Chapter 3. Vulnerability and Risk Classification

A vulnerability and risk classification system was developed to assist with the transition to adaptation. The purpose was to sort and characterize vulnerabilities and risks to make it easier to develop a robust adaptation response. The classification step also provided an opportunity to test the effectiveness of a unique approach for organizing and communicating the results of a vulnerability and risk assessment, and identifying key issues across diverse categories of assets.

Finding the Right Approach for the ART Project

The ART project staff designed the classification system in order to identify key issues and planning priorities in a way that would be replicable, straightforward to implement, and transparent to all, not just those directly involved in the project. Research on adaptation planning processes, examples from other planning efforts, and previous experience with prioritizing vulnerabilities informed the decision to use a classification rather than a numeric prioritization, ranking or rating approach. (Bintliff 2011).

Many adaptation planning processes prioritize vulnerability and risk numerically. The vulnerability and risk assessment of transportation projects conducted as part of the ART project is an example of this approach. The project consultants tested the use of ranking vulnerabilities, and developing integrated risk "scores" as a means to compare and prioritize different types of ground transportation assets (AECOM 2011). Scores were based on the average of numerical ratings assigned to different consequence criteria such as cost to rebuild the asset, economic impact of loss of the asset, and public safety issues due to impacts to the asset.

In practice, this approach provided a replicable method for factoring quantitative information, such as replacement costs and use levels, into prioritizations. However, it also presented some challenges. The criteria proved difficult for stakeholders to use when asked to score assets they did not own or operate, or of which they had little direct knowledge. In addition, some of the criteria were poorly suited for scoring certain types of ground transportation assets included in the project, such as the Bay Trail, and resulted in under-estimating the consequences of impacts to these assets. In order to balance vulnerability and risk scores, consequences to the region if the asset were to be lost were also considered. The consequence information came from stakeholder input and provided additional context about the significance of some assets. The project consultants conveyed this additional consequence information in risk profile sheets that were prepared for a subset of the transportation assets.

Examples from other planning efforts have also shown that numerical ratings can be misleading. Scores are generally assigned based on best professional judgment rather than a quantitative analysis. However, the use of a numerical score can suggest that a quantitative analysis was undertaken or that there is a level of certainty that does not exist. Furthermore, averaging across different scoring criteria to obtain a single value can over-simplify the overall risk, and potentially underestimate severe consequences (Bintliff 2011). This may result in an asset being removed from further consideration in a study. A weighting system for different scoring criteria could address this issue, but it also makes the ranking process more complex and more difficult to interpret. It can be difficult to determine how risks and vulnerabilities were prioritized when the numerical score is taken forward without the appropriate context. Regardless of the scoring method, precise definitions of the assumptions used in the scoring system must be presented and communicated to ensure transparency, replicability, and clarity (Bintliff 2011).

For an adaptation planning project focused on one asset type with access to sufficient data for quantitative analysis, scoring can be helpful, especially to managers who are prioritizing issues for assets that they themselves manage. However, applying this method in the ART project across multiple asset categories, jurisdictions, and management boundaries would be complex and time-consuming, and ultimately unlikely to advance the development of adaptation strategies. For example, attempting to numerically rank and compare the Bay Bridge, the Oakland International Airport, the Emeryville Crescent, and the Bay Trail would not likely lead to useful outcomes.

Instead of a numerical scoring or ranking system, the ART project developed an approach to classify vulnerabilities and risks into actionable categories that would help asset managers and decision-makers understand the defining characteristics of an issue (e.g., its timing, scale, responsibility for management, etc.). This approach better supports informed discussions and decisions– both internal to the agencies participating in the ART project and in coordination with other interested parties and stakeholders – about priorities and potential adaptation strategies. Additionally, defining key issues and planning priorities in terms of actions to be taken rather than numerical risk rankings makes the results of the assessment clearer and more useful to decision-makers and asset managers.

The Classification Approach

Classifying the vulnerabilities and risks provided a way to organize and communicate the results of the ART assessment and helped project participants and other stakeholders prioritize issues, identify potential adaptation strategies and their tradeoffs, and recognize opportunities for new or improved coordination.

For each of the asset categories, information about sea level rise exposure, sensitivity, adaptive capacity, and consequences was summarized into brief issue statements. The issues were classified according to specific characteristics of vulnerability and risk. Staff and working group members chose characteristics that they felt would best help prioritize issues and weigh adaptation responses.

