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Climate Change Vulnerability Assessment, Adaptation, and Mitigation Plan Summary Report

June 2020





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Climate Change Vulnerability Assessment, Adaptation, and Mitigation Plan

Summary Report

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WSSC Water

Climate Change Vulnerability Assessment, Adaptation, and Mitigation Plan Summary Report

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Executive Summary

Purpose

In response to increasing climate change impacting water and wastewater facility assets, the Washington Suburban Sanitary Commission (WSSC) embarked on a multi-year project to assess and strategize the efforts required for long-term asset protection. Between 2016 and 2020, WSSC developed an integrated climate adaptation and mitigation plan as part of the Climate Change Vulnerability Assessment, Adaptation, and Mitigation Plan Project (CCVAAMP). The adaptation planning entailed three primary tasks:

- Climate Analysis and Projections
- Vulnerability Assessment and Adaptation Analysis
- Adaptation Recommendations and Climate Change Design Guide Development

A fourth task, Mitigation Planning, involved development of and updates to WSSC's entity-wide Greenhouse Gas Emissions (GHG) Inventory and development of a GHG Reduction Action Plan for its operations. The GHG Emissions Inventory and Action Plan is not discussed in detail in this document; however, the latest GHG Emissions Inventory and Action Plan Update and the GHG Inventory Development and Management Plan have been included as Appendices G and H.

The purpose of this report, and its associated electronic appendices, is to summarize and consolidate the results of the 5-year CCVAAMP effort.

Methods

Climate projections, including temperature, sea level rise, and precipitation projections, were developed based on several GHG emissions scenarios and planning horizons. Vulnerability analyses for WSSC facilities were completed in a multiphased approach. Facilities were screened for risk using available Federal Emergency Management Agency (FEMA) National Flood Hazard Layer (NFHL) floodplain data. The list of screened facilities was further refined by WSSC to prioritize facilities with greater operational impact. Those facilities identified through the screening process were prioritized for hydraulic modeling and vulnerability assessment.

Results of hydraulic modeling were used to develop a facility-specific design flood elevations (DFE). DFEs were used to complete facility vulnerability assessments based on WSSC asset management database output, review of facility as-built drawings, site visits, and site survey. Adaptation strategies for flood mitigation were developed for each site at the asset level, building level, and, in select cases, the sitewide level. Using the probability of flooding under current conditions, and the increased probability of flooding in future conditions, a cumulative risk avoided was computed based on replacement costs, adaptation strategy cost, and failure potential.

Vulnerability and Risk Assessment Results

Of the 49 facilities originally screened during Phase I of the CCVAAMP, 18 facilities were prioritized for investigations, and 8 of these facilities were found to be at risk to current and/or future (2065 100-year) flooding. Vulnerability assessments were completed on these eight facilities, results of which are summarized in Table ES-1.

Table ES-1 Summary of Assets at Risk and Recommended Adaptation Strategy Costs and Benefits (Cumulative Risk Avoided) for the Future 2065 100-year Flood Event

Planning Horizon	LOS 1 and 2 Assets at Risk[a]				All Assets at Risk			
	Quantity	Cost of Replacement	Strategy Cost[b]	Benefit	Quantity	Cost of Replacement	Strategy Cost[b]	Benefit
2065 100-year	71	$12,720,000	$1,104,000	$3,931,700	801	$113,790,000	$2,561,000	$27,321,700

Notes:

[a] Level of Service (LOS) 1 and 2 include assets that maintain the safety and protection of site personnel, maintain plant hydraulic capacity, and perform primary treatment for liquid processes.

[b] Costs presented are considered Conceptual/Planning Estimate + 100 percent/- 50 percent per American Society of Cost Estimating Engineers

Conclusions and Recommendations

The CCVAAMP facility vulnerability assessment was based on asset replacement cost information provided by WSSC's Asset Management Division (AMD). WSSC's internal process for identifying and approving capital projects is carried out by the AMD. The business case analyses carried out by AMD include operational consequences and considerations beyond the scope of the CCVAAMP investigation. Therefore, the output of this study is intended to be integrated into the existing process, to fully understand both asset-level and operational impacts of various flood risk conditions.

Two methods were used to evaluate the potential priority of resilience projects for the eight facilities found to be at risk of flooding:

- Cumulative risk to all assets, sorted in declining order of expected value of benefits from avoided damage to WSSC's physical assets.
- Return on investment (ROI), sorted in declining order of net return (benefits minus costs) per $ of strategy cost

Figure ES-1 shows the eight facilities in rank order based on cumulative risk avoided, compared to the strategy cost at each facility. The top four facilities in declining order based on risk ranking are Rocky Gorge Raw Water Pumping Station (RWPS), Parkway Wastewater Treatment Plant (WWTP), Broad Creek Wastewater Pump Station (WWPS), and Western Branch WWTP, with the remaining four facilities having essentially the same much smaller level of risk. However, as shown on Figure ES-2, based on ranking by ROI, the highest-ranked facilities are Rocky Gorge RWPS and Fort Foote WWPS, with little difference between the remaining six facilities.

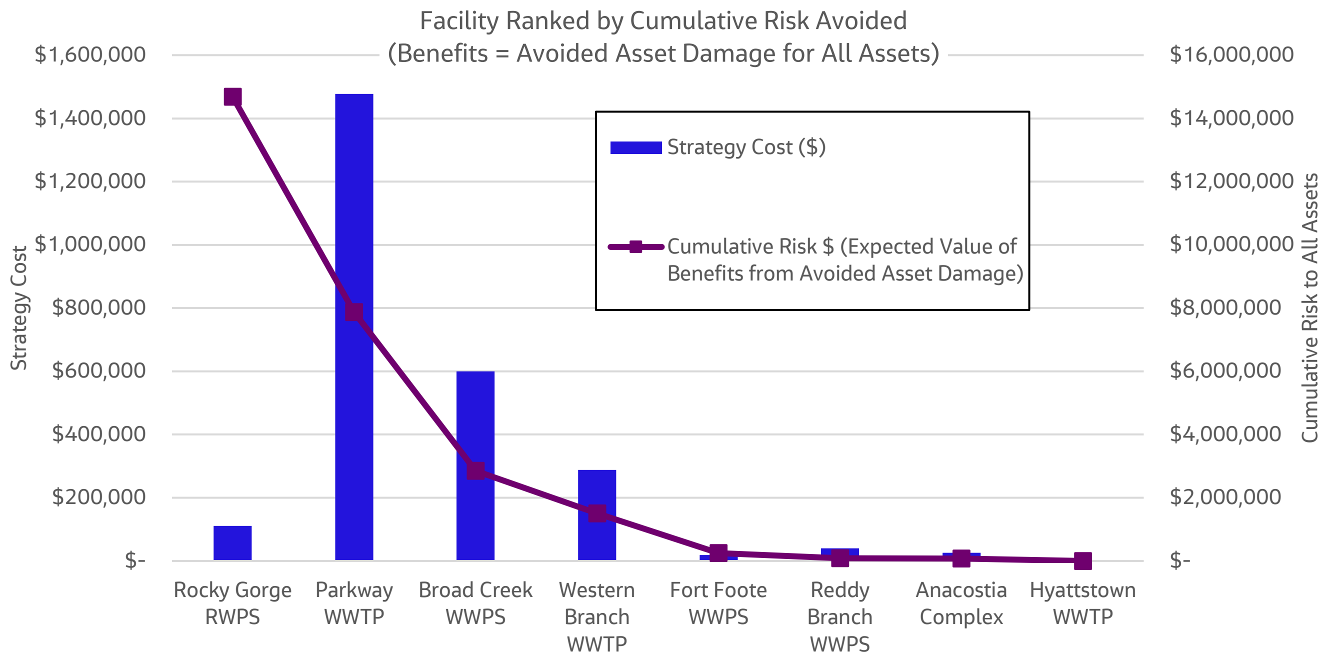

Figure ES-1. Facility Cumulative Risk Avoided and Strategy Costs Sorted in Order of Declining Risk

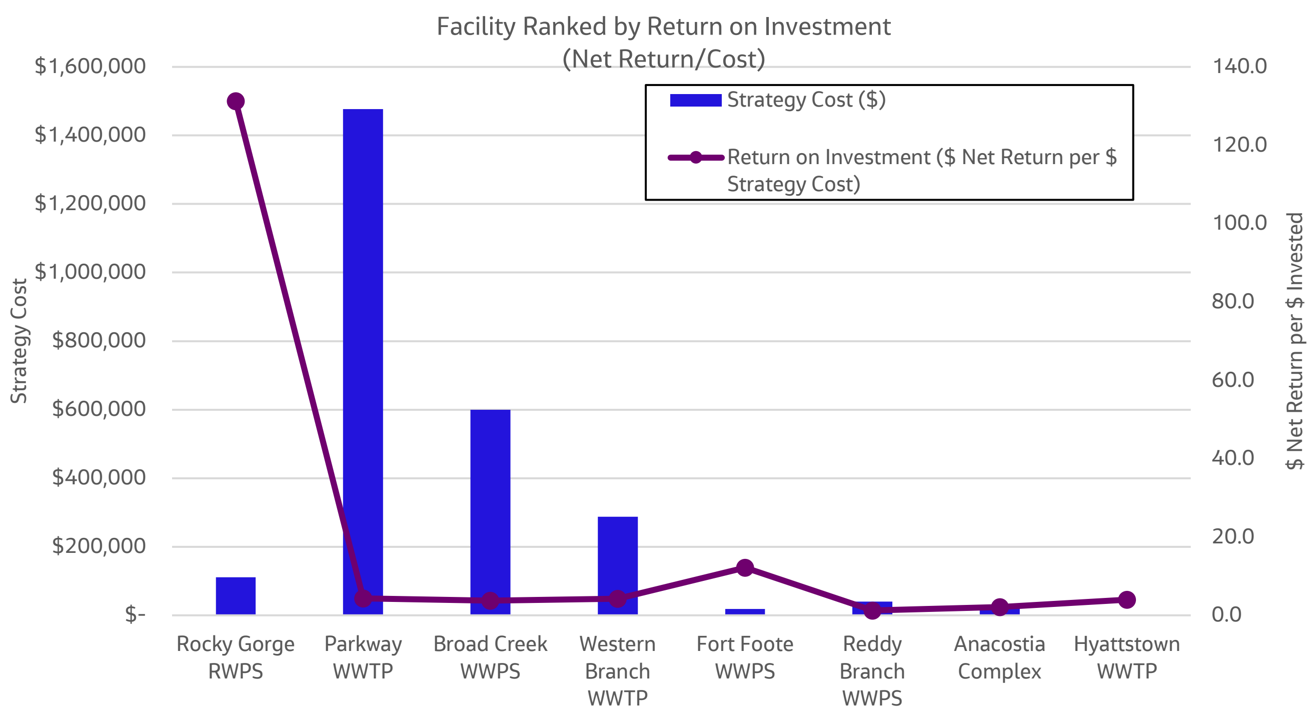

Figure ES-2. Facility Return on Investment and Strategy Costs Sorted in Order of Declining Return on Investment.

Initial investment in protections at Rocky Gorge RWPS and Forte Foote WWPS yields high ROI, with Rocky Gorge being an order-of-magnitude higher than Forte Foote. All strategies presented maintain a positive ROI with all but two with ROI greater than 3. This indicates that although the initial adaptation recommendations have a very high ROI ranking, subsequent recommendations still provide a benefit value of over three times the adaptation cost. The cumulative total cost for resilience measures at all eight facilities is $2.6 million.

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Acronyms and Abbreviations

AMD	Asset Management Division
BCA	Business Case Analyses
BWI	Baltimore/Washington International Thurgood Marshall
CCVAAMP	Climate Change Vulnerability Assessment, Adaptation, and Mitigation Plan Project
DFE	design flood elevation
FEMA	Federal Emergency Management Agency
FY	Fiscal Year
GCM	General Circulation Model
GHG	Greenhouse Gas Emissions
GIS	Geographic Information System
ICPRB	Interstate Commission for the Potomac River Basin
IDF	intensity, duration, and frequency
LOS	Level of Service
MHHW	mean higher high water
MSL	mean sea level
N/A	not applicable
NAVD88	North American Vertical Datum of 1988
NFHL	National Flood Hazard Layer
NGVD29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic Atmospheric Administration
NPV	net present value
RCP	representative concentration pathways
ROI	return on investment
RWPS	Raw Water Pumping Station
SLR	sea level rise

TM	technical memorandum
WFP	water filtration plant
WPS	water pumping station
WSSC	Washington Suburban Sanitary Commission
WWPS	Wastewater pump station
WWTP	Wastewater Treatment Plant

1. Introduction and Purpose

The purpose of this report and associated appendices is to consolidate the results of the 5-year Climate Change Vulnerability Assessment, Adaptation, and Mitigation Plan Project (CCVAAMP) efforts. Over the span of those 5 years, Washington Suburban Sanitary Commission (WSSC) developed an integrated climate adaptation and mitigation plan as part of the CCVAAMP project. The adaptation planning entails three primary tasks:

- Climate Projections and Modeling Scenarios (Sections 3 and 4 of this report)
- Vulnerability and Risk Assessment (Section 5 of this report)
- Adaptation Recommendations and Climate Change Design Guide Development (Section 6 of this report)

The fourth task, Mitigation Planning, involved the development of and updates to WSSC's entity-wide Greenhouse Gas (GHG) inventory and development of a GHG Reduction Action Plan for its operations. The mitigation planning task will not be discussed further in detail in this document, but the latest GHG Action Plan Update and the GHG Inventory Development and Management Plan have been provided in included as Appendices G and H.

1.1 Study Area

WSSC's service area spans over 1,000 square miles in Maryland's Prince George's and Montgomery counties located outside of Washington, D.C. (Figure 1-1). The service area includes approximately 5,800 miles of water distribution pipeline and 5,600 miles of wastewater collection pipeline. To supply water, WSSC operates and maintains two water filtration plants (WFPs): Patuxent and Potomac; and three reservoirs: Triadelphia, Rocky Gorge, and Little Seneca. Along with treatment plants, the water distribution system includes two water pump stations (WPS) and 49 water tanks. Wastewater treatment is provided at six wastewater treatment plants (WWTPs): Western Branch, Piscataway, Parkway, Seneca, Damascus, and Hyattstown. The wastewater collection system includes 27 wastewater pump stations (WWPS), 7 vaults, and 1 storage facility.

