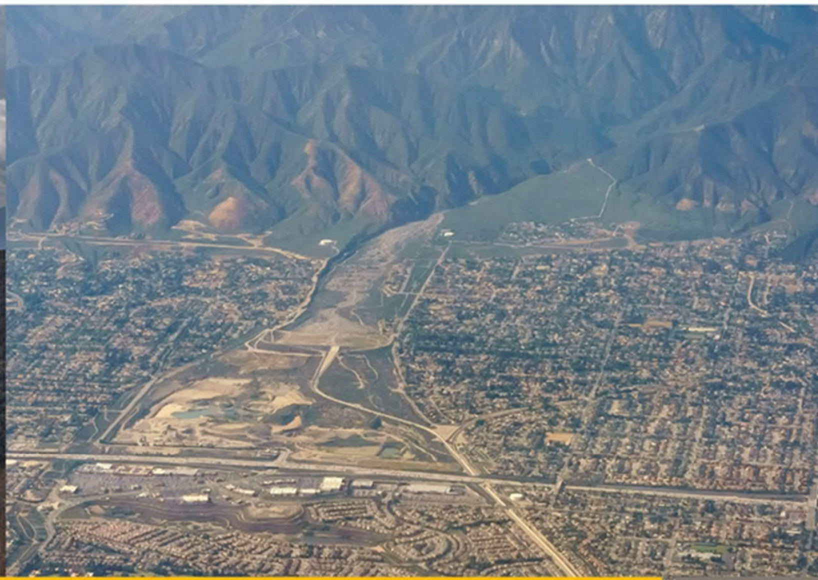

CLIMATE RESILIENT TRANSPORTATION INFRASTRUCTURE

GUIDEBOOK

WESTERN RIVERSIDE COUNCIL OF GOVERNMENTS | SAN BERNARDINO COUNTY TRANSPORTATION AUTHORITY

Climate Resilient Transportation Infrastructure Guidebook

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1. INTRODUCTION TO GUIDEBOOK

1.1 Purpose

Extreme weather and climate conditions can heavily influence transportation and other forms of infrastructure. This infrastructure is designed to withstand these conditions to a certain extent, given current criteria-based design practices. Yet almost all existing transportation infrastructure in the country, state, and Western Riverside County/San Bernardino County region was originally designed under the assumption that these conditions would remain relatively constant over time. Changing climate conditions, both observed and projected, are proving this assumption to be inaccurate and need to be appropriately considered to enable effective investments. When combined with other contributing factors, such as development adjacent to hillsides and fire-prone areas, these changing climate conditions increase the opportunity for physical damage to occur, and heighten the impact of a transportation facility being put out of service.

This Guidebook serves as a guide to help local practitioners make the transportation system more resilient to these changes. It is intended as a practical resource for jurisdictions and includes strategies, best practices, and methods for overcoming challenges and using climate resiliency tools to address changing patterns of extreme temperatures, heavy precipitation and flooding events, drought, and wildfires. It was tailored to address the diverse climate, terrain, and needs of the region to ensure the long-term viability of the transportation system.

The Guidebook is part of the larger Regional Climate Adaptation Toolkit for Transportation Infrastructure effort, also known as Resilient IE, a joint effort between the Western Riverside Council of Governments (WRCOG) and San Bernardino County Transportation Authority (SBCTA), funded by the California Department of Transportation (Caltrans).[1] It complements the city-level, climate-related transportation hazards and evacuation maps and other products developed as part of Resilient IE. The Guidebook also helps identify strategies that provide other benefits, such as the provision of alternative compliance stormwater facilities.

The Guidebook draws upon strategies that have been developed at the national and state levels. These strategies are tailored to the regional level for use by the intended audience of local jurisdictions, planners, and engineers within Western Riverside County and San Bernardino County. This Guidebook is one resource available to practitioners in the study region. Other resources include the technical and summary reports prepared by Caltrans for District 8 – documents that present an overview of how climate change may impact the region through changing temperature and precipitation conditions[2]. The resources developed for the region set the stage for understanding the ways the local climate is changing and how to begin applying that information. When combined with other resources available to quantify climate change (i.e. inputs available from State sources and identified later in this document), this collection forms the basis of how to design more climate resilient infrastructure.

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[1] www.wrcog.us/285/Resilient-IE
[2] https://dot.ca.gov/programs/transportation-planning/office-of-smart-mobility-climate-change/climate-change

1.2 Climate Adaptation and Resiliency

1.2.1 POLICY CONTEXT

California has passed a series of State level policies through Executive Orders (EOs) and legislative bills that have established expectations for State agencies, local jurisdictions, and transit agencies to address the impacts of climate change. Several EOs have helped to lay the foundation for resilience-informed policy and decision-making across California. EO S-20-06, signed in 2006, established the responsibilities and roles of the Secretary of the California Environmental Protection Agency and State agencies in climate change[3], and EO B-30-15, signed by Governor Brown in 2015, requires that climate change be considered in all State investment decisions and details further requirements for prioritization of resiliency approaches and strategies.[4]

Several State laws have since been passed, which provide further directives to State agencies and local authorities to act on and build resilience to climate change impacts within their jurisdiction. The key resiliency-related policies are outlined below:

- Senate Bill 379, passed in 2015, requires that, by January 1, 2022, all local jurisdictions must incorporate climate adaptation and resiliency planning into the safety element of its general plan or into its local hazard mitigation plan.[5]
- Senate Bill 1000, passed in 2017, requires the legislative body of each county and city to develop general plans with long term considerations safety elements surrounding hazards from geology, flooding, wildland and urban fires, and climate adaptation and resilience strategies. In addition, the bill requires that the general plan identify disadvantaged communities and develop environmental justice related goals and policies.[6]
- Assembly Bill 2800, passed in 2018, requires that State agencies account for climate impacts during planning, design, building, operations, maintenance, and investments in infrastructure. It also requires the formation of a Climate-Safe Infrastructure Working Group represented by engineers and architects with relevant experience from multiple State agencies, including the Department of Transportation.[7]

This policy background helps to set the stage for the remaining material in this Guidebook, which will serve to inform WRCOG/SBCTA efforts to adhere to these State objectives and build resiliency in the region.