Vulnerabilities were evaluated according to four classifications: *timing*, *management control*, *physical and functional qualities*, and *information*. Four additional classifications, *scale, people, ecosystem services,* and *economy*, were used to identify key dimensions of risk that should be considered in prioritizing issues.

Timing is an approximation of the onset of vulnerability: "near-term," "mid-century," or "end of century" describes when impacts are likely to be felt. The timing of vulnerabilities is potentially relevant to prioritizing issues and deciding how to sequence and coordinate adaptation strategies. All else being equal, issues that are likely to develop sooner should be prioritized. For example, managers deciding how to allocate limited funding for redesign of playing fields at multiple parks might choose to apply the funds to the playing fields that first become vulnerable to impacts. Similarly, awareness of differences in timing of impacts to contaminated sites would be helpful in setting priorities for remediation efforts.

The timing of vulnerabilities should not be used as a proxy for the importance of issues, or as a deadline for when to begin planning or taking action. Indeed, most of the issues identified in the ART assessment require significant lead-time for planning and implementation of strategies to reduce vulnerability and risk.

Most often the timing of a vulnerability will coincide with exposure of the asset (or system of assets) to one of sea level rise projections addressed in the ART assessment, but this is not always the case. For example, a shoreline feature (e.g., trail, wetland, etc.) might not be vulnerable to impacts until end-of-century despite being exposed to mid-century sea level rise, because it is resilient to impacts. In contrast, vulnerabilities may develop prior to exposure (e.g., in the near-term or mid-term) because of existing stressors on an asset, and/or interdependencies with other assets that are exposed to impacts earlier.

Management control describes challenging management characteristics of an asset. For example, the management or regulatory structure of some assets may result in the need for a long lead-time to develop and implement adaptation responses. This classification can also help agencies pinpoint challenges and opportunities within and outside their organizations for addressing certain vulnerabilities and risks. Management control factors that were considered include:

- **Multi-agency effort:** Many issues cannot be resolved with a single-agency effort because multiple agencies have relevant responsibilities and authorities. These situations often indicate the need for an early start to planning to allow enough time for inter-agency coordination.
- **Inadequate management approaches:** The ways in which agencies currently approach some issues may no longer be adequate to address new challenges that sea level rise impacts will introduce. For example, the planning horizons commonly used for activities such as capital improvement plans and general plan updates may need to be extended to take into account future sea level rise impacts. Another example could occur in a park where it becomes impossible to prevent flooding and managers must consider novel management practices to accommodate flooding and minimize consequences.
- **Inadequate authority or regulatory mechanisms:** Existing management authority or regulatory mechanisms may be too limited or inadequate to address certain issues. For example, agencies that regulate contaminated sites are limited in their ability to set and implement cleanup priorities because the majority of these sites are privately owned and cleanup depends on voluntary efforts. If property owners are unwilling to clean up such sites, additional time and effort are necessary to compel cleanup and extract or find funding. It is possible that none of the responsible agencies have the authority or mandate to address key aspects of vulnerability and risk presented by sea level rise.

  Managers may also face situations in which implementation of existing policies and regulations will exacerbate vulnerability to or consequences of sea level rise and storm event impacts.
- **Financing:** Sea level rise will introduce novel management challenges, and managers will encounter situations where there are no sources of money to apply towards addressing certain issues. Other financing challenges include restrictions on the use of available funds and the inability to access new funding sources that could be applied to resolve an issue. It is important to distinguish these challenges related to access to applicable funding sources from fiscal limitations on planning, operating or management budgets. Most agencies do and will continue to deal with budget limitations. Financing challenges associated with sea level rise vulnerabilities and risks may require seeking out new sources of funding outside of traditional budget allocations, and/or allowances for re-allocating funding.

Physical and functional qualities identifies a subset of existing conditions or design and functional aspects of an asset that make it acutely sensitive or severely limit its adaptive capacity to sea level rise and storm impacts. Factors that were considered include:

- **At or below grade:** Infrastructure such as roads, trails, living space in homes, or pump stations that are built at or below grade are more likely to be susceptible to flooding due to their low elevation.
- **Water sensitivity:** Exposure to water due to flooding or groundwater rise is especially damaging or harmful for certain types of assets. For example, electrical or mechanical components of utility systems might not be able to continue functioning if they get wet, resulting in loss of services (e.g., power, water treatment). Additionally, in areas with contamination, exposure to flooding and rising groundwater could result in water soluble contaminants going into solution and spreading.
- **Sensitivity to salinity:** Sensitivity to salinity is another factor that increases vulnerability to sea level rise impacts. Assets that are sensitive to salinity include grass and other landscape features, as well as corrodible materials used in utilities infrastructure and storage tanks.
- **Highly erodible:** Some assets are especially sensitive to impacts because they are highly erodible. Beaches, marshes, mudflats and levees (including trails built on levees) are obvious examples. Erosion is also a sensitivity factor for contaminated lands where sediment-bound contaminants could be spread, and for buried pipelines that could be uncovered due to erosion and thereby exposed to potential damage.
- **Increased liquefaction potential:** Seismic susceptibility of infrastructure is a significant concern throughout the Bay Area. Higher groundwater and longer-lasting flooding could increase the liquefaction potential of certain areas (permanently or temporarily), leading to a greater risk of damage to infrastructure during an earthquake.
- **Wetlands sensitivities:** For wetlands, an insufficient supply of sediment and limited space for accommodating inland shift of wetlands habitat are physical qualities that increase sensitivity to impacts.
- **Time-sensitivity:** Certain infrastructure in the subregion serves time-sensitive functions that cannot tolerate even short disruptions. For example, the seaport transports fresh agricultural products that would spoil if flooding caused delays or closures.
- **Lack of system redundancy:** For some types of assets, such as the seaport and airport, there is a fundamental, system-wide lack of redundancy or alternatives for serving comparable functions. Some vulnerable assets lack redundancy because suitable alternatives are also vulnerable to impacts.
- **Dependence on vulnerable assets:** The functionality of some assets is dependent on other, vulnerable assets or systems. For example, some of the main access roads to Oakland International Airport are vulnerable to impacts before the airport itself. Therefore, while the airport may not be exposed, its function may be severely constrained if passengers and goods cannot get to and from the airport.
- **Fixed, linear systems:** The rail system used for cargo and passenger transportation is especially sensitive to impacts because it relies on fixed, linear infrastructure. Depending on the location, damage at a single point along one rail line can potentially disrupt service throughout the rail network until the damage is repaired.

Information identifies challenges in obtaining the information necessary to sufficiently understand sea level rise vulnerability and risk. In preparing the ART assessment, project staff determined that these challenges were not only barriers to fully understanding the issues, but were themselves causes of vulnerability and risk. Easy access to relevant, up-to-date, and appropriate information bolsters managers' capacity to successfully address the issues

identified in the ART assessment. Types of information challenges that were identified included:

- **Lack of information:** For some assets, necessary information – such as elevation data or precise locations of hazardous materials – has not been collected or compiled, or is so outdated as to no longer be relevant.
- **Unavailable information:** In other cases, relevant information exists, but is not available to managers because, for example, it is held privately, or the cost of acquiring or analyzing it is prohibitive.
- **Poorly coordinated information sources:** Another common information challenge encountered during the ART assessment was that necessary information is collected or held by multiple sources that are poorly coordinated. Inconsistencies in collection methods or reporting norms (e.g., naming systems) can make it virtually impossible to compile the various data, or even cross-reference overlapping data sources.

Scale describes the geographic level(s) at which the consequences of a climate impact will be felt. In combination with other classifications, scale can help managers identify issues with serious consequences that need to be prioritized; identify possible adaptation strategies by considering the whole system; and identify other managers and stakeholders that may need to be involved in developing an adaptation response. Scales considered range from the site or asset itself (e.g., loss of homes) to the nationwide consequences of sea level rise and storm event impacts (e.g., disruptions in service at Oakland International Airport).

People broadly categorizes how the consequences of an issue affect people where they live, work, access key services such as health care, and conduct other necessary day-to-day activities. Combined with the other classifications, this underscores high consequence issues that managers and decision-makers should prioritize. Factors considered were impacts to:

- **Health and safety:** Damage and disruptions to emergency response centers such as fire and police stations, emergency shelters, and health-care facilities could prevent effective response and recovery from sea level rise and storm event impacts.
- **People where they live:** This includes damage to homes and entire neighborhoods as well as disruptions to key services that residential areas rely on, such as utilities.
- **People's livelihoods:** Impacts on employment centers as well as employees' access to jobs via roads, the Bay Trail, and transit were identified.
- **Socially vulnerable populations:** The ART assessment identified populations such as renters, non-English speakers, persons with health or physical mobility constraints, and others who face greater barriers to planning for and responding to impacts.
- **People where they recreate:** The assessment identified consequences to public spaces, such as parks and the Bay Trail, that provide highly valued recreation opportunities.

