital terrain and sea level elevation. The ‘less than equal’ tool within ArcGIS was used to identify areas within the terrain that would be inundated based on the projected height of SLR and SS (in meters). SS inundation was corrected to omit areas not connected to a coastline. SLR and SS projections were compared to coastal elevation at the time the DEM was produced.

A.3 Ecosystems and the Biotic Environment

Literature review, available Geographic Information Systems (GIS) data and installation-provided descriptions, analysis and maps were used to assess baseline characteristics of ecosystems at the installation and create a baseline ecosystem feature map comprised of an ecosystem shapefile layer clipped to the installation's boundary.

Polygon layers containing land-cover, ecosystem, and wetlands data were drawn from the USAF AFCEC Environmental GIS Project. If the installation-specific data were provided to the USAF AFCEC Environmental GIS Project and/or uploaded into GeoBase, they were used. If installation-specific data was not available, public sources were used as an alternative. Online sources included the USGS GAP-Analysis Project, the Multi-Resolution Land Characteristics (MRLC) Consortium's NLCD, and the United States Fish and Wildlife Service (USFWS) National Wetlands Inventory dataset.

A.3.1 Ecosystem Classification

The ecosystem classification follows the National Hierarchical Framework of Ecological Units or Bailey's Ecoregions (Bailey, 2014), which is a regionalization that links soils, physiography, and ecosystem types to stratify the landscape into progressively smaller areas. This classification is unlikely to be drastically modified under the climate change scenarios evaluated. Therefore, analysis focused on those ecosystems and vegetation types deemed vulnerable to the RCP 4.5 and RCP 8.5 climate change scenarios.

A.3.2 Vulnerability

Potential impacts of a moderate emission scenario (RCP 4.5) and a high emission scenario (RCP 8.5) on ecosystems under climate data from a decadal time series around 2030 (2026-2035) and 2050 (2046-2055), were evaluated using the framework developed by Comer et.al. (2012) for the Habitat Climate Change Vulnerability Index (HCCVI).

This index uses a two-dimension analysis of climate change sensitivity and ecological resilience for each ecosystem type distribution within a given ecoregion, using combined quantitative and qualitative approaches. Quantitative estimates for sensitivity to climate change included climate projections for the decadal averages studied (climate induced stress), land cover condition (historic and projected) and flooding analysis, which were normalized to 0.0–1.0 scores.

Analysis of downscaled global climate forecasts for temperature and precipitation variables provided an indication of the relative intensity of climate-induced stress. Climate projection models were used to correlate and map current ecosystem distributions with a suite of key climate variables from a 1980 baseline. Then, the location of that same climate projection as predicted for 2030 and 2050, provided an indication of the directionality, magnitude, and overlap of geographic shift for species from the community and ecosystem. Finally, where available, models of hydrologic regime were used to forecast trends in the alteration or 'departure' from expected conditions for upland vs. riparian/aquatic communities, respectively.

Qualitative resilience categorizations used in this vulnerability assessment of the ecosystems at the installation were based on the following criteria:

- Review of the ecological characteristics of each type of ecosystem/land or vegetation cover/ecosystem present at the installation;
- Assessment of the adaptive capacity of each ecosystem/land or vegetation cover/ecosystem based on published scientific research.

The scores for sensitivity and resilience were combined to determine the categorical estimate of climate change vulnerability by the years 2030 and 2050 for each ecosystem type.

For the HCCVI, climate-change vulnerability was expressed in three categories: high, moderate, and low. Therefore, the index ratings are quite general, but this is because predictive uncertainty is often high, and the overall intent is a generalized indication of vulnerability. This is analogous to a scoring of "endangered" or "threatened" for a given species, but here focused specifically on climate change vulnerability, and applied to community and ecosystem types. A general framework of the concepts evaluated for each vulnerable ecosystem is shown in Figure A-4.

Once vulnerable ecosystems were identified, baseline and inundation maps, ecosystem maps and area tables were generated to reflect the current coverage of vulnerable ecosystems at the installation. Flooding (flood inundation) and/or SLR and SS projections based on the analysis provided by climate and hydrology models were also overlaid with ecosystem data to assess potential impacts.

