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U.S. Department of Transportation
Federal Highway Administration

FHWA Climate Resilience Pilot Program:

Metropolitan Transportation Commission

The Federal Highway Administration's (FHWA)'s Climate Resilience Pilot Program seeks to assist state Departments of Transportation (DOTs), Metropolitan Planning Organizations (MPOs), and Federal Land Management Agencies (FLMAs) in enhancing resilience of transportation systems to extreme weather events and climate change. In 2013-2015, nineteen pilot teams from across the country partnered with FHWA to assess transportation vulnerability to extreme weather events and climate change and evaluated options for improving resilience. For more information about the pilot programs, visit: **http://www.fhwa.dot.gov/environment/climate_change/adaptation/**.

The Metropolitan Transportation Commission (MTC), the San Francisco Bay Conservation and Development Commission (BCDC), the California Department of Transportation, District 4 (Caltrans) and San Francisco Bay Area Rapid Transit District (BART) partnered to assess adaptation options for key transportation assets vulnerable to sea level rise (SLR) in the San Francisco Bay Area. The project team refined their previous vulnerability assessment with additional SLR mapping and hydraulic analysis. Using the revised vulnerability data, the project team developed a comprehensive suite of adaptation strategies for three focus areas in the Alameda County sub-region, and through an evaluation process, they selected five adaptation strategies for further development. The strategies cover physical and policy-based options, as well as future research needs.

Scope

The project team assessed potential adaptation strategies for infrastructure identified as vulnerable to SLR through the team's 2010-2011 FHWA Climate Resilience Pilot project. Adaptation strategies were developed for three focus areas in Alameda County that include a confluence of major transportation assets as well as other important community assets, including:

- The San Francisco-Oakland Bay Bridge Touchdown
- The Oakland Coliseum Area
- The Hayward State Route 92 Corridor

This study is helping to inform regional and state policy and investment decisions and serving as a framework for similar projects.

Objectives

- Create a refined understanding of transportation SLR and storm surge exposure, vulnerability, and risk by analyzing the extent, depth, and pathways of inundation.
- Produce a suite of high-level climate adaptation options that address a number of scales (e.g., asset specific, asset and surrounding areas) and criteria to evaluate them.
- Develop five refined adaptation options with specific and detailed actions.

San Francisco-Oakland Bay Bridge toll plaza. Photo courtesy of MTC

Bay Area Rapid Transit Oakland Coliseum station. Photo courtesy of MTC

Low-lying road in the Hayward focus area. Photo courtesy of MTC

Approach

Vulnerability and Consequence

The project team developed and internally administered an online survey wherein asset managers assisted in refining the team's 2010-2011 FHWA Climate Resilience Pilot project vulnerability assessment. The project team sought to collect survey responses for all core transportation assets in the three focus areas that were originally determined to be vulnerable. Survey questions fell into the following categories:

- ***Governance Challenges (management/control)***: Used to determine vulnerabilities due to challenges with management, regulation, availability of financing resources, or flexibility of funding or permitting;
- ***Information Challenges***: Used to determine vulnerabilities due to deficient, incomplete, or poorly coordinated information;
- ***Physical Characteristics***: Used to determine vulnerabilities due to how an asset was designed or built; and
- ***Functional Characteristics***: Used to determine vulnerabilities due to dependencies and interrelationships with other assets and asset categories.

This survey data also helped the project team understand the consequences of damage on society and equity, the environment, and the economy.

The project team geocoded the survey responses (assigned attributes within a GIS platform) to make the information readily accessible for subsequent analyses.

Exposure

The project team conducted a more refined analysis of potential exposure to future SLR within the focus areas. The team used six reference water levels on top of a daily high tide (mean higher high water or MHHW), including 12, 24, 36, 48, 72, and 96 inches. The last two scenarios are currently beyond the projected 2100 SLR levels; however, they are considered important for understanding extreme storm surge events. For example, the 72 inch scenario could represent 48 inches of SLR plus a 5-year storm event or 36 inches of SLR plus a 50-year storm event. Table 1 demonstrates the various combinations of SLR and storm surge, with each color in the table corresponding to one reference water level.

The project team undertook an additional riverine flooding analysis for the Oakland Coliseum focus area. The analysis leveraged an existing steady-state Hydrologic Engineering Center–River Analysis System (HEC-RAS) hydraulic and hydrologic model.

The exposure analysis also identified critical inundation pathways, which connect shoreline inundation areas to low-lying inland areas.