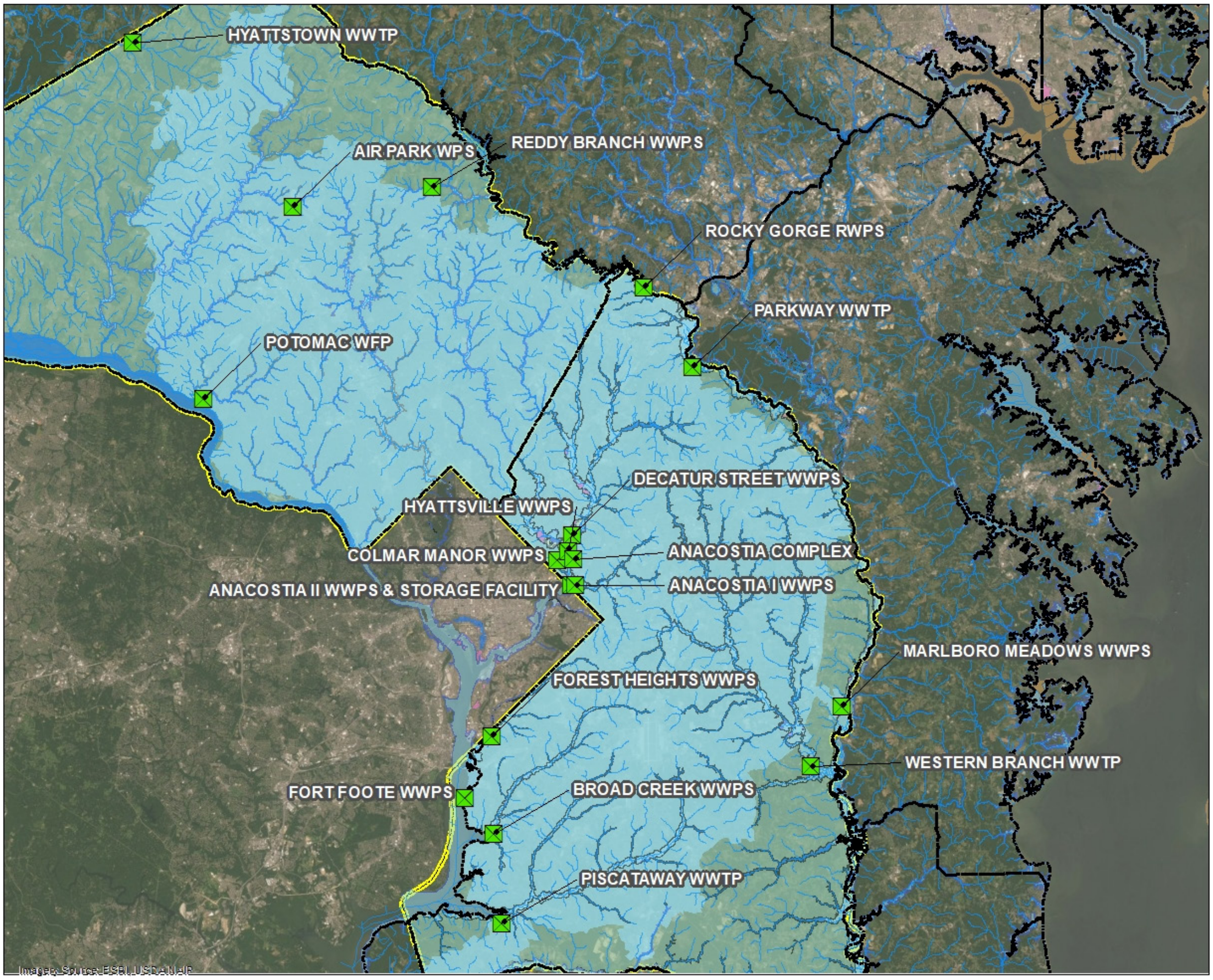

Figure 1-1. WSSC Service Area

Highlighted facilities have been included in the CCVAAMP vulnerability assessment.

1.2 Climate Hazards

Climate change threats include extreme rainfall, storms, temperatures, sea level rise and drought. The projected impacts of drought on WSSC's water supply safe yield were not included in the CCVAAMP because they were covered in separate regional studies by the Interstate Commission for the Potomac River Basin (ICPRB) (ICPRB, 2015 and 2017). Climate hazards addressed in the CCVAAMP study include flooding, loss of power, damage to electrical equipment, and operational difficulties.

Climate projections developed for CCVAAMP include rainfall, temperature, and sea level rise (SLR). While climate projections for temperature and a high-level assessment of facility electrical reliability have been completed, the facility assessment component of CCVAAMP focused primarily on the hazard of extreme riverine and coastal flooding. The various types of flooding because of extreme climate conditions are illustrated on Figure 1-2.

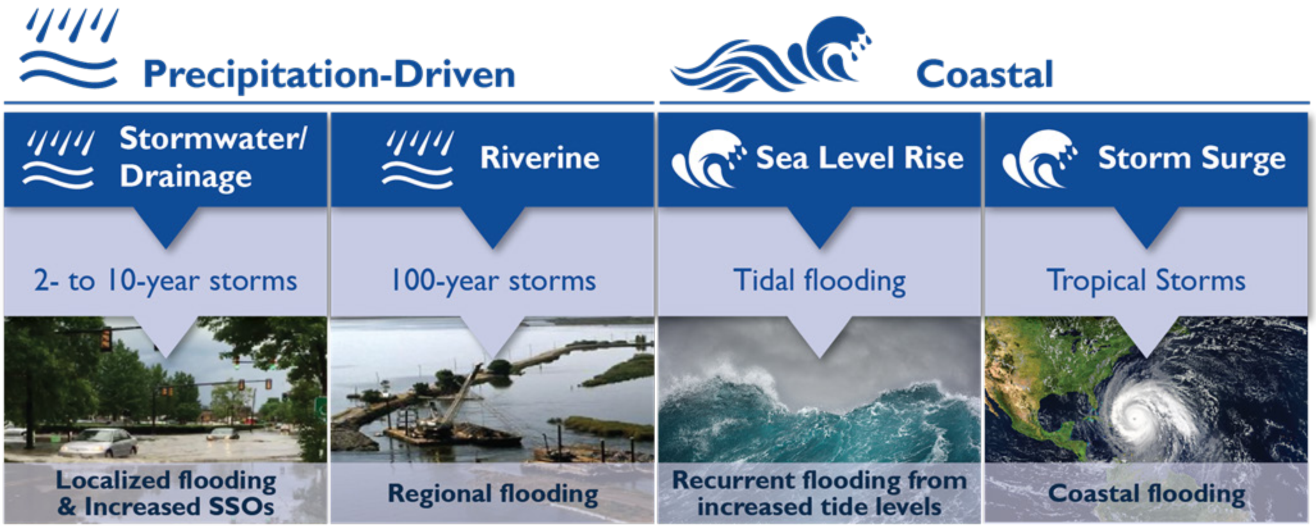

Figure 1-2. Causes of Flooding Due to Climate Change

The CCVAAMP focused on estimating future impacts of riverine (precipitation-driven) and sea level rise (coastal) on WSSC facilities.

1.3 Level of Service

WSSC uses a risk-based framework to guide flood protection efforts for water and wastewater treatment and pumping facilities. The framework incorporates the consequence of failure of an asset, as well as the probability of failure, to guide decision-making for climate adaptation and emergency response. Priorities for Level of Service (LOS) are established to ensure safety during the event, protection of equipment from damage, continuity of service, and timely recovery after waters have receded.

The safety and protection of site personnel is of foremost importance. Sites where access road flooding is projected may not be safely accessible to staff during and immediately before a weather event. Therefore, strategies at those locations may need to focus on permanent protections, as opposed to temporary protections that require installation by WSSC personnel before a weather event. Figure 1-3 illustrates WSSC's priorities for flood protection of water and wastewater treatment plant assets.

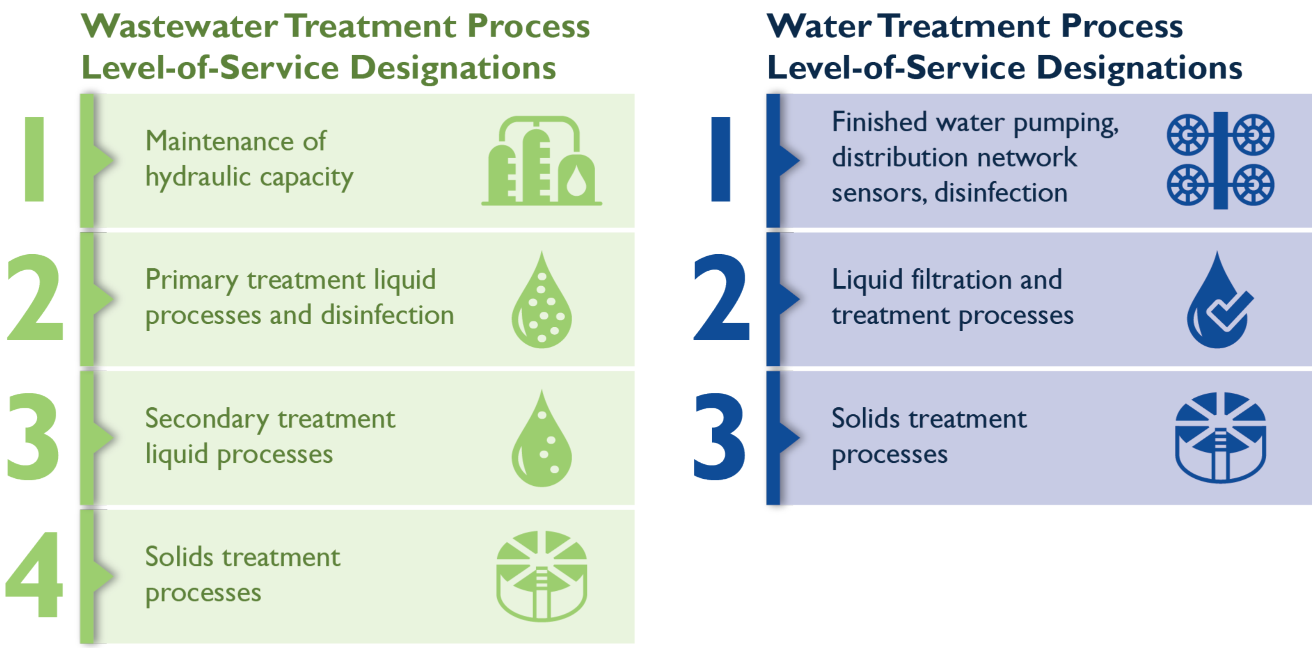

Figure 1-3. WSSC Asset Level of Service Designations for Wastewater and Water Treatment Processes

LOS designations are assigned to allow prioritization of specific process elements during extreme events.

2. Approach and Assumptions

The process of assessing and addressing climate change risk involved multiple steps illustrated on Figure 2-1. Key to a successful approach illustrated on Figure 2-1, is the development of an informed climate adaptation plan framework and regular monitoring and reassessment of the framework based on emerging climate research and data.

Figure 2-1. Six Steps in Vulnerability and Risk Assessment

Periodic re-assessment of the risk assessment based on emerging climate science is needed to ensure the results are based on best available information.

Early CCVAAMP workshops focused on development of a climate adaptation plan framework, including identification of key climate variables associated with hazards that impact WSSC assets and operations. Some examples include extreme precipitation that may exacerbate flood risk for facilities in riverine areas or coastal storm surge compounded by SLR that may increase flood risk for facilities in coastal areas.

The framework included development of climate projections for these key climate variables, which were then used to select climate change scenarios for subsequent modeling and analysis of vulnerability and risk of flooding. Risk assessment was focused on facility (vs. linear) assets. Climate projections were documented in the technical memorandum (TM), *Climate Projections and Scenarios for Washington Suburban Sanitary Commission Climate Vulnerability Assessment* (CH2M, 2018), included as Appendix A, Climate Projections and Scenarios. Climate scenarios were developed based on General Circulation Model (GCM) results from the Intergovernmental Panel on Climate Change Fifth Annual Assessment. Planning horizons of 2040, 2065, and 2100 were selected for modeling scenarios based on the different life cycles of mechanical assets (usually replaced after 20 to 25 years) and structural components (usually constructed to last 50+ years).

An initial risk screening of WSSC water and wastewater facilities, including treatment plants, pump stations, storage facilities, and various vaults, was completed in Phase 1/Fiscal Year (FY) 2016 (FY16) of CCVAAMP using available Federal Emergency Management Agency (FEMA) National Flood Hazard Layer (NFHL) data and WSSC Geographic Information System (GIS) facilities data. The results of this screening are documented in the *Preliminary GIS Overlay Analysis of WSSC Facilities in FEMA Floodplain* (CH2M, 2016a), included as Appendix B, Preliminary Screening of WSSC Facilities in FEMA Floodplain. The screening identified 49 facilities out of 200+ that were located either within the 100-year or 500-year floodplain boundary or within a horizontal 100-foot buffer of the current 100-year floodplain boundary. Through several workshops and interview, a second screening was conducted to refine the list to facilities with existing flooding issues and those more critical to WSSC operations. Based on this second screening, 18 facilities were prioritized for hydraulic modeling and vulnerability assessments. Results of the screening efforts are summarized on Figure 2-2.

Figure 2-2. Results of Preliminary Screening

Screening was completed using available GIS facility locations and effective NFHL floodplains from FEMA.

Preliminary screening efforts were completed for linear assets in the collection and distribution systems such as manholes and valve vaults. While preliminary, the outcome of the screening indicated many wastewater collection assets are in the 100-year floodplain. Water and sewer pipeline assets were not analyzed in detail for this study; however, general guidance on design flood elevation (DFE) and flood protection methods is discussed in Draft *Design Guide for Protecting Facilities from Future Climate Extremes* (CH2M, 2019). The guidance is intended to be used in conjunction with WSSC's *Pipeline Design Manual* (WSSC, 2017).

The initial list of priority facilities was classified according to their controlling flood mechanism. The WSSC service area I located on either side of the "Fall Line", a boundary between two physiogeologic provinces: the Piedmont and the Coastal Plain. The Piedmont and neighboring Ridge provinces are characterized by hilly topography while the Coastal Plain is flat. The geologic divide between the two is referred to as the "Fall Line" and roughly denotes the transition between areas tidally influenced (east of the Fall Line) and those that are not (west of the Fall Line), as illustrated in Figure 2-3. Areas located to the east of this geologic demarcation are typically areas of tidal influence, that is areas subject to coastal flooding typically due to storm surge, which is defined as rising water level as a result of atmospheric pressure changes and wind associated with coastal storms. Areas located to the west are typically characterized by riverine flood mechanisms. Pluvial flooding, or flooding resulting from localized rainfall, was not included in the facility assessment. The controlling flood mechanism determined selection of flood modeling tools, as described in Section 4.

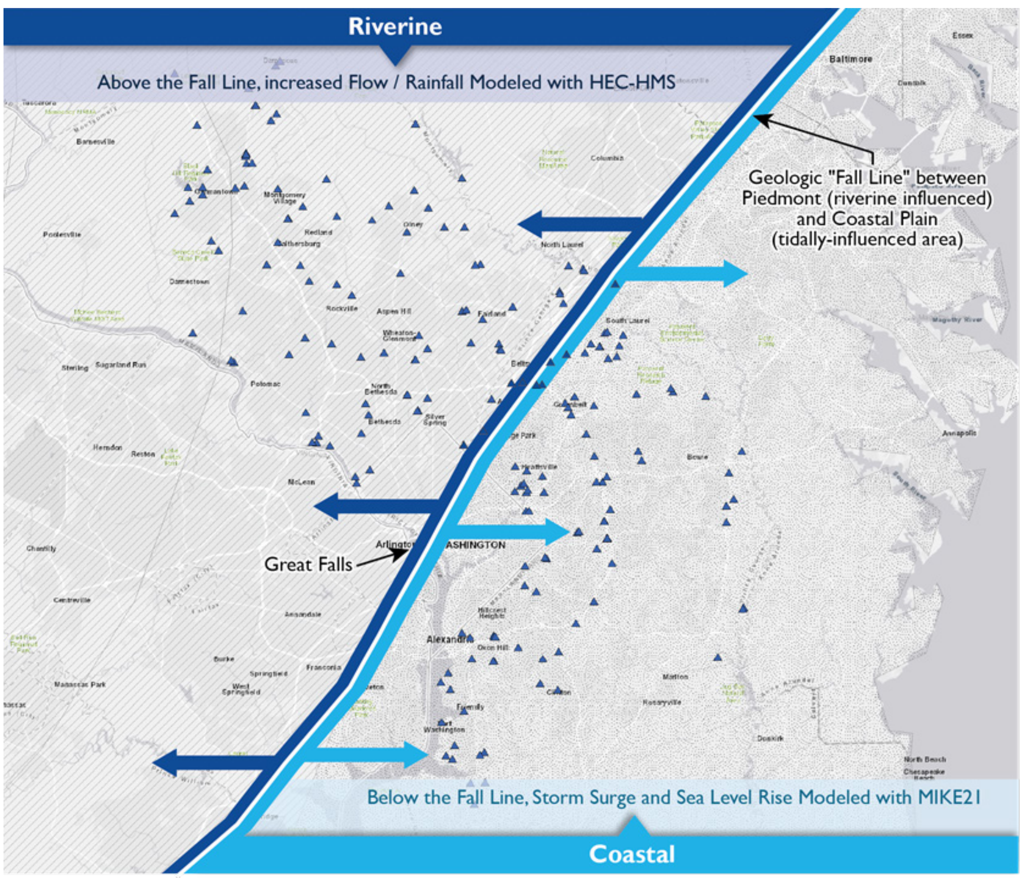

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Figure 2-3. Geologic Fall Line – Identification of Typically Controlling Mechanism of Flooding for CCVAAMP Facilities

The Fall Line is located along the boundary between the Piedmont and Coastal Plain physiogeographic provinces. Facilities "above" the Fall Line are primarily at risk due to riverine flooding. Those "below" the Fall Line, closer to the Chesapeake Bay and Atlantic Ocean, are primarily at risk due to coastal/tidal flooding.