Maps were created from the series of layered maps depicting the flood inundation shapefiles overlaid on the baseline ecosystem layer to show the extent of the projected inundation due to flooding. The maps provide a visual comparison of the projected inundation with the baseline inundation due to flooding. Four maps were created, one for each projected scenario. The baseline ecosystem is also presented to show possible affected ecosystems and the extent of the inundation relative to the different ecosystem classes.

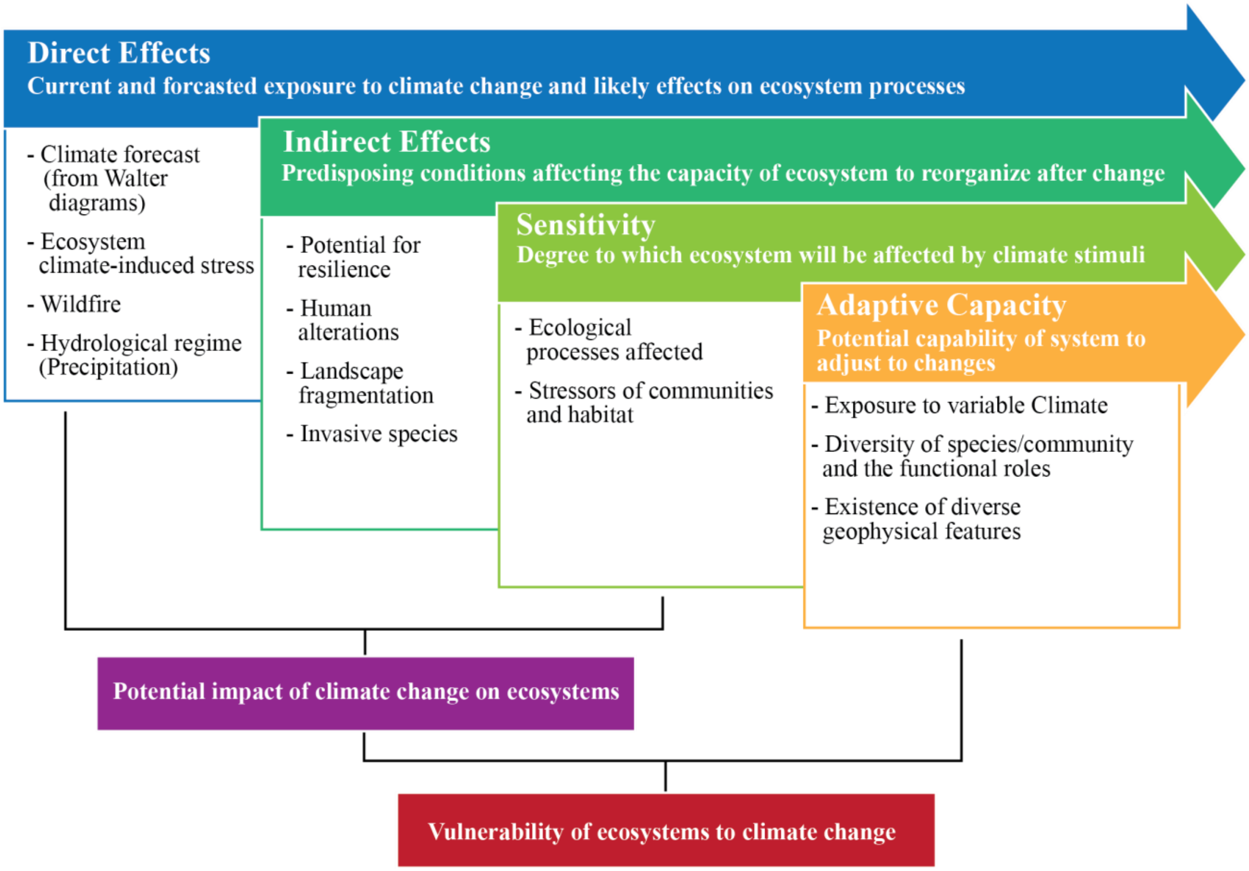

Figure A-4. Framework used to evaluate direct and indirect effects, sensitivity, and adaptive capacity of vulnerable ecosystems.