1.2.2 RISK-BASED DESIGN

Much of transportation design is based on a study of historical conditions and the assumption of a level of stationarity of those conditions for the entire period an asset will be in place. Climate change at its basis presents planners and designers with uncertain future conditions, a reality that will be the case for decades to come as efforts continue to better understand the earth's response to warming conditions. The assumptions of climate change are that a warming planet and the associated increasing energy in the atmosphere are changing those conditions, impacting the severity of storms, extending wildfire seasons, increasing temperatures, and raising sea levels. There are large uncertainties inherent as to the timing and severity of these changes, which makes decision-making on climate change and effective design somewhat challenging.

Risk-based design is an approach that considers potential futures, the possible consequences associated with those changes, and estimates for how the system may be impacted to determine what strategies should be taken.

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[3] http://www.climatechange.ca.gov/state/executive_orders.html
[4] https://www.gov.ca.gov/news.php?id=18938
[5] https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160SB379
[6] https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB1000
[7] http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB2800

It varies from current design practice as current practice relies on established design criteria to recommend design approaches. Effective design involves looking forward to assess how various design inputs (precipitation, temperature, etc.) are anticipated to change, and how those future conditions should be incorporated into design.

Risk-based design strategies are a way of developing an effective adaptation response to climate stressors and dealing with the uncertainties of future climate conditions. Designing to future climate conditions requires a perspective shift compared to current design policies and practices. It requires a restructuring of design practice, due to uncertainties in future conditions and how those uncertainties are assessed to ensure that the most appropriate and cost-effective design is forwarded for implementation. Being different from current practice means it will require an extended period of dialogue to implement and inform stakeholders of the basis for decisions. Risk-based approaches also consider system impacts as a part of decision-making, another perspective change that will need to be considered. The graphic below highlights the various conditions that are changing and how they should be considered as a part of any decision-making process and facility design.

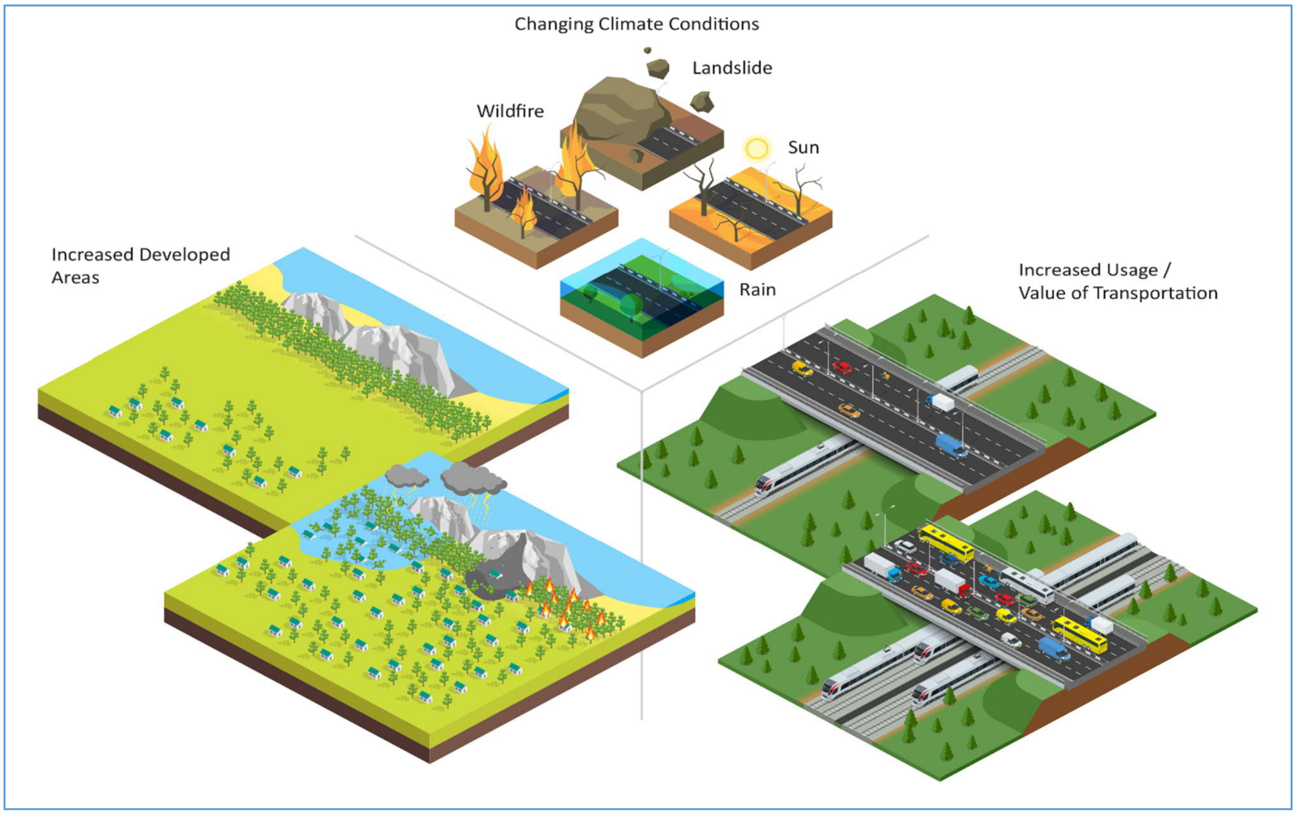


Figure 1 - Dynamic Conditions Considered as Part of Risk-Based Design

Risk-based approaches break down the process of facility design into a robust and comprehensive review of a system and how it should be designed. It inserts critical dialogue on consequence of failure to include impact to the facility (damage/loss to an asset), as well as broader regional implications associated with loss of traveler access on a roadway. This dialogue enters the design perspective and enables a comprehensive financial analysis to guide effective investments.