Detailed flood modeling was completed surrounding a subset of the at-risk facilities based on priorities set by WSSC. Modeling is discussed in greater detail in Section 4 and modeling results TMs are included in Appendix C, Modeling Results. Results from hydraulic modeling were used to identify individual facility DFEs.

Several WSSC facilities were included in a vulnerability assessment pilot study in Phase 2/FY17. The pilot study approach was used to complete vulnerability assessments in subsequent years (Phase 3/FY18, Phase 4/FY19, and Phase 5/FY20). The vulnerability assessment process uses outputs from various previous steps (Figure 2-4) to identify at-risk assets. Once identified, adaptation strategies for the assets were identified and a cost analysis conducted.

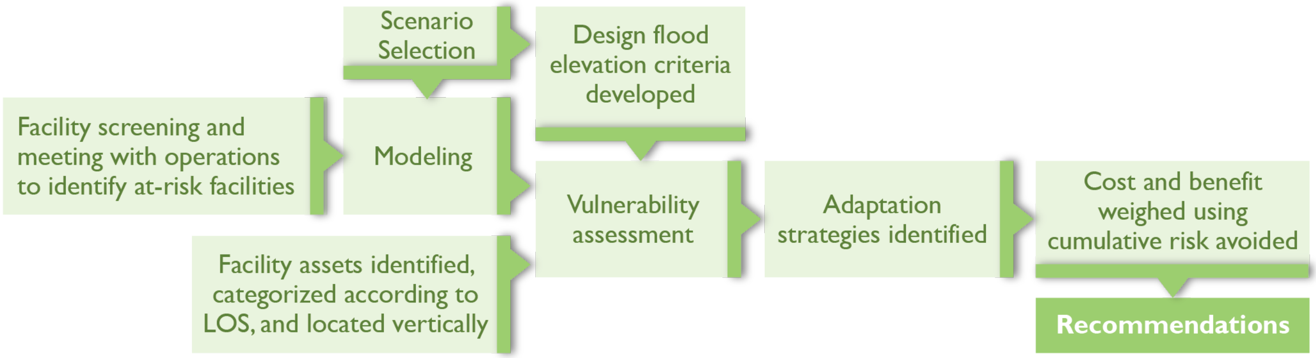


Figure 2-4. Facility Vulnerability Assessment and Adaptation Planning Approach

Scenario selection and design criteria development define the level of risk for the vulnerability assessment and cost analyses.

The vulnerability assessment collected asset-level inventory and replacement cost data from WSSC Asset Management Division and located the assets vertically using facility as-builts, survey, and facility site visits. Vulnerabilities were identified and adaptation strategies were developed for the assets at risk. The benefits of flood protection were compared to costs of adaptation strategies and avoided replacement costs to determine if flood protection measures were recommended. Benefits were calculated based on the monetized risk using asset replacement costs times the probability of asset damage due to flooding (see Section 5 for explanation of how monetized risk was calculated). Other enterprise risks such as customer impacts and reputational risk to WSSC should also be considered when determining the merit of flood control measures; however, such enterprise risks were not in the scope of the CCVAAMP study.

3. Climate Projections and Scenarios

There are at least four key climate variables that could affect planning for WSSC: SLR, storm surge, precipitation, and temperature. Facilities are potentially subject to flooding from SLR, surge, and increased precipitation intensity. Electrical and mechanical equipment can be impacted by extreme temperatures. Projections developed as part of CCVAAMP are used for modeling of flood impacts using selected climate change scenarios. The results of the following analyses were documented in *Climate Projections and Scenarios for Washington Suburban Sanitary Commission Climate Vulnerability Assessment* (CH2M, 2018), included as Appendix A, Climate Projections and Scenarios.

3.1 Precipitation Intensity, Duration, and Frequency Projections

Projected changes in precipitation intensity, duration, and frequency (IDF) were estimated for 12 National Weather Service stations in and around the WSSC service area for the planning horizons of 2040, 2065, and 2100. The projected IDF amounts for the 2-, 10-, 100-, and 500-year return periods are summarized in Figure 3-1. For the purposes of CCVAAMP hydrologic analysis, projections for the most appropriate individual gauge were used.

The projections were developed for medium and high GHG emission scenarios referred to as representative concentration pathways (RCP): RCP 6.0 was selected as the medium scenario and RCP 8.5 as the high scenario. For each RCP, the median value is used for all projections from 30 most recent GCMs. Projected percent changes in IDF amounts were applied to the historical baseline to estimate projected IDF amounts.

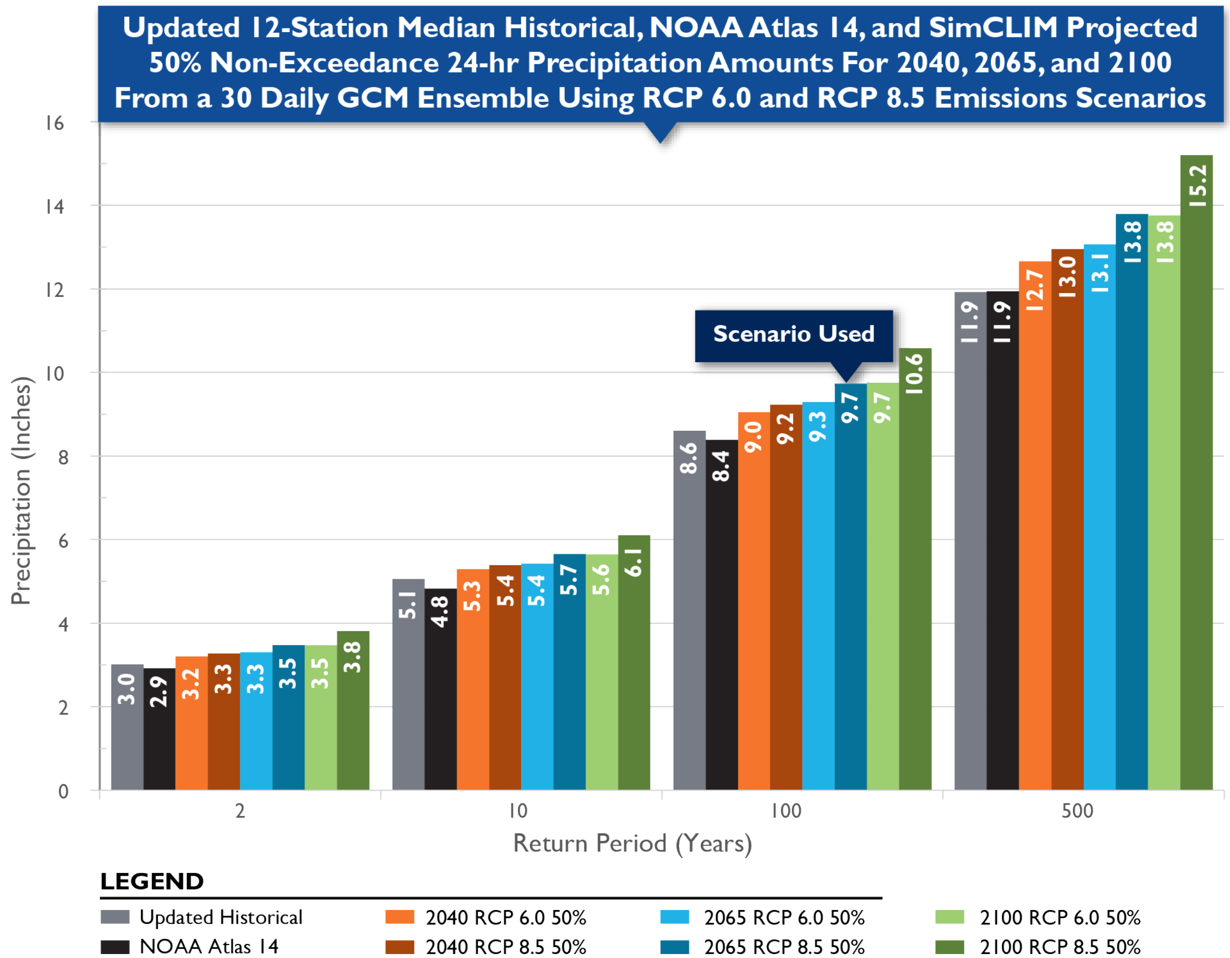


Figure 3-1. 12-Station Historical Median and Projected Changes in Precipitation IDF

For the purposes of CCVAAMP hydrologic analysis, projections for the most appropriate individual gauge were used for the 2065 RCP 8.5 50% scenario

Projected change (in percent) for the median IDF amounts for all 12 stations from the historical baseline were calculated for 2040, 2065, and 2100 using RCP 6.0 and RCP 8.5. As shown in Figure 3-2, for the 100-year return period, projected changes were 5 to 7 percent for 2040, 8 to 13 percent for 2065, and 13 to 23 percent for 2100. For the 500-year return period, projected changes were 6 to 9 percent for 2040, 10 to 16 percent for year 2065, and 15 to 27 percent for 2100.

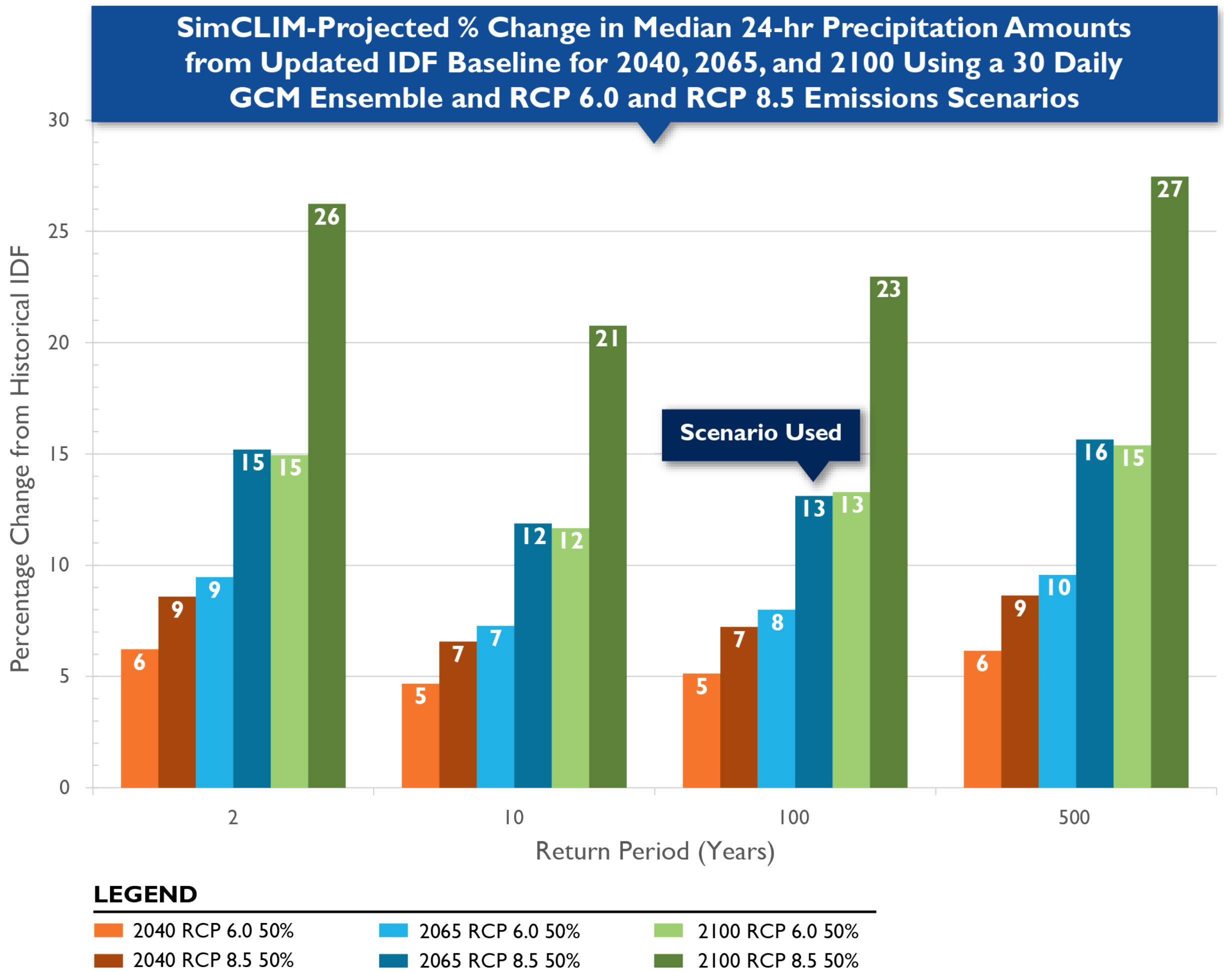


Figure 3-2. 12-Station Projected Percent Change in 24-Hours Precipitation IDF Amounts (SimCLIM, 2015)

For the purposes of CCVAAMP hydrologic analysis, projections for the most appropriate individual gauge were used for the 2065 RCP 8.5 50% scenario.

3.2 Maximum Temperature Projections

Historical and projected annual maximum temperature frequencies were determined at 5-degree intervals for Baltimore/Washington International Thurgood Marshall (BWI) Airport, which indicates a shift in the frequency of warmer annual temperatures for 2040, 2065 and 2100, for RCP 8.5.

The SimCLIM climate projection tool was used to analyze the projected annual number of days above a maximum daily temperature threshold of 104 degrees Fahrenheit (°F) for Baltimore, Maryland. The threshold temperature of 104°F was selected as consistent with the “Extreme (High) Annual Design Condition” for 20-year return period via *American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) Handbook 2009 (Baltimore).* Historical and projected annual maximum temperature frequencies at 5-degree intervals for BWI Airport are shown on Figure 3-3. The figure indicates a shift in the frequency of warmer annual temperatures for 2040, 2065 and 2100; however, not until after 2065 are there projected to be more than 5 days over 104 degrees per year.