The SLR and SS inundation layers for each scenario were overlaid on the baseline ecosystem layer to visually depict potential areas of concern for each projected scenario. Each map features the inundation layers for the 4.5 RCP and 8.5 RCP scenarios, and they are organized by the projected model year. The area of inundation for flooding was also compared to the MC2 projected ecosystem scenarios (when available). If the inundation shapefiles covered an area where the MC2 ecosystem type changed from the baseline to one of the projected model years, the area and percent coverage were calculated. Finally, the flood and SLR and SS area tables compare the area of each inundation shapefile to the total area of the installation boundary. The percentage of coverage was calculated to quantify the extent of each inundation layer and to see what percentage of the installation was affected. The change in percentage from one inundation scenario to the next was also included to show whether the area of inundation was increasing or decreasing, compared to the baseline projection.

A.3.3 Fish and Wildlife

Fish and wildlife assessments use climate projections, as well as information related to climate and fish and wildlife species derived from the installation's INRMP. Important variables used in the analysis to determine impacts of climate change on fish and wildlife species include average monthly temperatures, monthly precipitation, and intensity/frequency of storm events, changes in vegetation, projected fire behavior and maps depicting habitat loss through inundation. With this information, qualitative analysis was done to address potential direct and indirect effects of vulnerable fish and wildlife populations. One example of a direct effect would be displacement of a terrestrial species due to habitat inundation. An example of an indirect effect would be increasing temperature causing algal blooms in benthic habitats leading to depletion of dissolved oxygen and displacement of aquatic organisms.

A.3.4 Threatened and Endangered Species and Species of Concern

Vulnerability assessments of threatened and endangered species were conducted using a framework developed by Thomas et al. (2011). The framework defines vulnerability status through the intersection of two dimensions: risk of climate-related decline in existing range and benefits of unaided climate-related expansion. Scores for the first dimension incorporate observed population declines within the species historic/current range and projected effects of climate change in that range. Scores for the second dimension incorporate observed and projected range expansion. Both dimensions are modified by inclusion of risks and benefits that are not directly related to climate change and have a measure of uncertainty.

Data from USFWS listing and recovery documents, state threatened and endangered species databases, NatureServe Explorer and other published literature were used in completing the framework. Population-level data and trends are used. Framework calculations are included on the attached DVD to allow installations to update the analysis using installation-specific sub-population observations.

A.4 Mission Impacts on Natural Resources

A.4.1 Natural Resource Constraints to Mission and Mission Planning

The qualitative assessment of climate change impacts to the military mission closely follows the framework of Army Techniques Publication ATP 2-01/MCRP 2-3A, Intelligence Preparation of the Battlefield (IPB) (United States Army, 2014). The basics of this framework are general enough to be used to analyze mission requirements for any military branch and have been done so using Air Force documents related to the branch's specific mission requirements. IPB is a four-step process used by the U.S. Army (and Marine Corps) to provide a "systematic, continuous process of analyzing the threat and environment in a specific geographic area." (United States Army, 2014). Although this framework is designed for continual feedback over a long period, it was used here to assess impacts for multiple emission climate scenarios and time frames.

The four-step IPB process as applied to the mission impact analysis was tailored to Air Force mission types (primarily the 12 Air Force Core Functions), the biological and physical environment of each installation, and the potential primary and secondary effects of climate change on these operational environments and environmental features.

1. Describe the Operational Environment. This step collects all available data and information including but not limited to: geographical and climatic area of interest (AOI), mission types conducted within the AOI, habitat and vegetation types within the AOI, mission related infrastructure (including ranges, training areas, buildings, roads, and any other infrastructure relevant to the military mission), and the results of the climate and hydrologic analyses described in section 1.1. Sources include GIS layers, results of all other analyses used for the INRMP climate assessment, INRMPs, as well as Air Force mission related documents such as Installation Complex Encroachment Management Plans (ICEMAP), Air Force Doctrine Documents (AFDD) and Command Strategic Plans.
2. Describe Environmental Effects on Operations. Data and information from Step 1 were synthesized to define any spatiotemporal overlap between climate change effects on environmental exposures (e.g., wind, heat, sea level rise, flooding), military operations required to complete the mission, and environmental conditions required for these critical military operations.
3. Evaluate the Threat. A qualitative judgment was made as to the extent and severity of any of the overlaps identified in Step 2. Climate change related threats were deemed as low, moderate, or high risk depending on the predicted or inferred level of impact. This level of impact is contingent on factors such as importance to the mission, possibility of the partial or full attainment of the mission with workarounds, and redundancy (such as multiple locations capable of fulfilling mission requirements or alternate routes available for personnel and equipment movement).
4. Determine Threat Courses of Action. This step was not conducted in the mission impacts assessment, although it is at least partially fulfilled by considering adaptation strategies within the INRMP climate change assessment.