Ecosystem Services identifies consequences on the services provided by a natural shoreline feature (e.g., wetland). Types of services that were considered include biodiversity, flood and erosion control, water quality improvement, and carbon sequestration. For example, loss of a wetland that acts as a buffer between the Bay and inland areas could diminish the protection that it provides against flooding and erosion in adjacent neighborhoods. These consequences may also result from secondary effects due to impacts on other asset types (e.g., a wastewater treatment system), which in turn harm the capacity of a natural shoreline to provide ecosystem services.

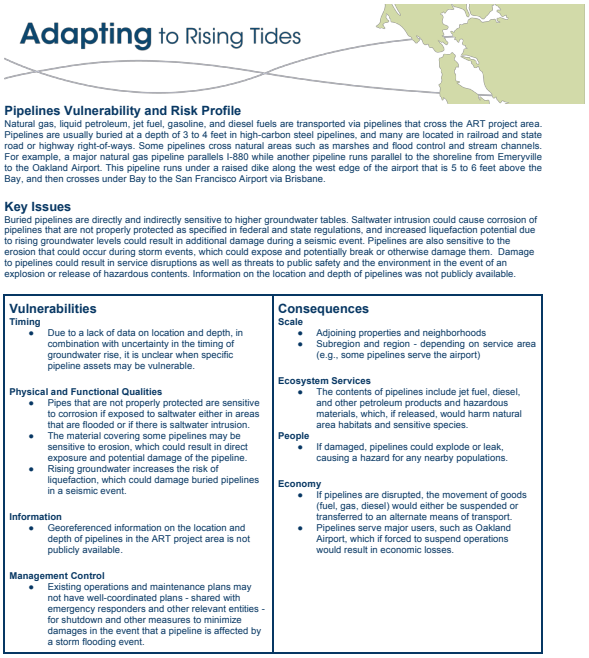
Economy identifies consequences on important drivers of economic health in the region and subregion. These include impacts to goods movement, commuting, employment centers, and business sectors.

Outcomes of the Classification Step

Applying the classification system generated products and outcomes that support adaptation planning.

Asset Category Profiles: Classifications for each asset category (i.e. community land use, facilities and services; ground transportation; airport; parks and recreation; etc.) have been summarized into profiles (Figure 1) that detail the important and common characteristics of vulnerability and risk for that category. These asset category profiles helped define key issues from the assessment. The profiles also enabled ART project staff and the working group to identify a pool of strategies for each category that could be applied to reduce exposure and sensitivity or, conversely, increase adaptive capacity for assets within that category.

Figure 1. Example of a profile sheet for an asset category



Adapting to Rising Tides

Pipelines Vulnerability and Risk Profile

Natural gas, liquid petroleum, jet fuel, gasoline, and diesel fuels are transported via pipelines that cross the ART project area. Pipelines are usually buried at a depth of 3 to 4 feet in high-carbon steel pipelines, and many are located in railroad and state road or highway right-of-ways. Some pipelines cross natural areas such as marshes and flood control and stream channels. For example, a major natural gas pipeline parallels I-880 while another pipeline runs parallel to the shoreline from Emeryville to the Oakland Airport. This pipeline runs under a raised dike along the west edge of the airport that is 5 to 6 feet above the Bay, and then crosses under Bay to the San Francisco Airport via Brisbane.

Key Issues

Buried pipelines are directly and indirectly sensitive to higher groundwater tables. Saltwater intrusion could cause corrosion of pipelines that are not properly protected as specified in federal and state regulations, and increased liquefaction potential due to rising groundwater levels could result in additional damage during a seismic event. Pipelines are also sensitive to the erosion that could occur during storm events, which could expose and potentially break or otherwise damage them. Damage to pipelines could result in service disruptions as well as threats to public safety and the environment in the event of an explosion or release of hazardous contents. Information on the location and depth of pipelines was not publicly available.

Vulnerabilities

Timing
- Due to a lack of data on location and depth, in combination with uncertainty in the timing of groundwater rise, it is unclear when specific pipeline assets may be vulnerable.

Physical and Functional Qualities
- Pipes that are not properly protected are sensitive to corrosion if exposed to saltwater either in areas that are flooded or if there is saltwater intrusion.
- The material covering some pipelines may be sensitive to erosion, which could result in direct exposure and potential damage of the pipeline.
- Rising groundwater increases the risk of liquefaction, which could damage buried pipelines in a seismic event.

Information
- Georeferenced information on the location and depth of pipelines in the ART project area is not publicly available.