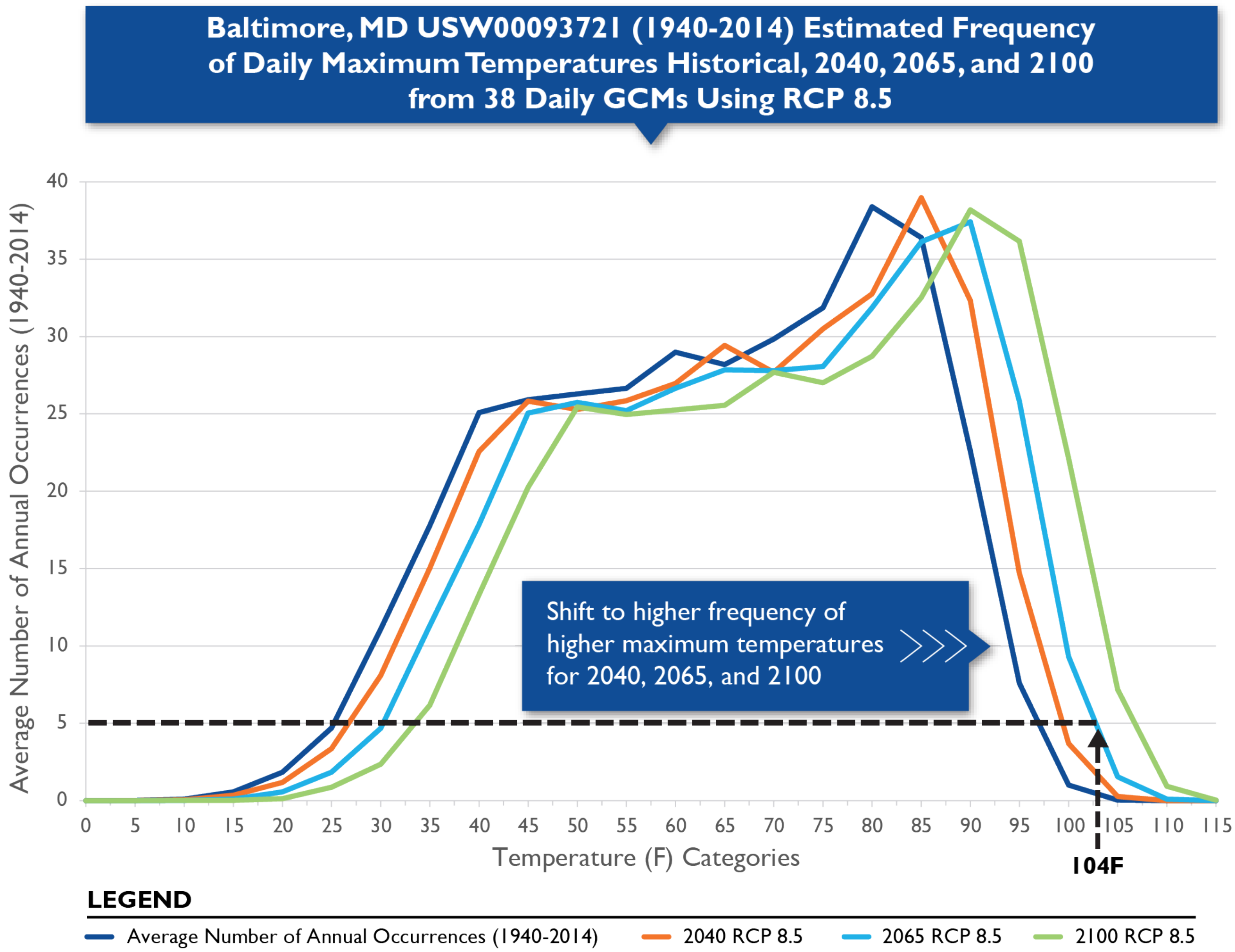


Figure 3-3. Historical and Projected Annual Maximum Temperature Frequencies for BWI Airport

3.3 Sea-level Rise Projections

Five National Oceanic Atmospheric Administration (NOAA) tide gauges were identified in the WSSC project area.

Projected changes in mean sea level (MSL) and average high tide, referred to as mean higher high water (MHHW), were developed at the tide gauges nearest to the WSSC project area for the years 2040, 2065, and 2100. The projections were based on 24 SLR GCMs using medium (RCP 6.0) and high (RCP 8.5) GHG emission scenarios. Nonexceedance probabilities of 50 percent (median), 67 percent, and 90 percent were also calculated to provide SLR upper end boundaries from the SLR GCMs as shown on Figure 3-4. Projections are inclusive of land subsidence but not accelerated ice sheet melting.

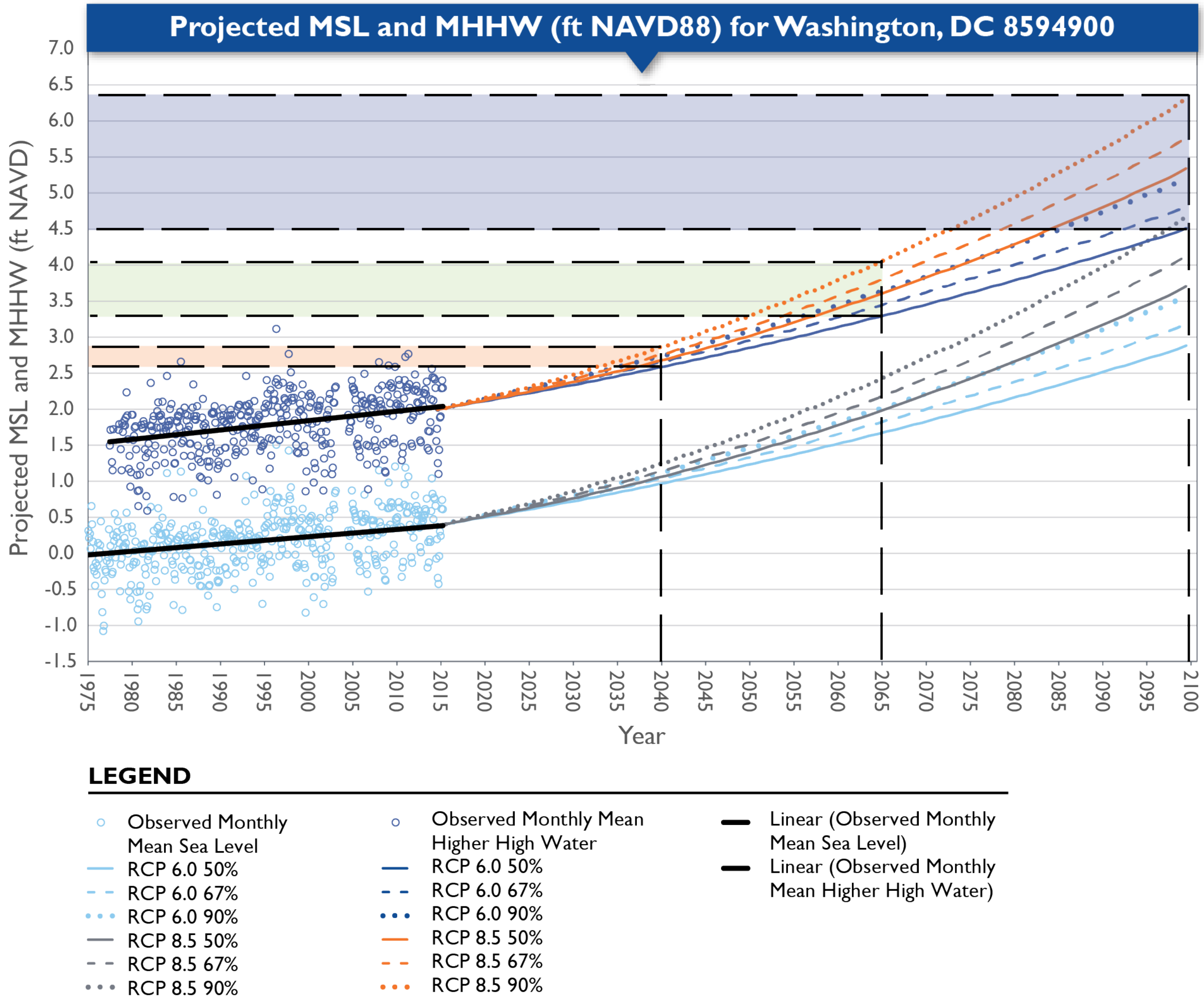


Figure 3-4. Relative Sea-Level Rise Projections for Washington, DC (Gauge #8594900)

For year 2040, projected change in MHHW ranges from 1.7 feet (median) to 2.9 feet (90 percent nonexceedance). For year 2065, change in MHHW ranges from 2.3 (median) to 4.0 feet (90 percent NE). For year 2100, projected change in MSL ranges from 3.6 feet (median) to 5.9 feet (90 percent NE).

3.4 Modeling Scenarios

Eight surge scenarios comprising combinations of SLR projections and available FEMA stillwater elevations were developed for coastal modeling (see Figure 3-5). Twelve riverine scenarios were developed using available precipitation projections (Figure 3-6). The range of climate change scenarios were identified to provide WSSC with planning information that would be applicable in different applications. While the vulnerability assessment work completed as part of CCVAAMP focused mainly on electrical and mechanical assets, which typically have a lifespan of 20 years, WSSC can use the results to understand future impacts on longer lived assets and/or long-term and short-term operational impacts. Based on the scenarios provided, workshops with WSSC were held to identify a single appropriate scenario for establishing facility DFEs. A mid-range planning horizon of 2065 was identified as the facility DFE scenario. The mid-range horizon provides a conservative planning horizon for electrical and mechanical assets. The facility DFEs based on the 2065 100-year event have been included in the

Draft Design Guide for Protecting Facilities from Future Climate Extremes provided in Appendix F. The 2065 100-year design criteria has been preliminarily accepted by the Asset Management Division (AMD) to purposes of conducting a business case analyses (BCA) on the Draft Design Guide recommendations.

Scenario used to define facility DFE (Scenario 8)

Scenario Description	Base		Scenarios											
	100	500	1	2	3	4	5	6	7	8	9	10	11	12
Emissions Scenario (RCP)														
RCP 6.0, 50% non-exceedance			●	●	●	●	●	●						
RCP 8.5, 50% non-exceedance									●	○	●	●	●	●
Planning Horizon														
2040			●			●			●			●		
2065				●			●			○			●	
2100					●			●			●			●
Return Period														
100	●		●	●	●				●	○	●			
500		●				●	●	●				●	●	●
Applied Precipitation (in.)														
12-Station Median[1]	8.6	11.9	9.0	9.3	9.7	12.7	13.1	13.8	9.2	9.7	10.6	13.0	13.8	15.2

1. The 12-station median is presented in this table. Results from the appropriate invidual gauge was used to develop facility-specific river discharge volumes.

Figure 3-5. CCVAAMP Coastal Modeling Scenarios

Scenario 7 (2065 100-year RCP 8.5 90% NE) results were utilized to define coastal facility DFE.

Scenario used to define facility DFE (Scenario 7)

Scenario Description	Base		Scenarios							
	100	500	1	2	3	4	5	6	7	8
Emissions Scenario (RCP)										
RCP 6.0, 50% non-exceedance			●			●				
RCP 8.5, 50% non-exceedance				●			●			
RCP 8.5, 90% non-exceedance					●			●	○	●
Planning Horizon										
2040			●	●	●					
2065									○	
2100						●	●	●		●
Return Period										
100	●		●	●	●	●	●	●	○	
500		●								●
Applied Sea level Rise (unit)										
Potomac River[1]	0.0	0.0	0.9	1.0	1.2	2.8	3.7	4.6	2.4	4.6
Patuxent River[2]	0.0	0.0	0.9	1.0	1.2	2.9	3.7	4.6	2.4	4.6

1. Sea level rise is estimated and applied at the Lewisetta tide gauge, located at the boundary of the Potomac River model.
2. Sea level rise is estimated and applied at the Solomon's Island tide gauge, located at the boundary of the Patuxent River model.

Figure 3-6. CCVAAMP Riverine Modeling Scenarios

Scenario 8 (2065 100-year RCP 8.5 50% NE) results were utilized to define riverine facility DFE.

4. Modeling Methods and Results

Modeling to support CCVAAMP vulnerability assessments was completed for 18 locations across the study area. Those areas classified as controlled by riverine flood mechanisms were modeled using 1-dimensional steady state analysis via United States Army Corps of Engineers HEC-RAS tools[1]. Effective models were obtained from the FEMA Engineering Library. Hydrologic analysis methods and results are documented in *River Hydrology Modeling WSSC CCVAAMP* (CH2M, 2016c). Riverine hydraulic modeling methods and results are documented in *River Floodplain Modeling and Mapping WSSC CCVAAMP* (CH2M, 2017). Both documents are included in Appendix C, Modeling Results.

Areas classified as under the influence of surge conditions were modeled using the MIKE 21 Flow Flexible Mesh module in the MIKE suite of hydraulic software from DHI.[2] Models were developed for the Patuxent and Potomac Rivers. The Patuxent River model was tied to the Solomon Island tide gauge (NOAA Station #8577330) and the Potomac River model to the Lewisetta tide gauge (NOAA Station #8635750) and calibrated using historic gauge data from Hurricane Sandy (Washington, DC NOAA Station #8594900). Coastal hydraulic modeling methods are results are documented in *Surge and Sea Level Rise Modeling WSSC CCVAAMP* (CH2M, 2016b). Revisions to analysis for Western Branch WWTP are documented in *Western Branch WWTP Flood Risk Modeling Refinements and Vulnerability Assessment Update* (CH2M, 2020). Both documents are included in Appendix C, Modeling Results.

The geographic extent of modeling produced for CCVAAMP is illustrated on Figure 4-1.

[1] https://www.hec.usace.army.mil/software/hec-ras/
[2] https://www.mikepoweredbydhi.com/products/mike-21

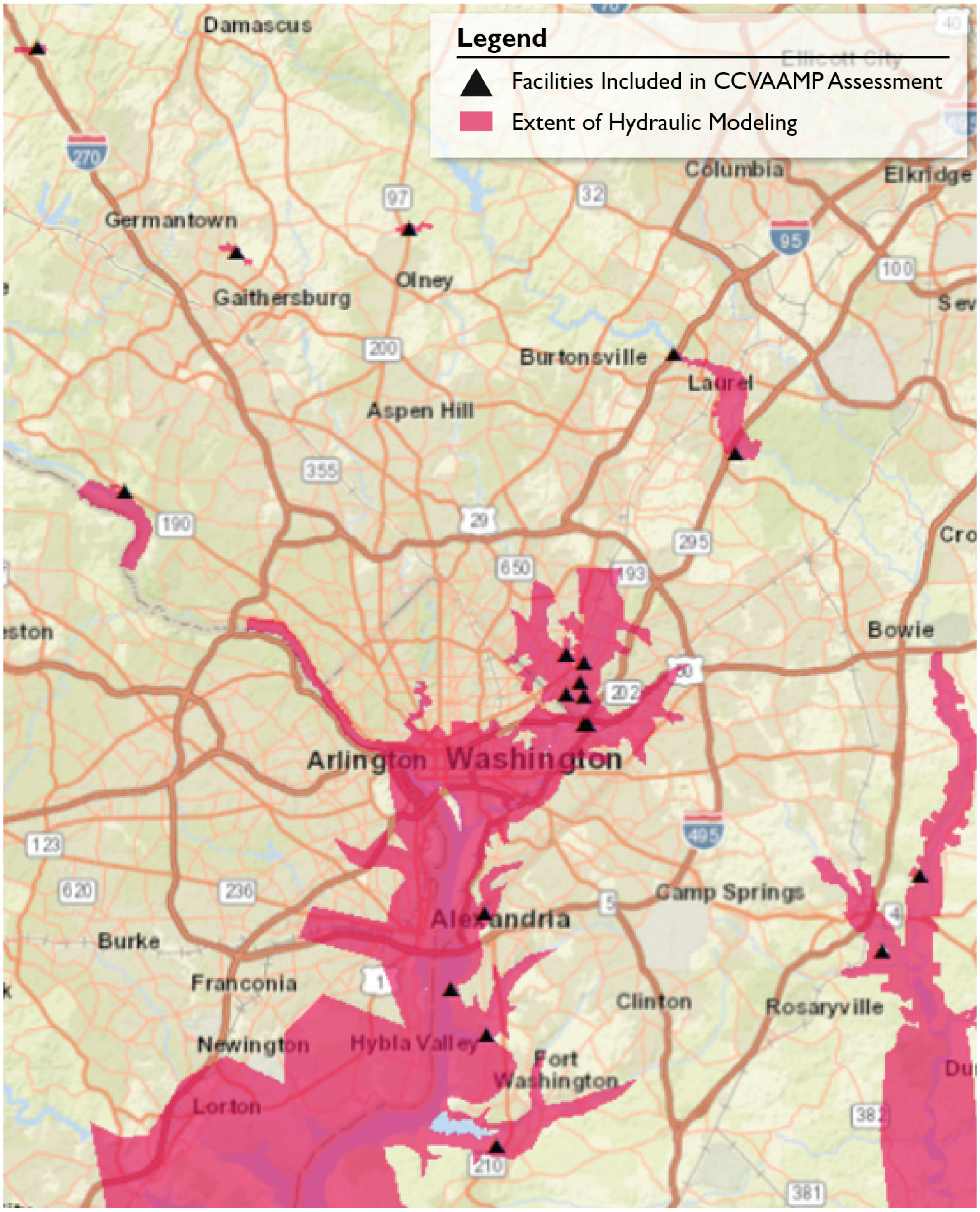
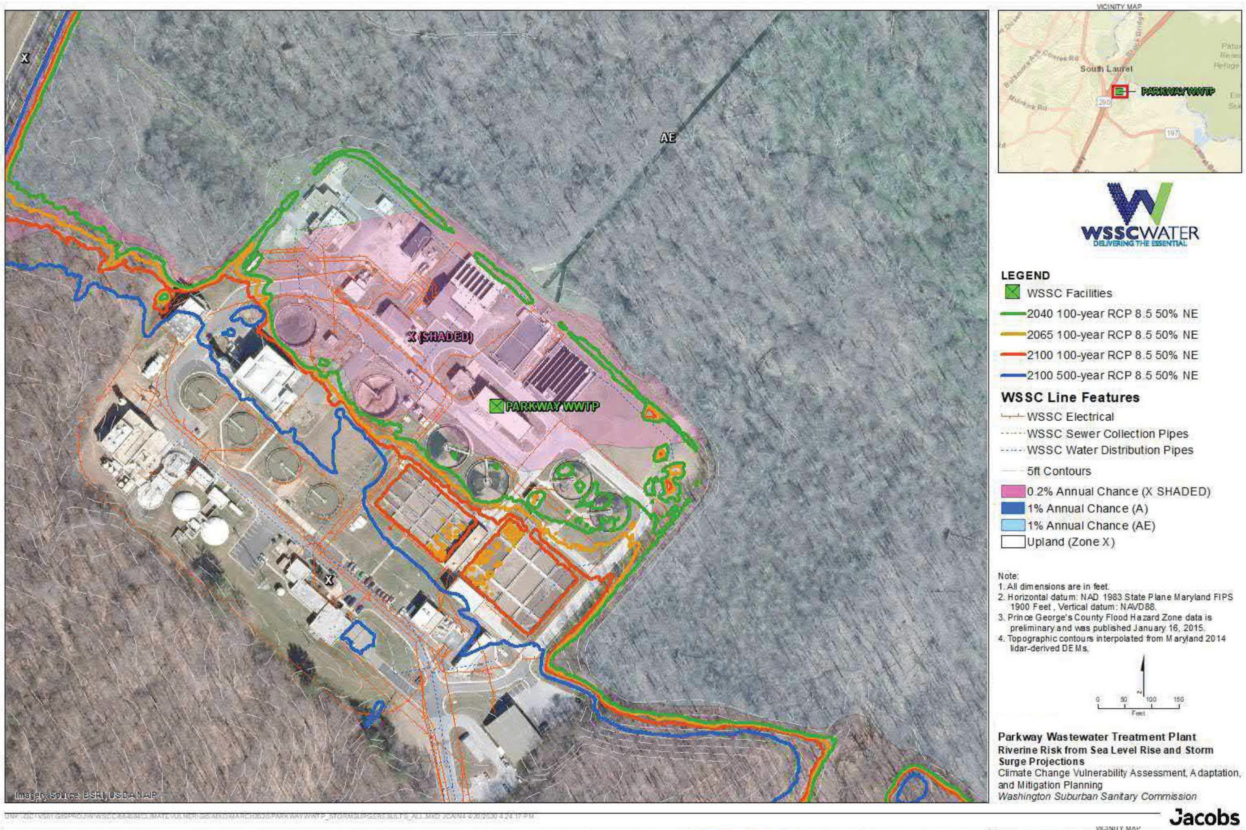