A.5 Fish and Wildlife Management

Fish and wildlife management is based on climate projections and vulnerabilities of fish and wildlife species. The framework for adaptation strategies is shown in Figure A-6 (Comer et al., 2012). Ideally, natural adaptation methods that provide multiple benefits to ecosystems would be implemented. One example is use of native plants in beach nourishment and stabilization projects, as they provide cost-effective means of developing habitat for a number of wildlife species while providing structural support, in contrast to construction of hard infrastructure, which is costly and inefficient in promoting natural ecosystems. In some cases, there are no feasible adaptation strategies available to combat effects of climate change, such as loss of alpine tundra due to rising temperatures or loss of coral reefs due to ocean acidification. Adaptation strategies to prevent loss of fish and wildlife species indicated as important or vulnerable in the installations INRMP are provided in a qualitative format.

A.6 Outdoor Recreation and Public Access to Natural Resources

Impacts of climate change on outdoor recreation and public access to natural areas are based on current recreational demands and opportunities listed in INRMPs and climate projections provided though this project. Qualitative analysis was done using data that included average monthly temperatures, monthly precipitation, and intensity/frequency of storm events, changes in vegetation, projected fire behavior and maps depicting habitat loss through inundation. In some cases, future climate should have little to no effect on recreational opportunities and no changes in management are deemed necessary. In other cases, recreational access will need to be limited in vulnerable habitat types to limit competition between habitat needs of fish and wildlife. Such cases often involve sandy shorelines at risk of complete deterioration through sea level rise and increasing storm intensity/frequency where requirements for restoration (beach nourishment and stabilization) are in conflict with intensive recreational use. Occasionally recreational use can be of benefit to natural resources management. For example, providing increased hunting is a cost-effective tool in managing invasive species, but will need to be balanced against constraints. Ideally qualitative analysis is conducted to determine land management practices which leave intact recreational opportunities highlighted in INRMP Section 7.2 Outdoor Recreation and Public Access to Natural Areas.

A.7 Management of Threatened and Endangered Species, Species of Concern and Habitats

Species-specific management actions directed at climate-related vulnerabilities are not recommended. The ecosystem-based, adaptive management approaches that are currently employed in INRMPs is a good foundation for building climate adaptation strategies to protect threatened and endangered species. Because species vulnerabilities were assessed at the population level, and not the specific populations at the installation, a generalized adaptation approach is suggested. Climate change consideration should be included in all steps of the adaptive management process (Figure A-5).

Figure A-5. Adaptation process from America's Climate Choices (Bierbaum et al., 2013).

Adaptation management actions can be forward-looking (proactive/prospective) or reactive (retrospective). The appropriate actions are site-specific and based on the needs of the threatened and endangered species in the context of the installation’s mission. Figure A-6 depicts examples of each type of adaptation strategies (Comer et al., 2012).