The sections that follow this one lay out specific design options that can help to reduce potential implications of changing climate conditions through engineering design strategies that seek to limit the potential damage from these extreme weather events. This section outlines how the approach to design should be altered to incorporate changing future climate conditions, the uncertainties inherent in estimates of future conditions, and the importance of an asset within the regional perspective. Incorporating these concepts into future capital investments ensures that regional investments consider a range of potential strategies and design standards.

A risk-based design approach is better suited than the design criteria storm method typically applied. These traditional criteria-based approaches typically apply a single standard for addressing a hazard (e.g., a 50-year or 100-year flood) and do not involve a consideration of data uncertainties or the impacts of broader system impacts. On the other hand, risk-based design approaches enable analysis of data uncertainties, and introduce larger discussions on consequences and asset value. This is true when considering climate change as a potential future condition, and when considering any factor that has inherent uncertainties, including current climate conditions.

Properly incorporating risk-based assessments that consider climate change and inherent uncertainties into design should have the following key perspectives:

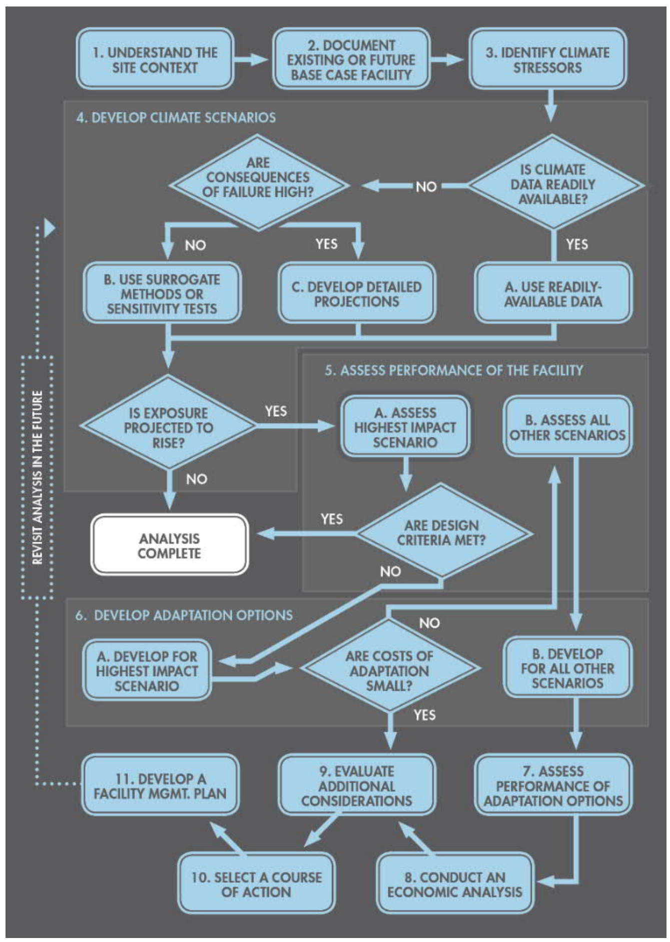
- Examine risk over an asset lifetime to determine the most appropriate design strategy through measures of cost-effectiveness in reducing/eliminating impacts.
- Incorporate multiple future scenarios to reflect uncertainties in current and future conditions.
- Better understand the consequence of hazards when they do occur, through estimating the broader social and economic values of transportation assets and system.

1.2.3 GENERAL GUIDANCE AND RESOURCES

Fortunately, there has been an abundance of research at the State and national levels to help transportation planners, designers, and managers address the risks that changing climate conditions pose to our transportation systems. Rather than provide an exhaustive review of these efforts, this Guidebook will highlight a few of the most relevant resources for the WRCOG-SBCTA region.

One helpful framework is the Federal Highway Administration's (FHWA's) Adaptation Decision-Making Assessment Process (ADAP)[8], which provides guidance on how to account for climate change in the design of civil works projects or facilities. The ADAP steps are captured in Figure 2. The FHWA website has a detailed description of the steps and how they can be implemented. The framework attempts to distill the most important elements of how agencies can make planning and design decisions amidst a changing climate. ADAP was developed as part of the FHWA Transportation Engineering

Figure 2 - FHWA ADAP Process



Source: FHWA

[8] https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/adap/index.cfm

Approaches to Climate Resiliency (TEACR) study[9], which provides information on how to incorporate climate change into project development.

There are several key features of ADAP that can be applied generally in this type of analysis:[10]

- Consideration of the facility's function within the broader transportation network and its location within the natural environment and coordination with relevant stakeholders. This provides an initial overview and documentation of the conditions present in the project area. (Step 1)
- Guidance on how to identify and/or develop appropriate climate projections. This links a general understanding of changing climate conditions with the specific metrics needed for facility design based on the stressor of concern. (Step 4)
- Examination of several different climate change scenarios – a crucial planning step given the uncertainty involved in estimating future climate conditions. This enables a robust dialogue on the risk, response and costs associated with action and/or inaction for various response strategies. (Step 5)
- Incorporation of a range of possible types of adaptation options, exploring various strategies to determine those best able to address noted conditions (e.g. minor design changes up to major system relocations). (Step 6)
- Full lifecycle economic analysis, performed across different climate scenarios to test robustness of the options. This effort assesses estimated conditions that could be present over the time frame the asset is in place, to quantify costs of maintenance, repair, etc. The output is an understanding of the comparative costs and benefits of each adaptation option (relative to the base case) under each climate scenario. (Step 8)
- Examination of climate change as a risk that should be considered when choosing which project alternatives or other decisions are preferable in terms of life cycle cost, resilience, regulatory and political settings. Responding to climate change will not be the only concern for designing an asset, and other considerations need to be incorporated into a robust process. (Step 10)