Figure 4-1. Geographic Extent of Hydraulic Modeling for CCVAAMP

Coastal modeling was developed for the Potomac and Patuxent Rivers. Riverine modeling was developed for various reaches corresponding to potentially at-risk facility locations.

Results of hydraulic modeling were used to identify a facility DFE. The DFE provides a reference elevation from which the facility vulnerabilities were determined. The vulnerability assessment process is documented in the following section. Floodplain mapping results for one riverine facility, Parkway WWTP, and one coastal facility, Broad Creek WWPS, are included on Figure 4-2. A complete tabulation of results for each facility is included in Appendix C, Modeling Results. Floodplain mapping of results are provided in Appendix D, Flood Mapping.



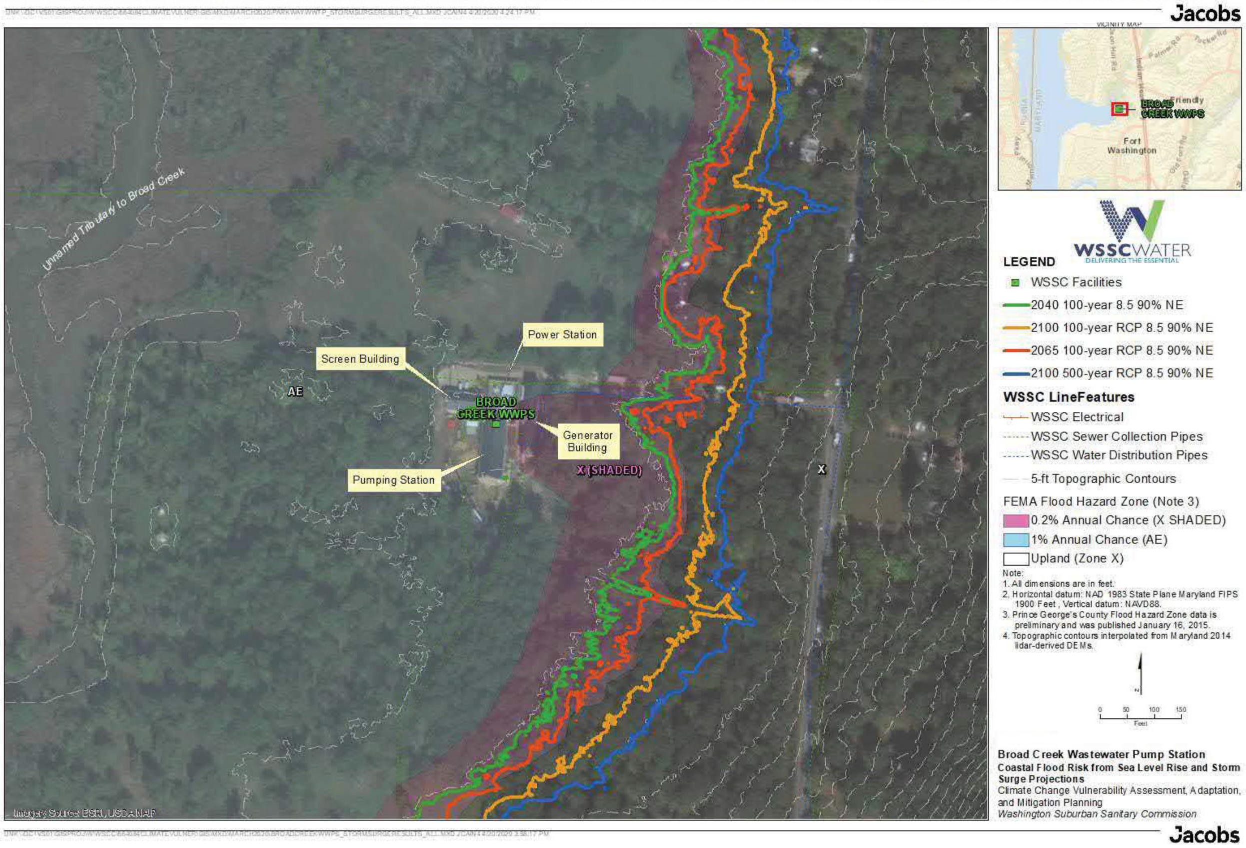


Figure 4-2. Results Floodplain for Parkway WWTP (upper) and Broad Creek WWPS (lower)

Results shown are for the 2065,100-year flood event (RCP 8.5), used for determination of the facility DFE.

The recommended DFEs for facilities included in CCVAAMP detailed modeling are determined by their modeling type (coastal or riverine) and are summarized in Table 4-1. These recommendations are based on the American Society of Civil Engineers Standard 24-14, *Flood Resistant Design and Construction* (ASCE, 2014). Riverine facilities are assumed to be in the Zone A classification of ASCE 24-14, which recommends 1-foot freeboard be added to the highest projected water surface elevation. Coastal facilities are assumed to be in Coastal High Hazard or Coastal A Zone for the purposes of ASCE 24-14, which recommends 2-feet freeboard be added.

Table 4-1 Design Flood Elevation Guide for Facilities Included in CCVAAMP Modeling

Modeling Designation	DFE
Riverine	Modeled 2065 100-year water surface elevation + 1-foot freeboard
Coastal	Modeled 2065 100-year water surface elevation + 2-foot freeboard

The DFE is intended to be applied to both existing and new equipment at these facilities. These estimates may be revised periodically as information on storm surge, SLR, and extreme precipitation projections is revised. DFEs for individual facilities are summarized in tabular form in Table 4-2.

Table 4-2 Design Flood Elevations for Selected WSSC Facilities

DFEs are based on computed water surface elevations plus freeboard

Facility	Flood Source[b]	County	Existing FEMA 100-yr Flood Elevation (NGVD29)	New WSSC DFE[a,c] (NGVD29)
Air Park WPS	Riverine	Montgomery	427.0	428.3
Anacostia 1 WWPS	Coastal	Prince George’s	16.9	19.0
Anacostia 2 WWPS and Storage Facility	Coastal	Prince George’s	15.1	17.2
Broad Creek WWPS	Coastal	Prince George’s	10.1	14.2
Colmar Manor WWPS	Coastal	Prince George’s	13.3	15.5
Decatur WWPS	Riverine	Prince George’s	17.1	19.8
Forest Heights WWPS	Riverine	Prince George’s	12.3	14.0
Fort Foote WWPS	Coastal	Prince George’s	10.5	14.4
Hyattstown WWTP	Riverine	Montgomery	362.8	364.3
Hyattsville WWPS	Coastal	Prince George’s	16.2	18.3
Marlboro Meadows WWPS	Riverine	Prince George’s	15.7	17.9
Parkway WWTP	Riverine	Prince George’s	113.1	116
Piscataway WWTP	Coastal	Prince George’s	9.3	13.5
Potomac WFP	Riverine	Montgomery	181.4	183.7
Anacostia Complex	Coastal	Prince George’s	15.5	17.6
Reddy Branch WWPS	Riverine	Montgomery	353.6	355.2

Facility	Flood Source[b]	County	Existing FEMA 100-yr Flood Elevation (NGVD29)	New WSSC DFE[a,c] (NGVD29)
Rocky Gorge RWPS	Riverine	Prince George’s	172.5	176.5
Western Branch WWTP	Coastal	Prince George’s	8.5	11

Notes:

[a] DFE is based on modeled 100-year return period flood elevation for a 2065 planning horizon, plus freeboard of 1 foot for riverine facilities and 2 feet for coastal facilities (per ASCE 24-14).

[b] These flood sources were determined as part of detailed CCVAAMP modeling. These classifications do not directly correspond to existing FEMA zone designations.

[c] Flood model results were converted from NAVD88 to NGVD29 using the FEMA Flood Insurance Study conversions by County. Montgomery County conversion: NGVD29 = NAVD88 + 0.704; Prince George’s County conversion: NGVD29 = NAVD88 + 0.78.

NGVD29 = National Geodetic Vertical Datum of 1929

NAVD88 = North American Vertical Datum of 1988

5. Vulnerability and Risk Assessment Methods and Results

Determination of facility climate change DFE provides the basis for the vulnerability and risk assessment process. Assets located at a facility are located vertically and determined to be at risk if located beneath the climate change DFE. The vulnerability and risk assessment process used for each facility followed six steps, shown on Figure 5-1.

5.1 Vulnerability Assessment

WSSC's Asset Management Group maintains a detailed asset database that includes replacement cost information. This database was used to identify the assets at the facilities selected for evaluation. An elevation was assigned to each asset through review of as-built drawings, survey, and facility site visits. Those assets determined to be at risk of flooding based on the facility DFE were assigned an asset LOS. Finally, building-level or asset-level adaptation strategies were developed and costed. In some cases, where multiple areas were shown to be impacted, a site-wide adaptation strategy was developed.

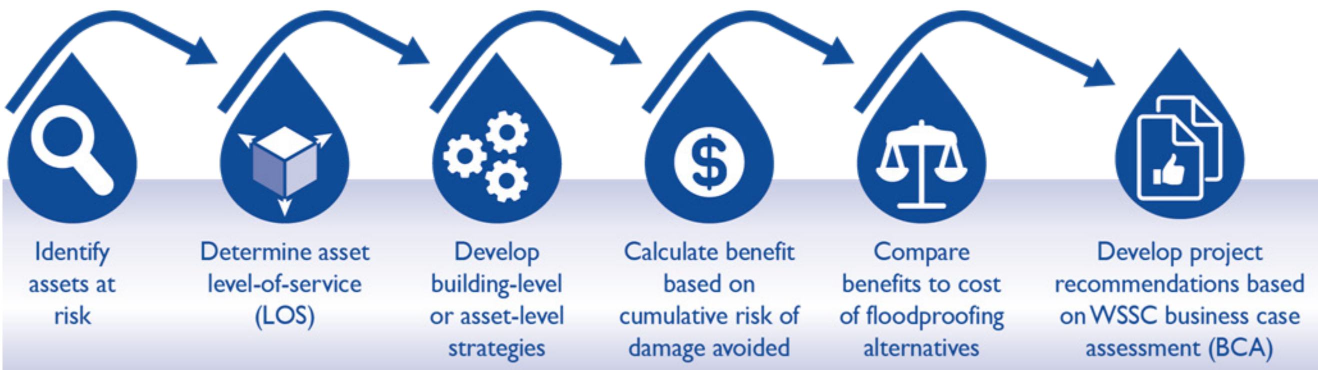


Figure 5-1. Risk Assessment/Alternative Development Process

Figure 5-2 gives an example of the assessment made for a RWPS. On the left side, flooding scenarios are developed for current and future projections to determine the elevation of flood water. The right side shows the assets at risk in the pump station by stating their elevations. The pink numbers determine the LOS priority.