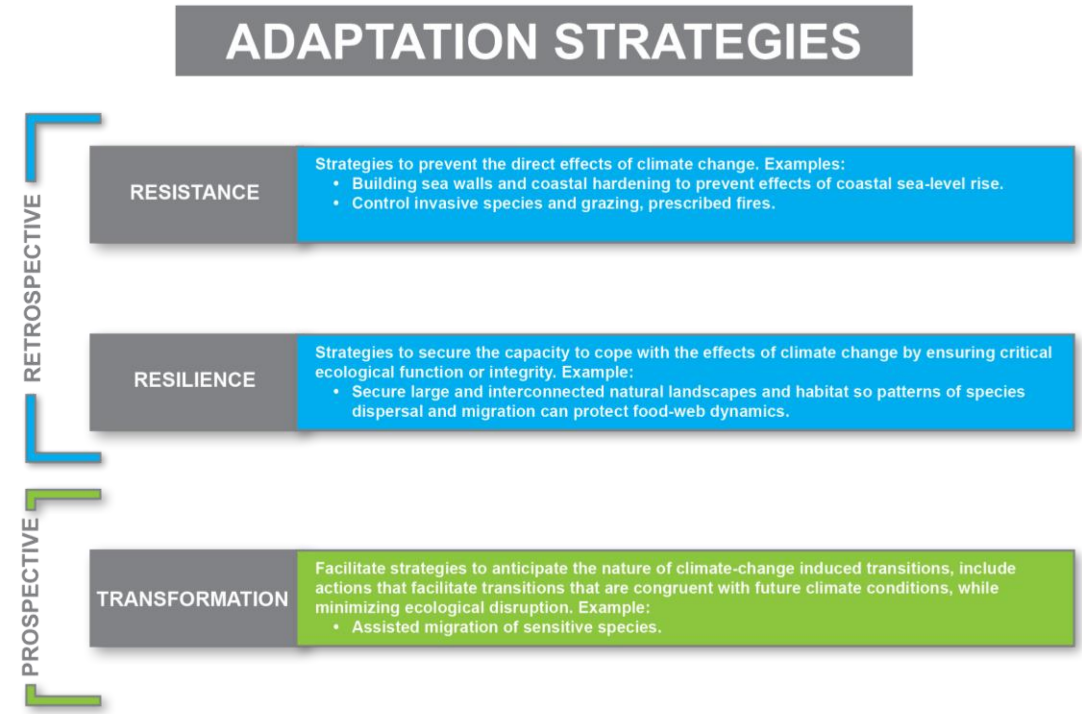

Figure A-6. Adaptation strategy framework.

A.8 Wildland Fire Management

The effect of future climate scenarios on wildland fire hazard was determined by considering each variable contributing to wildfire potential and evaluating its likelihood to worsen, improve, or remain unchanged and the magnitude of any change. Table A-2 shows the primary components of fire hazard, the metrics that comprise each, and the relevant indicators and measures from the projected climate scenarios evaluated. These factors were subjectively analyzed by subject matter experts. Sufficient data to produce a quantitative analysis is not currently available.

Many indicators of ignition and wildfire potential were not fully addressed because they are not available at the spatial or temporal resolution necessary for analysis, are beyond the scope of this study, cannot reasonably be estimated into the future, or are not expected to change. These variables are outlined in the table as well, but are assumed to remain equivalent to current day conditions.

Table A-2. Metrics of fire hazard, their indicators and measures, and whether they were considered in the analysis.

Fire Hazard Component	Metrics	Indicators and Measures	Considered in Analysis
Ignition Probability	Ignition Success	Temperature	Yes
		Precipitation Patterns	Yes
		Vegetation Communities	Yes
		Fuel Physical Characteristics	No
		Fuel Chemical Characteristics	No
		Shading	No
		Time of Day	No
		Aspect, Slope, Elevation	No
	Ignition Load	Human Activity (military and civilian)	No
		Lightning	No
Fire Behavior	Fuels	Temperature	Yes
		Fuel Load	Yes
		Vegetation Communities	Yes
		Fuelbed Physical Characteristics	No
		Fuel Chemical Characteristics	No
	Weather	Temperature	Yes
		Precipitation Patterns	Yes
		Wind	No
	Topography	Slope	No
		Aspect	No

A.9 Coastal Zone and Marine Resources Management

Based on the projections from SLR and SS modeling, impacts on built infrastructure and assets were analyzed to identify various vulnerabilities.

CIP data contain spatial data layers for installation assets like real property (buildings and structures: housing, cantonment buildings, storage), transportation (roads, vehicle parking, bridges) and military range training. The data were overlaid on the projected inundation area due to SLR and SS to identify vulnerable assets. Assets within the projected inundation area are identified to be highly vulnerable and assets within 38 feet from the inundation boundary are identified to be moderately vulnerable.