Another platform relevant to the WRCOG-SBCTA region is the Cal-Adapt data repository.[11] Cal-Adapt provides location-specific climate projections for different hazards across California. Its extreme precipitation projections, wildfire projections, and extreme heat days projections are particularly relevant for the region and can be drawn from to determine inputs to facility level assessments. Cal-Adapt provides raw climate projections and visualization tools, such as:

- Annual Averages viewer, which shows past observations of, and expected changes to, temperature and precipitation by time period, climate models, and emissions scenario, Locations can be specified by text search; clicking on a map; selecting a census tract, county, or other available geography; or uploading a custom boundary as a shapefile or similar format.
- Extreme Precipitation viewer, which allows exploration of extreme precipitation observations and forecasts for different return periods and durations. The tool allows the user to look at precipitation magnitude, frequency, and timing.
- Wildfire viewer, which shows annual average acres burned for different models, emissions scenarios, locations, and timeframes.

Other helpful resources that focus on specific hazards or topics are included in the Chapter 3 strategy descriptions.

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[9] https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/synthesis/page06.cfm
[10] Caltrans Climate Action Report memorandum: Incorporating Climate Change Risk into Economic Analysis
[11] http://cal-adapt.org/

1.3 Regional Environment, Geography and Climate

This section provides a description of the current geography, environment and climate in the WRCOG/SBCTA region, and then briefly discusses climate-related transportation impacts in the region.

1.3.1 WESTERN RIVERSIDE COUNTY

Riverside County covers over 7,000 square miles from its western most border abutting Orange County and to the county's eastern most border which extends to the California-Arizona state border. Western Riverside County includes 18 cities ranging from populous urban communities of more than 320 thousand to small, rural communities of fewer than 10 thousand residents. The subregion also includes public park lands, including the San Bernardino National Forest and parts of Joshua Tree National Park. Western Riverside County experiences a Mediterranean Climate with dry and hot summers and wet and mild winters. Given the range of environments in the county, there is certainly fluctuation between the subregional climates. The Caltrans District 8 Vulnerability Assessment Summary Report[12] provides additional details on climate projections for western Riverside County and how climate change will impact State highway system assets in the county.

1.3.2 SAN BERNARDINO COUNTY

San Bernardino County extends from the eastern edge of Los Angeles and Kern Counties out to the Nevada and Arizona borders, encompassing over 20,000 square miles of land. The county consists of three general regions: the mountain region, the valley, and the desert.[13] Most the county's population resides in the valley region to the west. The mountain region is largely composed of public lands, and the desert region covers much of the county's area and includes parts of the Mojave Desert. San Bernardino County has a variable climate given the variety in the county's geography. Generally, the county experiences arid and hot summers and colder winters relative to other parts of southern California. The Caltrans District 8 Vulnerability Assessment Summary Report provides additional details on climate projections for San Bernardino County and how climate change will impact State highway system assets in the county.

1.3.3 TRANSPORTATION SYSTEM IMPACTS

The WRCOG/SBCTA region faces several significant weather and climate threats. Increased magnitude and frequency of extreme heat pose health hazards and can affect maintenance and operation of roadways and transit. Extreme cold in the mountain communities can also create hazards for infrastructure and users. Greater wildfire risks threaten public safety and can cause residual impacts, such as debris clogging drainage systems, that render the area more vulnerable to future storms. Changing heavy precipitation patterns present flood risks to the transportation system and communities.

There have been several recent weather events that have significantly affected the transportation system in the region. For instance, in February 2019, roads into Idyllwild in Riverside County were closed for the second time in six months. In late July and early August 2018, the Cranston Fire caused the closure of State Highways 74 and 243. After heavy rains on February 14, 2019, the roads were closed again due to severe flooding and road damage, washouts, and rock slides.[14] An $8 million emergency contract combined for both routes is making repairs to damages including, but not limited to: complete road loss, culvert repair/replacement, wash outs, slip outs, sink holes, slope instability resulting in rock fall, mud and debris flows, and damaged pavement. There are over 25

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[12] Caltrans Climate Change Vulnerability Assessment Summary Report, District 8, 2019.
[13] http://cms.sbcounty.gov/Portals/21/Resources%20Documents/CIR_2015_Report.pdf
[14] Idyllwild Town Crier, JP Crumrine, February 20, 2019. https://idyllwildtowncrier.com/2019/02/20/torrential-rain-severely-damages-highways/

locations on SR 243 with damage, including two locations with complete road loss. SR 74 has over 40 locations that will require repairs.[15]

Other current road closures on Riverside County roads due to flooding and storm damage include[16]:

- Box Canyon Road: Closed on September 30, 2018 from Painted Canyon Road to Interstate 10.
- 70th Avenue: Closed on October 1, 2018 from Cleveland to Windard Drive.
- Whitewater Canyon Road: Closed on February 14, 2019 from south of Village to northwesterly end.
- Bautista Road: Closed on February 25, 2019 from Tripp Flats Road to Conservation Camp.

Recent San Bernardino County road closures due to extreme weather include[17]:

- Essex Road and Goffs Road: Closed on July 25, 2017 between Interstate 40 South to National Trails Highway, closed due to bridge damage on National Trails Highway.
- Glass Road: Closed on February 14, 2019 from Seven Oaks Road to Highway 38 due to flooding and undermining.
- Ludlow Road: Closed on September 12, 2012 from Crucero Road West to end of road, due to washed out bridge.
- National Trails Highway: Closed on September 8, 2014 due to bridge damage from flooding.
- Radford Camp Road: Closed on February 14, 2019 from Seven Oaks Road to end, due to flooding and road undermining.
- Seven Oaks Road: Closed on February 14, 2019 from Glass Road to end, due to flooding and undermining.