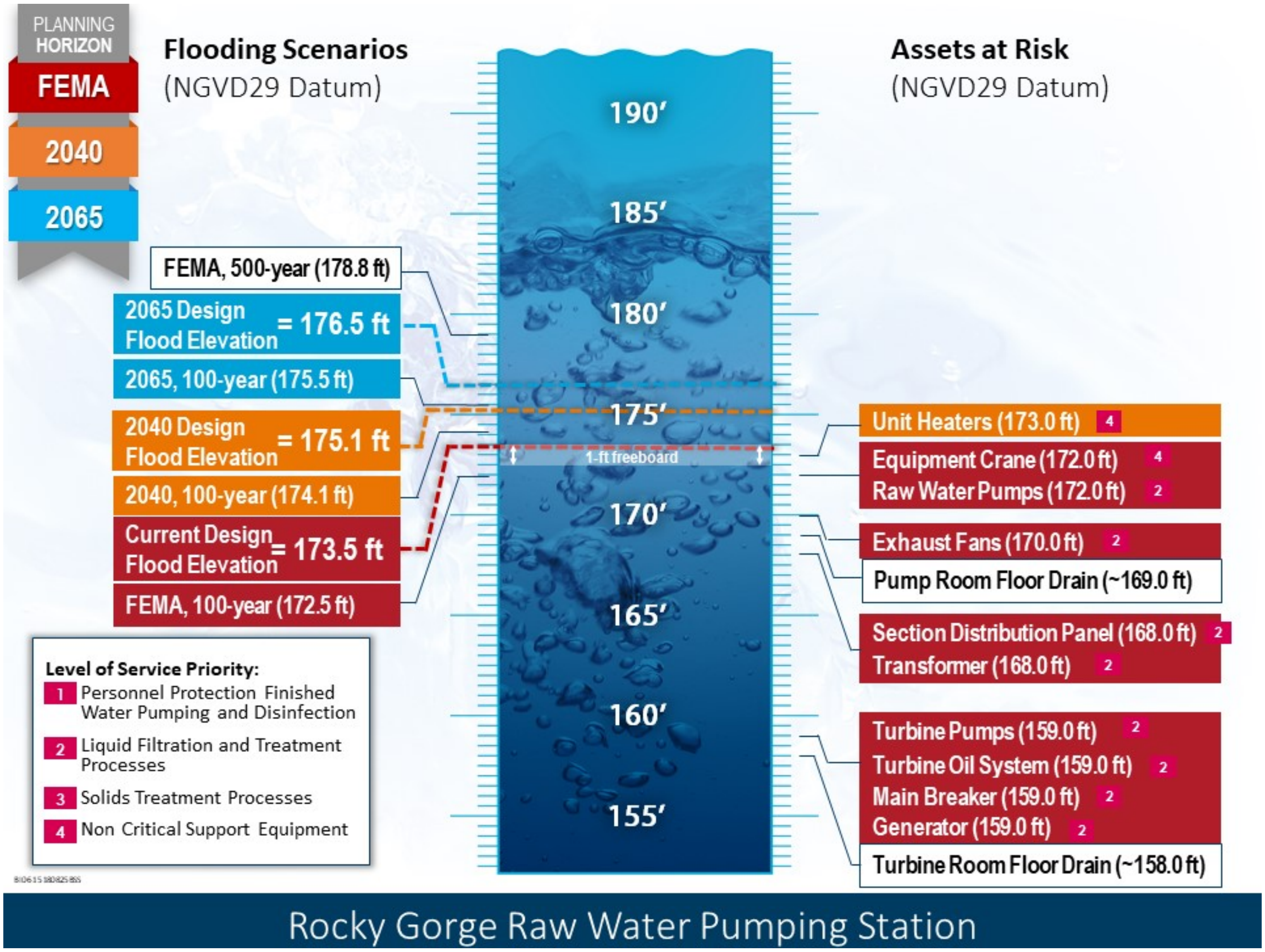


Figure 5-2. Example Risk Assessment for Rocky Gorge RWPS

Facility flood vectors, denoted by white labels on the right side of the water column, are currently located below the effective FEMA 100-year flood elevation.

Flooding can impact facility operations in addition to causing equipment damage. At WWTPs, high tailwater in the receiving stream can result in flow backups in the plant and reduce the plant's treatment capacity. Tanks can overflow from the inside or flood from the outside, resulting in sewage overflows, the need for reseeding of biological processes, or, in drinking water, contamination. Influent manholes can flood leading to introduction of floodwaters into the headworks, pumping stations and treatment process. Site flooding impacting access roads and pathways can prevent operators from accessing equipment.

Quantifying the operational impacts was beyond the scope of the CCVAAMP vulnerability assessment; however, potential operational vulnerabilities have been identified when possible. A comprehensive review of potential operational impacts was not conducted as part of this study.

5.2 Adaptation Analysis

The goal of the adaptation analysis was to develop flood protection strategies for each facility that address the vulnerabilities identified in the vulnerability assessment. The cost of each strategy was developed and compared with the calculated cumulative risk avoided.

5.2.1 Flood Protection Strategy Development and Cost Estimate

Adaptation strategies were developed according to the LOS of each asset. When practical, an asset-level permanent strategy (such as elevating or floodproofing the asset) was identified for all LOS 1 and 2 assets. When an asset-specific permanent strategy was not practical, a building-wide or area-wide strategy (such as sealing the building or constructing a static barrier) was proposed. For assets with LOS 3 through 5, building- and area-level strategies were developed. For selected facilities that appeared to have broad flood risk that impacted several buildings or areas, a sitewide strategy was also developed.

Flood mitigation strategies fall into two general categories: wet floodproofing and dry floodproofing. Wet floodproofing involves modifying a facility to allow floodwaters to enter the facility while limiting damage because of flooding. This can be achieved by protecting assets by elevating them or installing containment around them that enables them to be submerged without damage. Diagrams and example photos of wet floodproofing are provided on Figures 5-3, 5-4, and 5-5.

Dry floodproofing involves preventing floodwaters from entering a facility. Installation of floodproof doors, windows, and louver covers allows a building to be sealed. For some facilities, installation of a floodwall may be more cost effective. Temporary dry floodproofing measures include temporary door and window covers, building sandbagging, and temporary perimeter protections, such as a inflatable floodwall. Diagrams and example photos of dry floodproofing are provided in Figures 5-6 and 5-7.

For the purposes of the CCVAAMP adaptation strategy development, ease of installation was considered. Several of the facilities included in this analysis are not permanently staffed. Installation of some temporary measures, such as temporary door covers, was considered preferable to temporary perimeter protections because door barriers can be left in place.

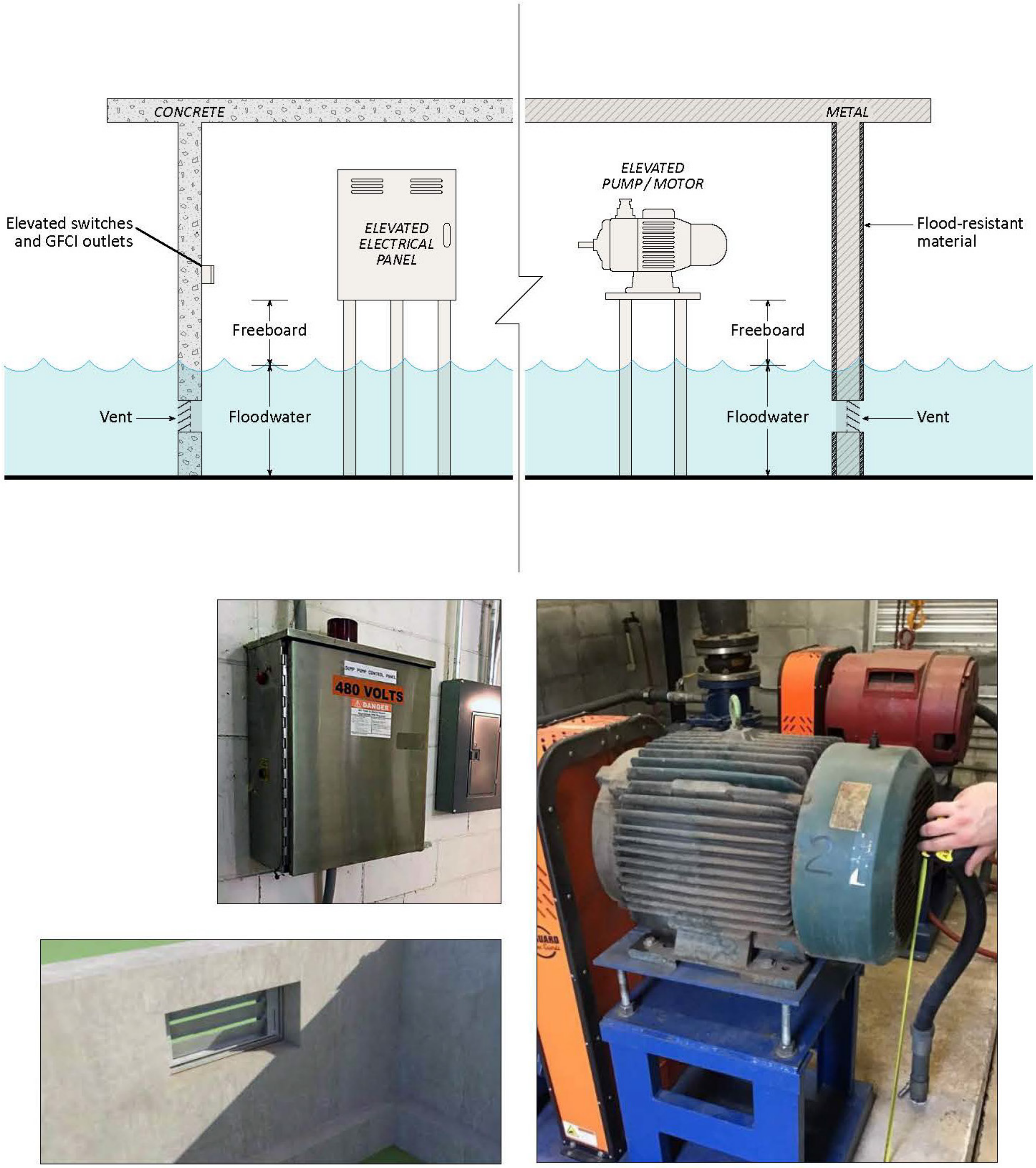


Figure 5-3. Wet Floodproofing – Elevation of Assets within a Facility

Photographs are (clockwise from top left): elevated electrical equipment, elevated motor, and flood vent allowing movement of water.

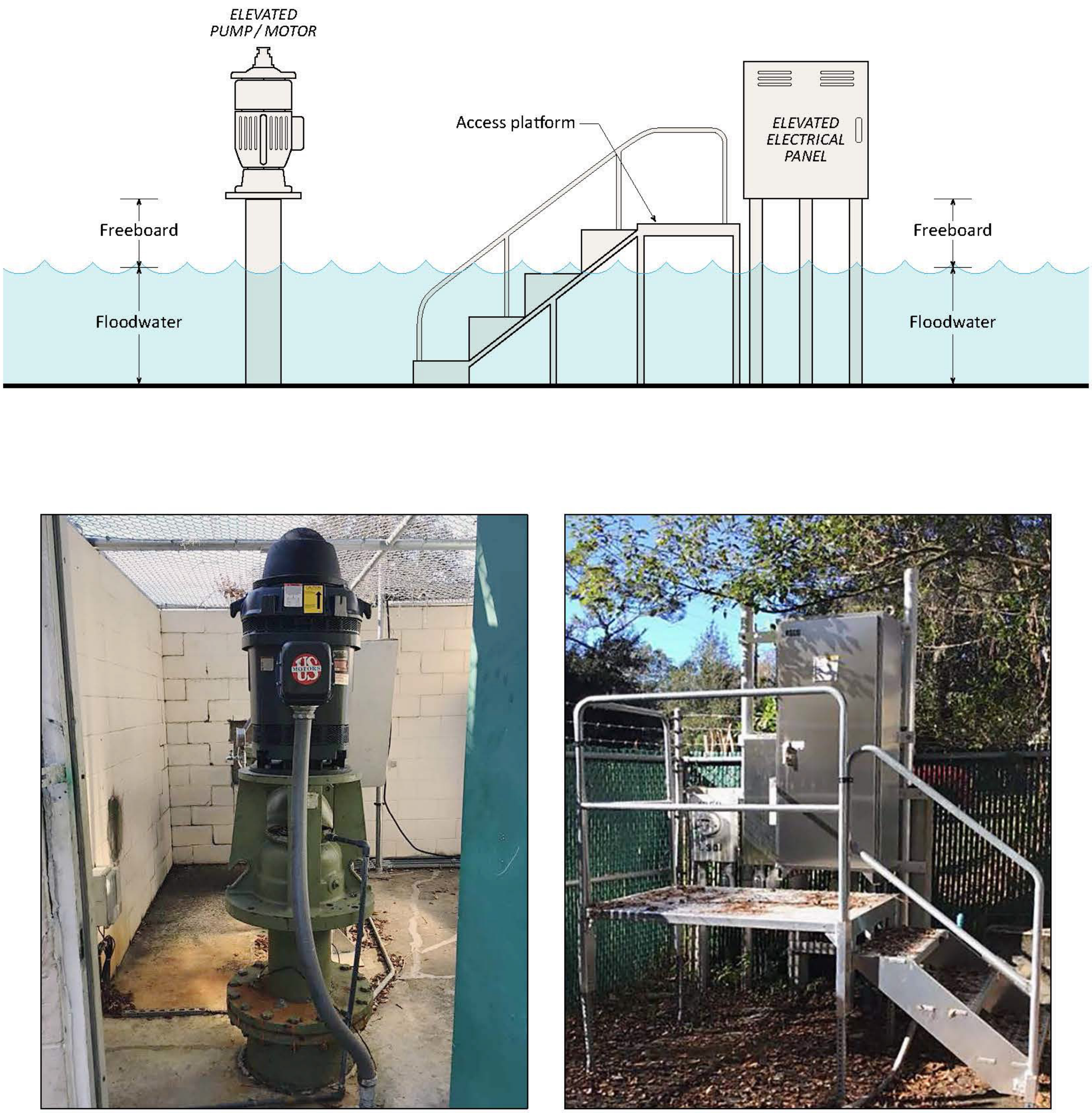


Figure 5-4. Wet Floodproofing – Elevation of Assets

Photographs are (from left to right): elevated pump motor, and elevated electrical panel.

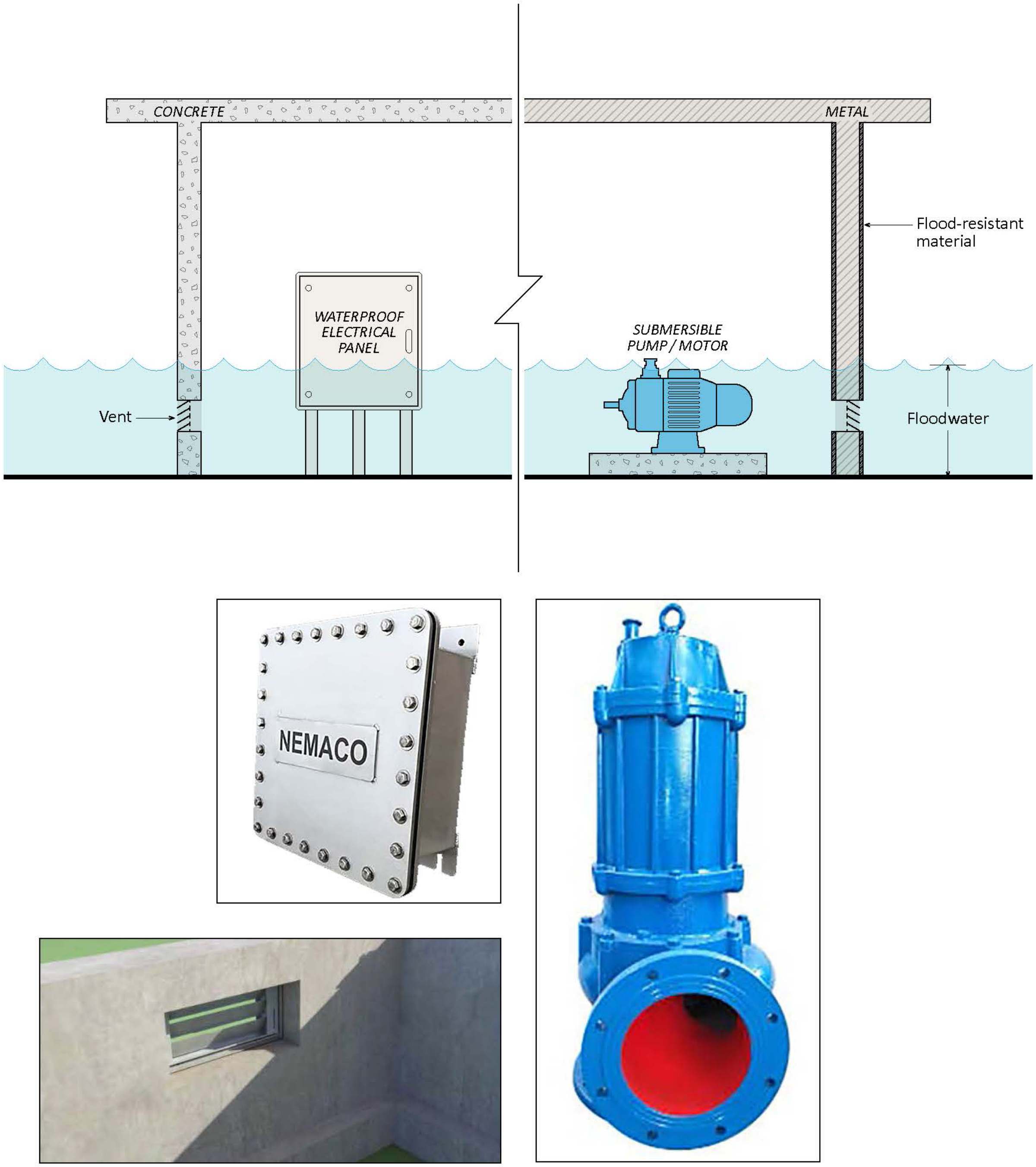


Figure 5-5. Wet Floodproofing – Use of Submersible Equipment and Cabinetry

Photographs are (clockwise from top left): floodproofed electrical box, floodproof pump, and flood vent allowing movement of water.