The NSSDA is typically used to report the radius of a circle of uncertainty, such that the true or theoretical location of a point falls within that circle 95 percent of the time. Based on the horizontal positional accuracy of the base map, the region of uncertainty is defined to be 38 feet, the same value that Federal Emergency Management Agency (FEMA) uses.

Suggested adaptation projects were rated by their difficulty to implement and their relative efficacy. Adaptation strategies to protect infrastructure and assets are suggested and rated by their ease of implementation and their relative efficacy. Adaptation strategies to protect infrastructure and assets are suggested and rated by their ease of implementation and their relative efficacy. Ease of implementation is ranked from 1 to 3, with 1 being most difficult to implement and 3 being the easiest to implement. Efficacy is ranked from 1 to 3, 1 being the least effective and 3 being the most effective.

The ecological impacts related to adopting each of the projects is stated to be positive if no negative impacts are expected. If these projects are expected to have negative ecological impacts, they are rated one (being as low negative impacts) through three (being high negative impacts) along with the corresponding literature reference.

Table A-3 displays an example summary of adaptation strategies and a more detailed list is provided on the DVD provided with this document.

Table A-3. Example summary of adaptation strategies for SLR and SS.

Strategy	Implementation	Efficacy	Resources	Ecological Impacts	Ecological Resources
Artificial Breakwaters	1	3	Climate ADAPT, 2015	Positive	Harris, 2009
Living Shorelines	1	2	NOAA, n.d.	Positive	NOAA, n.d.
Riprap	2	2	Ayres, 2018	1	Gittman, Scyphers, Smith, Neylan, & Grabowski, 2016
Erosion Monitoring	1	2	Climate Adapt, 2015	1	Tam, 2009
Bulkheads	2	3	Marine Construction, 2018	1	Hester et al., 2006

A.10 Data Sources and Literature

A.10.1 Data Sources

A.10.1.1 LOCA Projected Date

LOCA projected data was downloaded from Lawrence Livermore National Laboratory FTP site.

ftp://gdo-dcp.ucllnl.org/pub/dcp/archive/cmip5/loca/LOCA_2016-04-02/CCSM4/16th/

Information on LOCA data can be found at: http://loca.ucsd.edu/

Coverage Area: CONUS data for CCSM4 for these years:

Historical=1950-2005

RCP4.5/8.5=2006-2100

Climate variables: TMIN, TMAX, PRECIP

Resolution: Temporal=Daily, Spatial=1/16th degree (~6km)

A.10.1.2 DAYMET Historical Data

Archived and distributed through the Oak Ridge National Laboratory, the DAYMET data set provides gridded estimates of daily weather parameters for North America.

Data was downloaded from: https://daymet.ornl.gov/

Coverage Area: CONUS plus parts of Canada and Mexico for these years: 1980 to Most Current Year (2016)

Climate variables: TMIN, TMAX, PRECIP

Resolution: Temporal=Daily, Spatial=1km

A.10.1.3 Hydrologic Data Information

Geospatial data used in flood modeling were acquired from the USAF AFCEC Environmental GIS Project and various national and international open source GIS data repositories including:

- Elevation Data: USAF GeoBase, United States Department of Agriculture (USDA), USGS, NOAA, ArcOnline and other state/county/city data repositories
- Land Cover Data: USAF AFCEC Environmental GIS Project; National Land Cover Database (NLCD); Dynamic Global Vegetation Model (MC2); and other state/county/city data repositorie
- Soils Data: USGS Web Soil Survey (https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm) and other state/county/city data repositories

- Watershed Boundaries: USGS HUC boundaries, USGS StreamStats and ArcHydro Tools
- Stream Network: National Hydrography Dataset (NHD), USAF GeoBase
- Common Installation Picture (CIP) Data: USAF GeoBase
- Environmental Data: USAF AFCEC Environmental GIS Project

Data collected from open source databases generally required processing before it could be used in modeling. Varying spatial resolution, extent, quality of data and attributes as well as varying data formats were reconciled prior to use. ESRI's ArcGIS tools including ArcHydro were used for processing geo-spatial data.

Hyetographs NOAA Atlas 14 online tool: https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html

StreamStats: https://water.usgs.gov/osw/streamstats/

A.10.2 Literature

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