Holy Fire, Western Riverside County, August 2018

In August 2018, more than a dozen large wildfires burned during the dry season across California[18]. As temperatures rise and precipitation patterns become more unpredictable, the risk of wildfires is expected to increase.[19] Recent studies have found that the droughts of the last 15 years were "more intense than early- to mid-20th century droughts, with greater temperature and precipitation extremes," which could contribute to more severe fires.[20] In August 2018, one of the region's most severe wildfire on record erupted in Western Riverside County. The Holy Fire, a fast-moving brush fire burned in the Cleveland National Forest near Riverside County, forcing the Sycamore Creek[21] McVickers, Rice Canyon, Horsethief, Glen Eden, El Cariso Village, Sycamore and Rancho Capistrano, Trabuco and Holy Jim communities[22] to evacuate.

The fire grew up to 4,000 acres in the span of a single day,[23] burning through a total at 22,870 acres before being

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15 Riverside County Transportation Department, http://rctlma.org/trans/Road-Maintenance/Road-Closures
16 Riverside County Transportation Department, http://rctlma.org/trans/Road-Maintenance/Road-Closures
17 San Bernardino County, http://cms.sbcounty.gov/dpw/Operations/RoadClosures.aspx
18 http://cdfdata.fire.ca.gov/incidents/incidents_statsevents
19 Caltrans Climate Vulnerability Assessment, June 2019
20 Joseph Crockett, Leroy Westerling., "Greater Temperature and Precipitation Extremes Intensify Western Us Droughts, Wildfire Severity, and Sierra Nevada Tree Mortality," Journal of Climate 31(1):341-354. doi:10.1175/JCLI-D-17-0254.1 (2018), https://cloudfront.escholarship.org/dist/prd/content/qt3t39d8jq/qt3t39d8jq.pdf?t=osfbdf&v=lg
21 https://www.10news.com/news/holy-fire-grows-in-acreage-containment-on-day-six
22 https://www.nbclosangeles.com/news/local/Holy-jim-trail-Fire-Trabuco-Canyon-Brush-490189491.html August 6, 2018.
23 Ibid

contained[24] in October 2018.[25] The Holy Fire crossed over 17 miles of trails and 26 miles of roads[26], destroying 18 homes, and burned 6,000 feet of guardrail along California State Route (SR) 74, requiring the highway to remain closed indefinitely west of Lake Elsinore.[27]

Closures were enforced for the Holy Fire burned areas, some areas are still closed and are scheduled to open in September 2019.[28] Governor Jerry Brown declared a state of emergency on August 11, 2018 after six days of burning. [29]

Blue Cut Fire, Cajon Pass, San Bernardino County, 2016

There were many severe wildfires following the drought from 2011 to 2017, one of the most notable being the 2016 Blue Cut Fire in Cajon Pass. The Blue Cut Fire jumped I-15 in Caltrans District 8 and destroyed 105 homes, 213 other buildings, multiple vehicles, and pieces of highway infrastructure. The fire burned 36,274 acres off I-15 and Highway 138 north of San Bernardino, closing roads and eliminating access, before it was contained. Also in 2017, a brush fire on Highway 91 in Riverside County damaged the side slope, landscape area, and the metal beam guard rail.

The Resilient IE vulnerability assessments and climate-related transportation hazards and evacuation maps provide more information on expected future impacts to the transportation system of climate-related hazards.

2. LOCAL AND REGIONAL PLANNING AGENCY CHALLENGES AND SOLUTIONS

2.1 Funding

2.1.1 OVERVIEW

The constrained infrastructure funding environment can be a major challenge to implementing some climate resilient infrastructure strategies. Smaller jurisdictions may be at a disadvantage in securing funding via grants for resiliency studies/projects due to a combination of limited funding, staff availability, and expertise.

Fortunately, resiliency elements can often be incorporated into projects or maintenance activities that are already planned, without large cost increases. Also, some of the strategies discussed in this Guidebook do not require heavy capital investment. In cases where significant capital is needed, there are several sources of potential funding.

The transportation system is funded from a mix of different sources. The majority of transportation project funding in both Riverside and San Bernardino Counties comes from local and regional, rather than federal or State, funding sources.[30] In the SCAG region, local option sales tax measures are the single largest category of

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[24] USDA https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd594859.pdf
[25] USDA https://www.fs.usda.gov/detail/cleveland/home/?cid=FSEPRD590615
[26] BURNED-AREA REPORT USDA https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd594859.pdf
[27] https://www.pe.com/2013/08/06/lake-elsinore-damage-to-keep-ortega-highway-closed-indefinitely/
[28] USDA https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd594859.pdf
[29] https://abc7.com/gov-brown-declares-state-of-emergency-for-oc-ie-due-to-holy-fire/3919450/
[30] Source breakdowns are from the 2019 SCAG Federal Transportation Improvement Program (FTIP), which includes a comprehensive list of surface transportation projects that are subject to federally required action or that will receive federal funding over the next six years.

transportation revenues across local, State, and federal sources.[31] These voter-approved taxes include Riverside County's Measure A and San Bernardino County's Measure I.