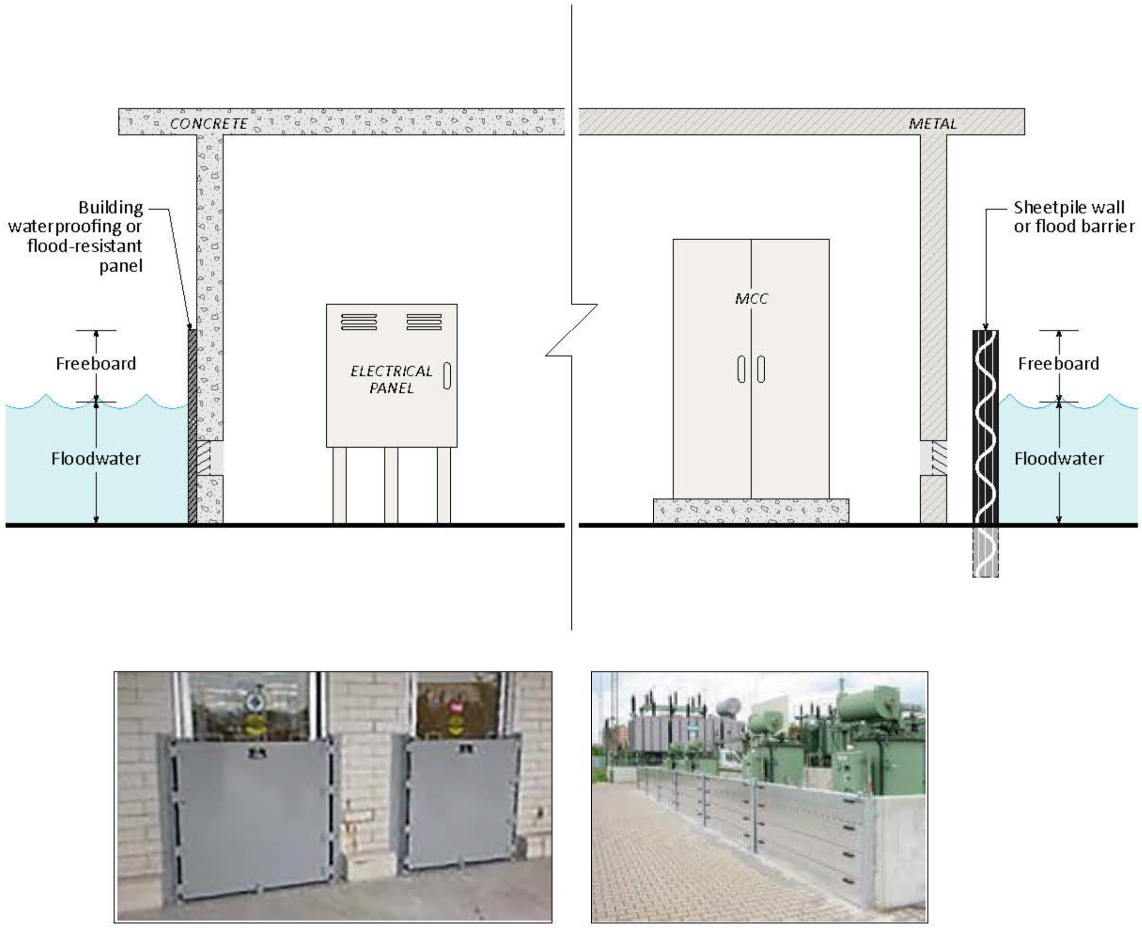


Figure 5-6. Dry Floodproofing – Installation of Static Barriers for Facility Protection

Photographs are: floodproofed door covers (left) and removeable flood barrier (right).

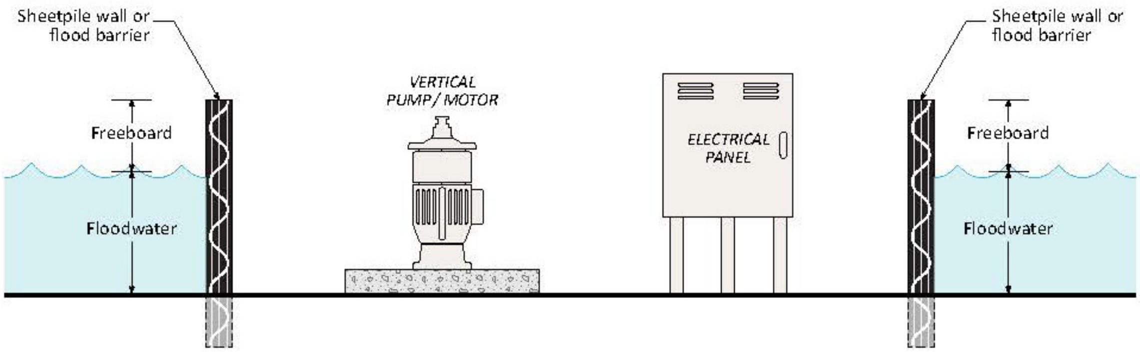


Figure 5-7. Dry Floodproofing – Installation of Static Barriers for Equipment Protection

Photographs are: floodproof cement masonry wall (left) and sheetpile floodwall (right).

The types of adaptation strategies considered as well as the resiliency level and the failure potential of each type of strategy are presented in Table 5-1. The resiliency level of a strategy is assessed based on the effectiveness of the strategy against a flood event, with strategies that involve limited or no human intervention assessed as more resilient than those that require deployment, for example. The failure potential of a strategy is the estimated probability of failure of the strategy if a flood occurs; these estimations reflect the strengths and weaknesses of each type of strategy, including whether a strategy is complicated to install or requires deployment before a flood event.

Table 5-1 Adaptation Strategies and Associated Failure Potential

Strategy	Resiliency Level	Failure Potential	Explanation of Failure Potential
No Action	No Protection	100%	No strategy
Sandbagging	Low	15%	Human element of installation, more complex installation
Temporary Barriers	Moderate	15%	Human element of installation

Strategy	Resiliency Level	Failure Potential	Explanation of Failure Potential
Seal Building/ Control Room	Moderate/Medium	10%	May leak in from conduits; difficult to detect
Construct Static Barrier	High	5%	Alternative flood pathways other than over the wall
Flood-proof Equipment	High	5%	May exceed rated pressure
Elevate Equipment	Very High	0%	If elevated to DFE only risk from larger storms and greater climate change

The cost of each alternative was estimated using a combination of historical data, vendor information, and professional cost estimates. Each estimate includes equipment costs, installation costs, design contingency, and general contractor overhead and profit markups, unless otherwise specified. Detail regarding markups is summarized in Table 5-2.

Table 5-2 Markups added to Adaptation Strategy Costs

Markups	%
General Conditions and Overhead	25
Contractor Profit, Bond and Insurance	24
Design Contingency	40

5.2.2 Cumulative Risk Avoided to 2040 (Expected Value of Benefits from Avoided Physical Asset Damage)

To estimate the cost-effectiveness of each adaptation strategy, the cumulative risk avoided from 2018 to 2040 was calculated for the implementation of each adaptation strategy. The cumulative risk avoided is essentially the direct benefit that WSSC gains by investing in a given adaptation strategy for a given facility. The benefits are measured in expected value terms (that is, the product of likelihood of flooding and the consequences of flooding). The consequences of flooding include the estimated costs of replacing the damaged assets.

Recommended adaptation strategies were identified by selecting those strategies where costs are less than the cumulative risk avoided for a particular group of assets.

In this analysis, the indirect damages to WSSC customers were not included, which WSSC accounts for separately as part the BCA that WSSC's AMD conducts for each proposed project as part of WSSC's Business Risk Exposure process, which is beyond the scope of this report.

The monetized annual risk avoided calculation is illustrated on Figure 5-8 and explained in the following text box and in Appendix E. After calculating the annual risk avoided for each year from 2018 until 2040, all annual risk avoided values were summed and discounted to present value. Detailed documentation of the methods and results of this calculation are presented in Appendix E.

Methodology for Calculating Benefits Using Cumulative Risk or Expected Value of Damages Avoided

In this report, the term "cumulative risk avoided" is used to refer to the expected value benefit concept, commonly used by economists and explained herein. The expected value benefit concept is illustrated by the following simplified example: Suppose a 100-year storm event would cause $2 million in damages. This means that there is a 1/100 chance of causing $2 million in damages or .01 x $2 million = $20,000 in expected value benefit in a given year. If only obtaining only 1 year of protection, then the expected value benefit is $20,000. However, when deciding about making an investment that would be protective for the next 30 years, damages have 30 chances to occur and not just one chance must be considered. Each year is an independent event and each year there is an expected benefit of $20,000. To arrive at the expected benefit over 30 years, take the sum (that is, 30 x 20,000 = $600,000). However, rather than take a straight sum, discount the future year's damages to express net present value (NPV) of investments in common year dollars. At 4-percent discount rate the expected value of the investment is $351,770. Thus, while the damages avoided equal $2 million, the expected value of the damages avoided is $351,770.

Using WSSC's asset elevation data, the benefit of providing flood protection at each facility was calculated as the cumulative risk avoided, which was determined based on each asset's replacement cost times the probability of flooding for each year and the probability that a given strategy will fail to floodproof the asset, which is known as the residual risk. This annualized risk is then summed for all years over the asset service life to determine the cumulative risk avoided, also known as the expected value benefit incurred by avoiding damages. Cumulative risk was determined by summing the annual risk avoided each year from 2018 to 2040. The planning horizon of 2040 was selected for the cumulative risk avoided analysis based on a 20-year service life of electrical and mechanical systems. The calculation accounts for climate change by assuming the probability of flooding changes over time based on flood modeling climate scenario results from previous tasks.

This calculation accounts for direct damages (cost of replacement) but not indirect damages to WSSC customers, such as business losses.

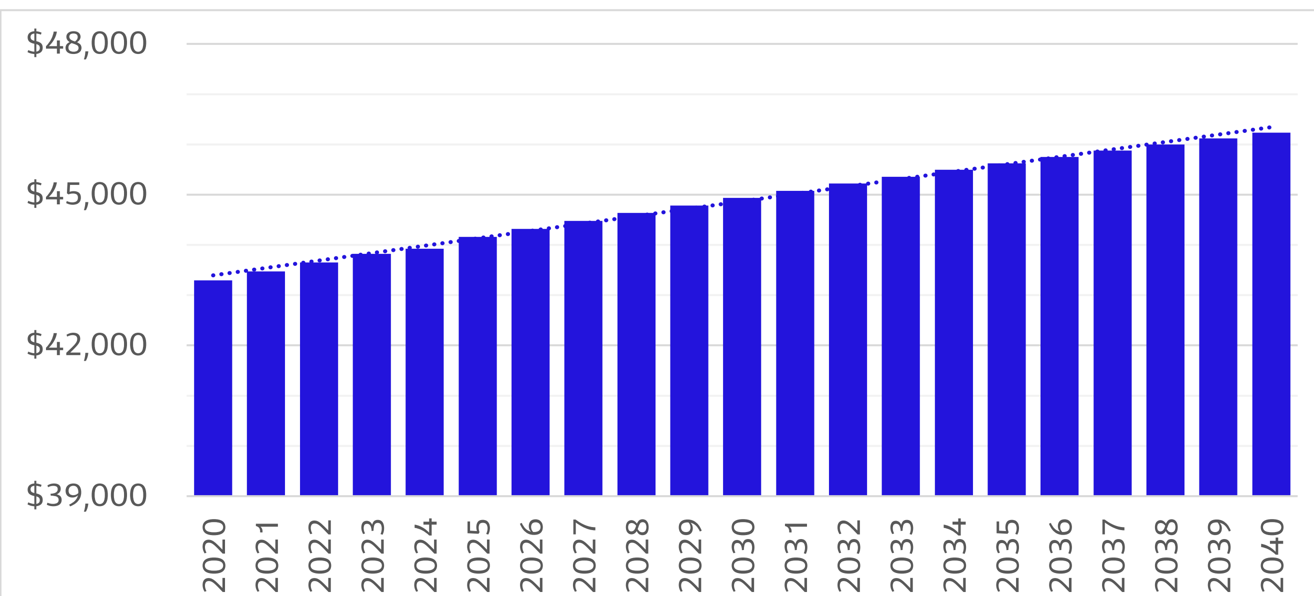


Figure 5-8. Illustration of Cumulative Risk Avoided as the Sum of Annual Risk

The sum of annual risk is the probability of flooding multiplied by the replacement cost of each asset over the expected life of the asset.

5.2.3 Strategy Selection

If the cumulative risk avoided was found to be greater than the cost of the alternative, the strategy was recommended for implementation. If the cumulative risk avoided was found to be less than the cost of the alternative, further analyses will be needed to determine if other indirect benefits other than equipment cost outweigh the cost of the alternative. For those strategies where the cumulative risk avoided was very close to the cost of the alternative, further BCA evaluations were recommended to understand whether operational benefits of the alternative may provide further incentive for the investment.

6. Results and Recommendations

6.1 Summary of Facilities at Risk

This section summarizes the facility adaptation recommendations developed during the CCVAAMP study. These recommendations are based on the extensive climate analyses, vulnerability assessments, and adaptation planning completed for the facilities.

In addition to adaptation recommendations at individual facilities, the results of the CCVAAMP study have been used to generate design guidance to enable WSSC to incorporate consideration of climate change into the capital design process. Design recommendations for climate change conditions are documented in Draft *Design Guide for Protecting Facilities from Future Climate Extremes* (CH2M, 2019). The design guide includes recommendations for flood protection, outfall tailwater design elevations, electrical reliability, stormwater design, GHG reporting for new projects, and other climate-related design considerations.

Based on initial screening conducted in Phase 1, 18 facilities were prioritized for hydraulic modeling and vulnerability assessment (Table 6-1). Based on detailed facility assessment, eight of these facilities were found to be at risk to flooding due to current and/or future (2065 100-year RCP 8.5) estimated conditions.

Table 6-1 Facilities Included in CCVAAMP Modeling and Vulnerability Assessment

Facility Type	Facilities
Wastewater Treatment Plants (WWTPs) - 4	▪ Hyattstown WWPS* ▪ Parkway WWTP* ▪ Piscataway WWTP ▪ Western Branch WWTP*
Water Filtration Plans (WFP) - 1	▪ Potomac WFP
Wastewater Pump Stations (WWPS) – 10	▪ Anacostia I WWPS ▪ Anacostia II WWPS and Storage ▪ Broad Creek WWPS* ▪ Colmar Manor WWPS ▪ Decatur Street WWPS ▪ Forest Heights WWPS ▪ Fort Foote WWPS* ▪ Hyattsville WWPS ▪ Marlboro Meadows WWPS ▪ Reddy Branch WWPS*
Water Pump Stations (WPS) – 2	▪ Air Park WPS ▪ Rocky Gorge RWPS*
Other – 1	▪ Anacostia Complex (Warehouse)*

Notes:

* Facilities found to be at risk to flooding because of current and/or future (2065 100-year RCP 8.5) estimated conditions.

Adaptation alternatives were identified at an asset level (for LOS 1 and 2 assets), on a building and area level, and sitewide, where practical. Recommended adaptation strategies were identified based on the cumulative risk avoided, that is, the benefit provided by protecting a particular group of assets. The results of the adaptation alternatives analysis are summarized at the facility level in Table 6-2 for LOS 1 and 2 assets and in Table 6-3 for all assets, with specific summary of recommended alternatives and cost/benefit analysis provided in the following subsections.