Adaptation Strategies

The project team developed a compendium of 124 adaptation strategies to directly address the governance, information, physical, and functional vulnerabilities identified in the vulnerability assessment. The strategies fell into three broad categories that reflect their scope:

- ***Core Asset Strategies*** – address vulnerabilities specific to one core asset
- ***Focus Area-wide Strategies*** – address vulnerabilities for core and adjacent assets through large-scale intervention (e.g., shoreline protection)
- ***Agency-specific Strategies*** – address internal agency management-related and information-related vulnerabilities (applicable across all focus areas)

Each strategy contains information on: asset(s) protected by the strategy; vulnerabilities addressed by the strategy; point(s) of intervention; partners; and timing.

Using a screening exercise, followed by a qualitative assessment, the project team selected five strategies for further development. The screening exercise included questions on the scale and replicability of the strategy, the barriers to implementation, the urgency of action, and impacts on society/equity, environment, and economy.

Table 1. Matrix of water levels associated with sea level rise and extreme tide scenarios for the Hayward focus area

	Daily Tide	Extreme Tide (Storm Surge)						
Sea Level Rise Scenario	Water Level above MHHW	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Existing Conditions	0	15	20	24	27	32	36	41
MHHW + 6-inch	6	21	26	30	33	38	42	47
MHHW + 12-inch	12	27	32	36	39	44	48	53
MHHW + 18-inch	18	33	38	42	45	50	54	59
MHHW + 24-inch	24	39	44	48	51	56	60	65
MHHW + 30-inch	30	45	50	54	57	62	66	71
MHHW + 36-inch	36	51	56	60	63	68	72	77
MHHW + 42-inch	42	57	62	66	69	74	78	83
MHHW + 48-inch	48	63	68	72	75	80	84	89

The qualitative assessment used an ordinal ranking system to compare the financial, social, environmental, and governance-related (e.g., funding, legal barriers) performance of the strategies. Using qualitative rather than quantitative rankings helped to remove false precision from the results. As a last level of review, the project team used their professional experience to select a final set of balanced strategies.

Impacts of Not Adapting vs. Adapting

The team created baseline future scenarios to demonstrate how, without any intervention, vulnerable assets would be affected by SLR and storm surge, and the resulting impacts on mobility (e.g., vehicle miles traveled, transit ridership), society (e.g., population and jobs impacted), and the environment (e.g., criteria pollutants, habitat protection). The team produced quantitative estimates of impacts using MTC's travel model, emissions modeling, GIS overlays of flood mapping, historic data, and professional judgment.

The project team then compared the baseline scenarios to the modeled performance of the five adaptation strategies. When possible, the change in level of protection was monetized to provide high-level estimates of total daily avoided costs. These costs can be compared to the costs of construction and maintenance to obtain an overall picture of the tradeoffs when maintaining the status quo versus adapting.

Key Results & Findings

Vulnerability assessment. The refined vulnerability assessment identified three types of exposed areas—shoreline inundation areas, critical inundation pathways, and inland inundation areas. Figure 1 provides a map of these areas in the Bay Bridge Touchdown focus area; the project team conducted similar analyses in the other two focus areas.

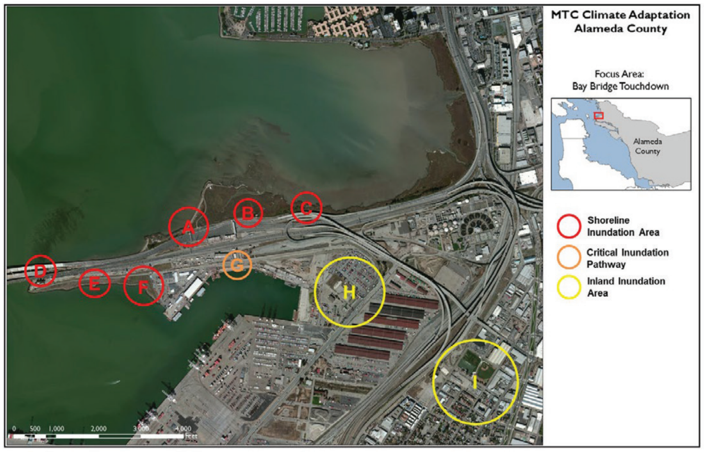

Figure 1. Bay Bridge Touchdown focus area site location map and inundation areas

Adaptation results. The five strategies selected for further development included:

- The San Francisco/Oakland Bay Bridge Touchdown – (1) A living levee to protect the Bay Bridge touchdown from inundation (see Figure 2); and (2) an offshore breakwater to minimize wave action;
- The Oakland Coliseum Area – (3) A living levee along Damon Slough to protect I-880 from coastal and riverine flooding;
- The Hayward State Route 92 Corridor – (4) A drainage study to better understand the inter-relationship between the highway drainage system and the surrounding areas; and
- Non-location specific – (5) Mainstreaming climate change risk in order to consistently consider climate change risk alongside other risks.