2.1.2 LOCAL

The Riverside County Transportation Commission (RCTC) administers Measure A funding, which will continue to fund transportation improvements through 2039. Western Riverside County, which includes all WRCOG member jurisdictions, receives an allocation of Measure A funding for Local Streets and Roads.[32] These are distributed to cities and the County by a formula based 75 percent on proportionate population and 25 percent on revenues generated by Measure A. To be eligible for these funds, each jurisdiction must file a "Five-Year Capital Improvement Program", updated annually, with RCTC; participate in the Transportation Uniform Mitigation Fee (TUMF) program; and participate in the in the Multi-Species Habitat Conservation Plan (MSHCP). Jurisdictions could direct funding toward resilient strategies by showing how these strategies meet some of the Riverside County Transportation Improvement Plan's Goals and Objectives. Notably, the following Goals and Objectives may be strongly aligned with resiliency strategies:

- "…provide adequate transportation facilities to accommodate reasonable growth in the future": Providing adequate facilities for future growth requires that future changes in climate and weather are considered. Resilient strategies do this directly.
- "Provide funding for the adequate maintenance and improvement of local streets and roads…": Resilient strategies consider the full lifecycle costs of projects, including how changes in project design can reduce future operations and maintenance costs resulting from extreme weather and climate. Accounting for full lifecycle costs also helps meet the Accountability goals of the Plan.

The San Bernardino County Transportation Authority (SBCTA) administers Measure I funding based on the Measure I Strategic Plan.[33] Local jurisdictions receive allocations on a per capita basis and must annually adopt a Five-Year Capital Improvement Plan which details the specific projects to be funded using the measure.[34] The Strategic Plan focuses mostly on project delivery guidance. Resilient transportation strategies can help fulfill some of this guidance, particularly the cost containment strategies in the Strategic Plan. One of the cost containment strategies states that "project scopes should be tailored to create a balanced, cost-effective transportation system". This Strategic Plan cost containment strategy cites the Caltrans Highway Design Manual, including that "design standards used for any project should equal or exceed the minimum given in the Manual to the maximum extent feasible, considering costs (initial and life-cycle), traffic volumes, traffic and safety benefits, right-of-way, socio-economic and environmental impacts, maintenance, etc." By analyzing the impacts of climate impacts on facilities as described in this Guidebook, jurisdictions can help minimize the costs. This Guidebook also advocates design standards related to weather and climate that exceed minimum requirements when cost effective.

2.1.3 REGIONAL

The Southern California Association of Governments (SCAG) is the federally designated Metropolitan Planning Organization (MPO) and State designated Regional Transportation Planning Agency (RTPA), and a Council of

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In Riverside County, FTIP projects are funded 69% by local sources, 28% by state sources, and 3% by federal sources. In San Bernardino County, FTIP projects are funded 64% by local sources, 29% by state sources, and 7% by federal sources. scagrtpscs.net/Pages/FINAL2016RTPSCS.aspx.

[31] According to the FY 2016-2040 RTP/SCS Revenues (Table 6.4): http://scagrtpscs.net/Documents/2016/final/f2016RTPSCS_06_PayingForThePlan.pdf.

[32] https://www.rctc.org/wp-content/uploads/2018/07/Measure-a-expenditure-plan-ordinance.pdf

[33] www.gosbcta.com/plans-projects/funding-measureI.html

[34] http://www.gosbcta.com/plans-projects/funding/MeasureI/MeasureIStrategicPlan-Part1-rev0917.pdf

Governments for the six-county area that includes the WRCOG-SBCTA region. As one of its primary responsibilities, SCAG develops the Regional Transportation Plan/Sustainable Communities Strategy (RTP/SCS) that sets the long-range vision, goals, and strategies for the region's transportation system.

Aligning with the RTP/SCS goals and performance measures often helps local jurisdictions receive federal and State funding, and is sometimes an explicit evaluation criterion for grant funds (e.g., see SB 1 LPP description below). The 2016-2040 RTP/SCS states that "working to make our region more resilient to the inevitable consequence of future climate change is a major priority of this Plan, and it will continue to resonate in future updates as we head toward 2040 and well beyond."[35] Resiliency strategies can help meet several of the nine formal RTP/SCS goals, especially the "Preserve and ensure a sustainable regional transportation system" goal. The RTP/SCS does not yet have a climate resilience-specific performance measure, but the plan does indicate that the region will establish an existing conditions measure that captures the "breakdown of population by demographic group for areas impacted by substandard housing, sea level rise, and wildfire risk."

SCAG also provides technical support to local agencies through its Sustainable Communities Program (SCP), The SCP program focuses on the value of effective growth planning from local jurisdictions and the SCAG region overall. SCP technical assistance calls for applications are opened every two or three years. The amount of funding and specific funding pots within each category vary and must be in accordance with the current RTP/SCS. Technical assistance applications must have a nexus to at least one goal of the RTP/SCS.[36] SCAG strives to keep the awards small ($100K - $300K) to provide more awards to more jurisdictions. There is not yet a climate adaptation funding cycle; it will likely be several years before adaptation is a specific funding category in the technical assistance program.

WRCOG provides grant writing services to its member jurisdictions through their Grant Writing Assistance Program. This program provides technical assistance, matching member jurisdictions with professional grant writers. The program includes regular updates to a posted grants repository with available funding sources in a variety of categories, including transportation infrastructure. The repository listing includes grant deadlines, name of grant, sponsoring agency, source of funds, maximum funding, match requirements, and level of effort/difficulty to develop the grant application.[37] Interested WRCOG member agencies must review the program guidelines and submit an interest form and/or application to be considered for assistance.

2.1.4 STATE

There are several different funding sources available at the State level. This Guidebook will mention a few sources targeted for local governments rather than serve as a comprehensive review of the State funding landscape. The Road Repair and Accountability Act of 2017, referred to as SB 1, invests approximately $54 billion in the transportation system over the next decade, with half of these funds going to local agencies (cities, counties, and transit agencies). SB 1 requires funding recipients to address climate impacts: "To the extent deemed cost effective, and where feasible, in the context of both the project scope and the risk level for the asset due to global climate change, the department and cities and counties receiving funds under the program shall include features in the projects funded by the program to better adapt the asset to withstand the negative effects of climate change and make the asset more resilient to impacts such as fires, floods, and sea level rise." The strategies in

> "Cities and counties receiving [SB 1] funds…shall include features in the projects funded by the program to better adapt the asset to withstand the negative effects of climate change and make the asset more resilient to impacts such as fires, floods, and sea level rise." – SB 1

35 scagrtpscs.net/Documents/2016/final/f2016RTPSCS.pdf
36 Conversation with SCAG's Sustainability Department
37 WRCOG, http://www.wrcog.us/266/Grant-Writing-Assistance

this Guidebook can help jurisdictions meet this adaptation requirement.