Management Control
- Existing operations and maintenance plans may not have well-coordinated plans - shared with emergency responders and other relevant entities - for shutdown and other measures to minimize damages in the event that a pipeline is affected by a storm flooding event.

Consequences

Scale
- Adjoining properties and neighborhoods
- Subregion and region - depending on service area (e.g., some pipelines serve the airport)

Ecosystem Services
- The contents of pipelines include jet fuel, diesel, and other petroleum products and hazardous materials, which, if released, would harm natural area habitats and sensitive species.

People
- If damaged, pipelines could explode or leak, causing a hazard for any nearby populations.

Economy
- If pipelines are disrupted, the movement of goods (fuel, gas, diesel) would either be suspended or transferred to an alternate means of transport.
- Pipelines serve major users, such as Oakland Airport, which if forced to suspend operations would result in economic losses.

To prioritize issues, evaluate strategies, understand implementation challenges and opportunities, and recognize coordination needs, planners and managers also need to take a detailed look at the vulnerabilities and risks to their specific assets of concern, (e.g. a neighborhood, a pipeline, an airport runway, a park, a wastewater treatment facility, etc). A valuable function of the category profiles has been to make this task much simpler. Rather than start from scratch with this analysis, an asset manager can use the category profiles as a starting point for identifying aspects of vulnerability and risk that may need to be addressed. The category profile also provides a backstop by calling out aspects that might easily be missed if a manager relied only on an asset-specific analysis. The pool of adaptation strategies – developed with the use of the category profiles – serves as a resource for building a response for the specific asset(s).

In testing the classification system for a specific asset or subset of assets, project staff and the working group identified mismatches. Mismatches are discrepancies or conflicts among characteristics of an issue that could hinder or delay development and implementation of adaptation strategies. For example, impacts on the roads that provide access to Oakland International Airport will have far-reaching consequences for airport operations, important utilities, ground transportation, and land use, services, and facilities near the airport. A large-scale, coordinated, multi-agency response will be needed to address these issues. However, the anticipated near-term occurrence of the impacts means that there is relatively little time to implement such a complex planning and response effort. Along with the other classifications,

recognizing these mismatches can help managers identify planning priorities and narrow in on appropriate adaptation strategies for specific assets.

Key, Cross-Cutting Issues: In addition to producing the profiles, conducting the classification step expanded the understanding of key issues identified in the vulnerability and risk assessment.[1] The consequence classifications – scale, people, environment and economy – called out key issues that have severe or widespread negative social, environmental and/or economic consequences. For example, severe consequences to public health and the environment and the local economy will result from partial or complete failure of a wastewater treatment plant even for relatively short time periods.

Details about the relationships among issues such as inter/dependencies among assets, and vulnerabilities and consequences that "cascade" from one asset or geographic area to another were also revealed. For example, the rail line which is essential for both cargo and passenger transportation is highly vulnerable within the subregion, but it is also vulnerable in northern Contra Costa County. Disruptions to the electrical utilities create a cascade of issues in other asset categories such as community land use, facilities and services; ground transportation and more. Some of the main access roads to Oakland International Airport are vulnerable to impacts long before the airport itself.

Additionally, certain issues emerged that have severe and/or widespread consequences and highly complex, intertwined vulnerabilities. These key, cross-cutting issues require holistic adaptation planning because actions to address vulnerabilities of an individual asset strongly affect other assets' vulnerability to sea level rise, and potentially limit the range of adaptation options available to managers of other assets. To test a method for informing and initiating this type of adaptation planning, project staff used the classification system to identify and further assess geographic areas, or "focus areas," within the subregion that have key, cross-cutting issues that must be addressed together. This focus area approach involves considering a suite of issues across multiple asset categories and jurisdictions in identifying and evaluating adaptation strategies and implementation options. The goal of this approach is to develop robust adaptation responses that increase resilience across different types of assets and geographic boundaries.

References

Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project. November 2011. Prepared by AECOM and Arcadis for the San Francisco Bay Conservation and Development Commission, Metropolitan Transportation Commission and the California Department of Transportation. Available at http://www.mtc.ca.gov/news/current_topics/10-11/sea_level_rise.htm

Assessing Climate Change Vulnerability & Risk. December, 2011. Prepared by Jacob Bintliff, BCDC Planning Intern, UC Berkeley College of Environmental Design, Department of City & Regional Planning. Available at: http://www.adaptingtorisingtides.org/project-reports/

[1] Key issues and cross-cutting issues are summarized in the Vulnerability and Risk Synthesis.