All of the strategies include information on the process and partners needed for implementation, preliminary scopes/conceptual designs (including cost estimates), potential barriers, and a summary of impacts of implementation.

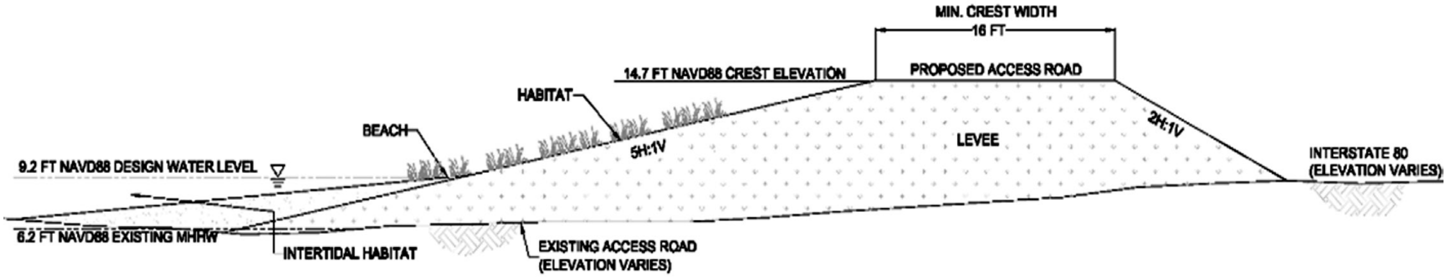

Figure 2. A cross-section of the designed living levee

Lessons Learned

Data collection can be cumbersome. There needs to be a balance between collecting data at an early stage in the project to help decide which assets are most vulnerable and conserving staff time by waiting to collect specific data for use in the development of adaptation strategies.

Additional SLR scenarios enhance understanding of vulnerability. Mapping only two SLR scenarios did not provide nuanced information on the timing and onset of flooding. The final six reference water level scenarios provided a more robust understanding of exposure.

> "This pilot project identified multimodal adaptation options and implementation strategies for vulnerable transportation infrastructure and the surrounding community. Understanding how vital infrastructure can be protected helps guide future investments."
>
> – Stefanie Hom, MTC Pilot Team

Site visits are useful for spot-checking vulnerability data. Site visits provide a better understanding of vulnerability; they can reveal drainage systems that were not captured in the LIDAR data.

Critical path analyses help to highlight locations for action. Critical path analyses highlight how inland areas become inundated or flooded – either from direct shoreline inundation or from a critical pathway, and are therefore useful in understanding key areas for intervention.

Focus the development of adaptation strategies on addressing pressing vulnerabilities. While the compendium of 124 adaptation strategies will be a valuable resource for the project partners and other agencies, the project team may have been better served by identifying priority vulnerabilities and developing a more limited set of adaptation strategies to specifically address those vulnerabilities.

Adaptation strategy selection should include local input. While a standardized qualitative assessment can be a good way to evaluate the performance of strategies, it should always be supplemented by the local knowledge and expertise of stakeholders and agencies.

Next Steps

Advance adaptation strategies. The recommended policy and research adaptation strategies could be pursued with little further scoping by appropriate agencies. The physical strategies will all require further analysis and design work to ensure they are the most appropriate solutions to address future flooding. The compendium of 124 adaptation strategies should be reviewed by the partner agencies, and strategies that could be relatively easily incorporated into existing day-to-day practice (such as updating of design standards in relation to waterproof sealant) should be implemented. Other high-scoring strategies should be identified for further analysis, and promising strategies could be considered at other shoreline areas.

Monitor and update. The project team should track and remain involved in complementary studies being undertaken by other agencies in the region.

Integrate results. The findings from this study, particularly in relation to vulnerable transportation assets and inundation flow paths, should be used to inform decisions regarding the 2017 update of the Bay Area's Sustainable Communities Strategy and Regional Transportation Plan, Plan Bay Area.

For More Information

Final report available at:
www.fhwa.dot.gov/environment/climate/adaptation/2015pilots/

Contacts:

Stefanie Hom
Associate Transportation Planner/Analyst
Metropolitan Transportation Commission
shom@mtc.ca.gov, 510-817-5756

Becky Lupes
Sustainable Transport & Climate Change Team
Federal Highway Administration
Rebecca.Lupes@dot.gov, 202-366-7808