SB 1 funded sources for local jurisdictions in the WRCOG-SBCTA region include, among others: [38]

- Local Streets and Roads Program (LSRP) formula funds for basic road maintenance, rehabilitation, and critical safety issues[39].
- Local Partnership Program (LPP) formula and competitive funds, available to agencies that have passed sales tax measures or developer fees, for road maintenance, rehabilitation, and other improvements[40]. Competitive program evaluation criteria particularly relevant for resiliency, include cost-effectiveness and consistency with the MPO Sustainable Communities Strategy, which in SCAG's case, explicitly calls for climate resiliency. Project nominations also need to describe and quantify benefits to disadvantaged communities and low-income areas; climate resilience strategies such as a cooling centers and multilingual evacuation notifications can benefit these populations.
- Solution for Congested Corridor Programs (SCCP) - The primary objective of the SCCP is to achieve a balanced set of transportation, environmental, and community access improvements within highly congested corridors throughout the state. Caltrans, regional transportation planning agencies, and county transportation commissions are eligible for the annually available $250 million. To be eligible, all projects must be included in an existing comprehensive corridor plan or regional transportation plan. The list of eligible project elements is expansive, and while not specifically tailored toward climate adaptation projects, the SCCP broadly encompasses projects that would be pursued to improve climate resilience.
- Transit & Intercity Rail Capital Program (TIRCP) - TIRCP is funded by appropriations from both SB-1 and Cap & Trade auction proceeds. The program funds capital improvements for the state's intercity, commuter, and urban rail systems, as well as improvements to bus and ferry transit systems statewide. One of the program's primary objectives is to fund "transformative projects," which serve to reduce greenhouse gas emissions through reducing congestion.
- Trade Corridor Enhancement Program (TCEP) - The TCEP offers roughly $300 million annually for infrastructure improvements on federally designated trade corridors of national and regional significance, on the primary freight network, and on other corridors that have a high volume of freight movement. Three of the core criteria for selection include: freight system factors (e.g., throughput), transportation system factors (e.g., safety and congestion reduction), and community impact factors (e.g., air quality, economic/job growth).
- Active Transportation Program (ATP) - The ATP was created by Senate Bill 99, and has been augmented by funding from SB-1 appropriations. The purpose to the ATP is to encourage increased use of active modes of transportation, such as walking and biking, increase safety and mobility for pedestrians, reduce greenhouse gas emissions, improve public health, and focus benefits toward disadvantaged communities. The 2019 ATP cycle consisted of three different components: a statewide and state administered component, a small urban & rural administered component, and a metropolitan planning organization component, meaning that ATP dollars are granted to each of these levels of government.
- State of Good Repair Program (SGR) - The purpose of SGR is to provide funding to support transit maintenance, rehabilitation, and capital projects. The program provides approximately $105 million annually to transit operators in California. The SGR program is intended to provide public value by improving transportation services by providing a sustainable source of funding to public agencies. While

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[38] http://rebuildingca.ca.gov/local-funding.html
[39] http://catc.ca.gov/programs/sb1/lsrp/
[40] http://catc.ca.gov/programs/sb1/lpp/

not specifically tailored toward addressing the impacts of climate change or mitigating greenhouse gas emissions, the SGR is a viable funding option for public transportation agencies to advance their core program.

- Affordable Housing and Sustainable Communities (AHSC) - Funded by cap and trade appropriations, AHSC provides funding to local governments, transportation and transit agencies, joint power authorities, schools, tribal governments, and housing developers to fund affordable housing development and transportation infrastructure. The goal of AHSC is to create cleaner and more livable cities by encouraging residents to opt for active modes of transportation. Eligible project elements include new transit vehicles, bike lanes, sidewalks, bus shelters, benches, and shade trees.

Aside from transportation-specific sources, jurisdictions can find support for resiliency strategies from other state agencies. One recently announced source is the California For All Emergency Preparedness Campaign Target County CBO Partners (ET) Program.[41] The program funds Community-Based Organizations (CBOs) to provide emergency preparedness training to vulnerable and diverse populations. Riverside and San Bernardino are both among the 6 counties targeted by this Program. Thus, while local jurisdictions would not apply for these funds directly, it could be a helpful supplement for the CBOs they work with and a way for these areas to improve the reach of their evacuation and other hazard planning.

2.1.5 FEDERAL

The Federal Highway Administration, Federal Transit Administration and other US DOT divisions administer most of the transportation funding at the federal level. Another notable potential source for resiliency-related projects are the Federal Emergency Management Agency (FEMA) Hazard Mitigation Assistance (HMA) grant programs. These include the Hazard Mitigation Grant Program (HMGP), Pre-Disaster Mitigation (PDM) program, and the Flood Mitigation Assistance (FMA) program. The first two programs are relevant for local transportation projects.[42] Local city and county governments are considered sub-applicants for HMGP and PDM grants and must apply through the State (Cal OES).

The purpose of HMGP is to help communities implement hazard mitigation measures following a "Presidential Major Disaster Declaration" in a region. It aims to enact mitigation measures that reduce the risk of loss of life and property from future disasters. Hazard mitigation includes long-term efforts to reduce the impact of future events. HMGP funds activities such as elevating structures, mitigating flood and drought conditions, and managing wildfire risk. Selection criteria includes, among others, conforming with approved State and local mitigation plans, demonstrating cost-effectiveness, and considering a range of alternatives. The general approach put forth in this Guidebook includes analyzing cost effectiveness over a project lifecycle and using a scenario-based approach to analyze different alternatives.