Table 6-2 Summary of Recommended Strategy Costs and Cumulative Risk Avoided for each Facility for LOS 1 and 2 Assets at Risk

Facility	LOS 1 and 2 Assets at Risk[a]			
	Quantity	Cost of Replacement	Strategy Costs[b]	Cumulative Risk Avoided
Air Park WPS	Facility found to not be at risk of flooding due to 2065 100-year event.			
Anacostia Complex	Facility access road and parking were shown to be at risk during a 2040 100-year event. Two manholes were shown to be at risk of flooding during a 2065 100-year event. Buildings found to not be at risk of flooding due to 2065 100-year event.			
Anacostia I WWPS	Facility access road and substation access stairway shown to be at risk during a current 500-year event. Buildings found to not be at risk of flooding due to 2065 100-year event.			
Anacostia II WWPS and Storage Facility	Facility not found to include LOS 1 and 2 assets. See Table 6-3.			
Broad Creek WWPS	Costs not developed for LOS 1 and 2 assets only. See Table 6-3.			
Colmar Manor WWPS	Facility found to not be at risk of flooding due to 2065 100-year event.			
Decatur Street WWPS	Assets found to not be at risk of flooding due to 2065 100-year event.			
Forest Heights WWPS	Facility found to not be at risk of flooding due to 2065 100-year event.			
Fort Foote WWPS	17	$1,480,000	$19,000	$250,700
Hyattstown WWTP	2	$20,000	N/A[c]	$1,000
Hyattsville WWPS	Facility found to not be at risk of flooding due to 2065 100-year event.			
Marlboro Meadows WWPS	Facility found to not be at risk of flooding due to 2065 100-year event.			
Potomac WFP	Facility found to not be at risk of flooding due to 2065 100-year event.			
Parkway WWTP	30	$8,500,000	$927,000	$3,480,000
Piscataway WWTP	Facility found to not be at risk of flooding due to 2065 100-year event.			
Reddy Branch WWPS	4	$510,000	$40,000	$50,000
Rocky Gorge RWPS	Facility not found to include LOS 1 and 2 assets. See Table 6-3.			
Western Branch WWTP	18	$2,210,000	$118,000	$150,000
TOTAL	71	$12,720,000	$1,104,000	$3,931,700

Notes:

LOS 1 and 2 assets for wastewater facilities include assets that maintain the safety and protection of site personnel, maintain plant hydraulic capacity, and perform primary treatment for liquid processes. LOS 1 and 2 assets for water facilities include assets that are required for finished water pumping, disinfection, and raw water filtration processes.

Cost estimates are considered Conceptual/Planning Estimates (+ 100 percent / - 50 percent) per American Society of Cost Estimating Engineers.

Strategy is relocation of small, loose equipment to slightly higher elevation, cost not developed.

N/A = not applicable

Table 6-3 Summary of Recommended Strategy Costs and Cumulative Risk Avoided for each Facility for All Assets at Risk

Facility	All Assets at Risk			
	Quantity	Cost of Replacement	Strategy Costs[a]	Cumulative Risk Avoided
Air Park WPS	Facility found to not be at risk of flooding due to 2065 100-year event.			
Anacostia Complex	37+[b]	$470,000	$26,000	$80,000
Anacostia I WWPS	Facility found to not be at risk of flooding due to 2065 100-year event.			
Anacostia II WWPS and Storage Facility	Facility found to not be at risk of flooding due to 2065 100-year event.			
Broad Creek WWPS	31	$42,820,000	$600,000	$2,850,000
Colmar Manor WWPS	Facility found to not be at risk of flooding due to 2065 100-year event.			
Decatur Street WWPS	Facility found to not be at risk of flooding due to 2065 100-year event.			
Forest Heights WWPS	Facility found to not be at risk of flooding due to 2065 100-year event.			
Fort Foote WWPS	17	$1,480,000	$19,000	$250,700
Hyattstown WWTP	2	$20,000	N/A	$1,000
Hyattsville WWPS	Facility found to not be at risk of flooding due to 2065 100-year event.			
Marlboro Meadows WWPS	Facility found to not be at risk of flooding due to 2065 100-year event.			
Potomac WFP	Facility found to not be at risk of flooding due to 2065 100-year event.			
Parkway WWTP	157	$25,100,000	$1,477,000	$7,870,000
Piscataway WWTP	Facility found to not be at risk of flooding due to 2065 100-year event.			
Reddy Branch WWPS	9	$700,000	$40,000	$90,000
Rocky Gorge RWPS	460	$38,820,000	$111,000	$14,680,000
Western Branch WWTP	88	$4,380,000	$288,000	$1,500,000
TOTAL	801	$113,790,000	$2,561,000	$27,321,700

Note:

[a] Cost estimates are considered Conceptual/Planning Estimates (+ 100 percent / - 50 percent) per American Society of Cost Estimating Engineers.

[b.] The number of assets are estimated based on equipment list provided by facility management

6.2 Potential Sequence of Resilience Projects

The CCVAAMP facility vulnerability assessment was based on asset replacement cost information provided by WSSC's AMD. WSSC's internal process for identifying and approving capital projects is carried out by the AMD. The BCAs carried out by AMD include operational consequences and considerations beyond the scope of the CCVAAMP investigation. Therefore, the output of this study is intended to be integrated into the existing process in order to fully understand both asset-level and operational impacts of various flood risk conditions.

Two methods were used to evaluate the potential priority of resilience projects for the eight facilities listed in Table 6-2, where some facilities were found to be at risk of flooding:

- Cumulative risk to all assets, sorted in declining order of expected value of benefits from avoided damage to WSSC's physical assets
- Return on investment (ROI), sorted in declining order of net return (benefits minus costs) per $ of strategy cost

As explained herein, the top four facilities in declining order based on risk ranking are Rocky Gorge RWPS, Parkway WWTP, Broad Creek WWPS, and Western Branch WWTP, with the remaining four facilities having essentially the same much smaller level of risk. However, based on ROI the highest ranked facilities are Rocky Gorge RWPS and Fort Foote WWPS, with little difference between the remaining six facilities.

Figure 6-1 shows the eight facilities in rank order based on cumulative risk avoided, compared to the strategy cost at each facility.

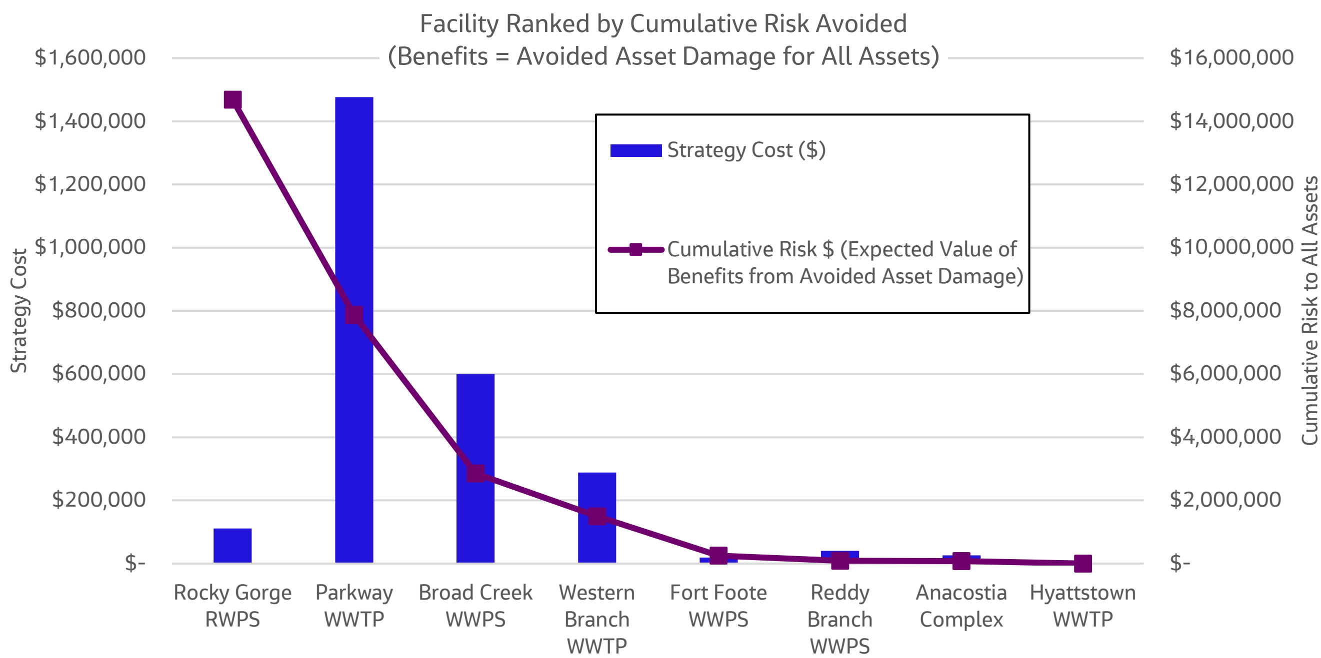


Figure 6-1. Facility Cumulative Risk Avoided and Strategy Costs Sorted in Order of Declining Risk

Figure 6-2 shows the eight facilities in rank order based on declining ROI, compared to the strategy cost at each facility. To determine ROI, the NPV of benefits was calculated as the present value of benefits (that is, cumulative risk avoided) minus strategy costs. The ROI was then calculated as the $ Net Return/$ Cost = NPV/$ Cost, based on the net dollars for each dollar that is invested.

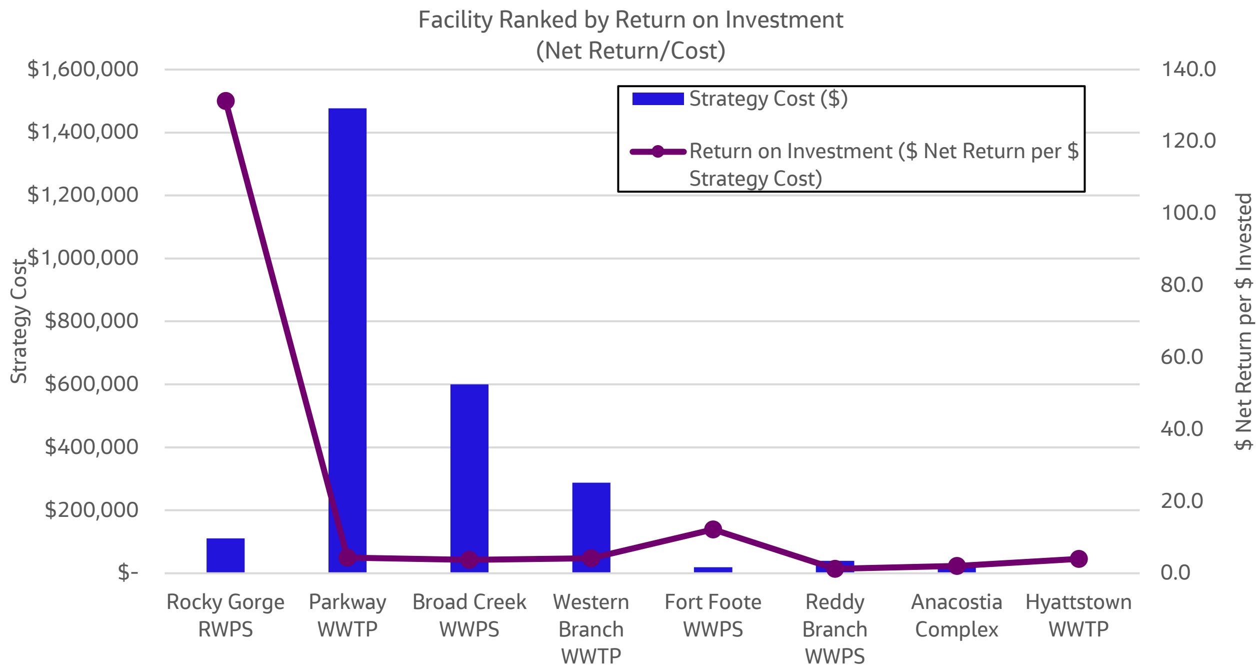


Figure 6-2. Facility Return on Investment and Strategy Costs Sorted in Order of Declining Return on Investment.

Table 6-2 provides the summary strategy cost, cumulative risk and ROI data for all eight facilities, as shown on Figures 6-1 and 6-2.

Initial investment in protections at Rocky Gorge RWPS and Forte Foote WWPS yields high ROI, with Rocky Gorge being an order-of-magnitude higher than Forte Foote. All strategies presented maintain a positive ROI with all but two with ROI greater than 3. This indicates that although the initial adaptation recommendations have a very high ROI ranking, subsequent recommendations still provide a benefit value of over three times the adaptation cost. The cumulative total cost for resilience measures at all eight facilities is $2.6 million.

Table 6-4 Summary of Facilities with Recommended Resilience Investments, including Strategy Costs, Cumulative Risk Avoided and Return on Investment for each Facility for All Assets at Risk

Facilities with Flood Risk out to 2065	Cost of Replacement ($)	Cumulative Risk ($)	Net Present Value ($ Net Return)	Return on Investment ($ Net Return per $ Strategy Cost)	Strategy Cost ($)[a]	Cumulative Cost ($)
Rocky Gorge RWPS	$ 38,820,000	$ 14,680,000	$ 14,569,000	131.25	$ 111,000	$ 111,000
Fort Foote WWPS	$ 1,480,000	$ 250,700	$ 231,700	12.19	$ 19,000	$ 130,000
Parkway WWTP	$ 25,100,000	$ 7,870,000	$ 6,393,000	4.33	$ 1,477,000	$ 1,607,000
Western Branch WWTP	$ 4,380,000	$ 1,500,000	$ 1,212,000	4.21	$ 288,000	$ 1,895,000
Hyattstown WWTP	$ 20,000	$1,000	$ 800	4.00	$ 200	$ 1,895,200
Broad Creek WWPS	$ 42,820,000	$ 2,850,000	$ 2,250,000	3.75	$ 600,000	$ 2,495,200
Anacostia Complex	$ 470,000	$ 80,000	$ 54,000	2.08	$ 26,000	$ 2,521,200
Reddy Branch WWPS	$ 700,000	$ 90,000	$ 50,000	1.25	$ 40,000	$ 2,561,200

Note:
[a] Cost estimates are considered Conceptual/Planning Estimates (+ 100 percent / - 50 percent) per American Society of Cost Estimating Engineers.

While adaptation strategies that clearly provide a benefit when compared to the strategy costs have been recommended, it is noted that benefit is calculated based on replacement cost and cleanup costs alone. Operational impacts because of loss of power or loss of unit processes, have not been quantified as part of this investigation. Therefore, adaptation strategies that have been developed but not recommended, including those where the calculated benefit (cumulative risk avoided) is close or slightly under the strategy cost itself, are recommended to be investigated by means of a WSSC BCA, where appropriate, to quantify operational risk that may be averted.

6.3 Policy Recommendations

The purpose of the CCVAAMP has been to develop climate projections, quantify risk because of climate change, and provide recommendations for immediate and long-term resiliency. Many of the facility-level recommendations are summarized in this report. They include both adaptation strategies as well as adoption of DFEs for use in future design at a facility. The recommendations put forth in this report are based on applying a planning horizon that was established through discussions with WSSC management. However, these recommendations should be revisited regularly to ensure the latest improvements in climate science are incorporated.

Guidance for increasing climate resilience are included in the Draft *Design Guide for Protecting Facilities from Future Climate Extremes* (CH2M, 2019), included as Appendix F. WSSC AMD will complete a BCA for application of the flood protection guidance included in this document. Guidance for other aspects of resiliency, including power supply and electrical system reliability, are included as well. It is recommended that the Draft *Design Guide for Protecting Facilities from Future Climate Extremes* be further expanded to include instrumentation and controls systems resiliency and adopted by WSSC for use in future designs.

7. References

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