The PDM Grant Program provides resources to assist jurisdictions with a pre-disaster natural hazard mitigation program. PDM aligns with resilient system planning and investment in that "the goal is to reduce overall risk to the population and structures from future hazard events, while also reducing reliance on Federal funding in future disasters. This program awards planning and project grants and provides opportunities for raising public awareness about reducing future losses before disaster strikes. Mitigation planning is a key process used to break the cycle of disaster damage, reconstruction, and repeated damage." FEMA releases a fact sheet each year describing the Agency's priorities for the Program and funding criteria.[43]

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[41] https://www.caloes.ca.gov/pages/Grant-Details.aspx?itemID=277&ItemTitle=2018-19%20California%20For%20All%20Emergency%20Preparedness%20Campaign%20Target%20County%20CBO%20Partners%20(ET)%20Program%20RFP

[42] http://www.fema.gov/hazard-mitigation-grant-program

[43] https://www.fema.gov/pre-disaster-mitigation-grant-program

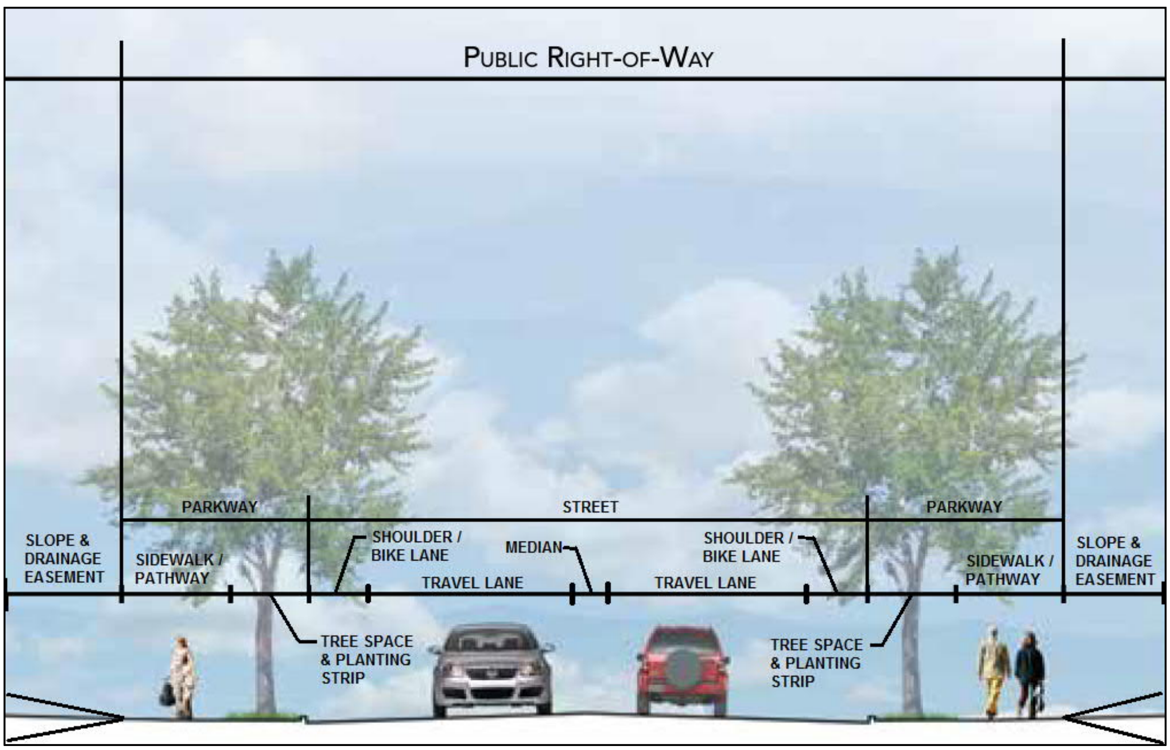
2.2 Site Design and Right-of-way

There are several site design and right-of-way related challenges to climate resilient infrastructure implementation including:

- Limited right-of-way.
- Potential changes to transportation patterns and modes of transportation.

Within the available public right-of-way there is limited surface and underground right-of-way area available to accommodate often competing needs for travel lanes, parking, bike lanes, pedestrian sidewalks/paths, and utilities. In constrained right-of-way areas, this often leads to limited availability for implementation of climate resilient infrastructure strategies.

Figure 3 - Typical Road Public Right-of-Way



Source: County of San Diego Green Infrastructure Guidelines, 2019.

Additionally, potential future changes to transportation patterns, modes of transportation, or utility needs may complicate current implementation of strategies that may need to shift or move to accommodate these future changes. For example, increased use of transit, ride share, or autonomous/automated vehicles may require reconfiguration of lanes to accommodate enhanced mobility, and installation of new utilities may conflict with functionality or area available for climate resilient strategy implementation.

Potential solutions to overcome these site design, road configuration, and right-of-way challenges are:

- Early strategy planning for right-of-way and utility setback/layouts and evaluation of compact development and street widths.
- Integration with complete streets and urban forestry concepts.
- Below ground stormwater capture and storage (structural soil, biofiltration soil storage).

- Inclusion of spare conduits for future utility and communication conduit construction to avoid street disruption or displacement of facilities.
- Use of off-site stormwater management facilities through an Alternative Compliance program.

WRCOG completed a study in 2016 to analyze the opportunities and constrains that new development and redevelopment projects confront to meet requirements for on-site control and dispersal of stormwater runoff. WRCOG evaluated the feasibility of developing a regional water quality mitigation program to meet regional Municipal Separate Storm Sewer System (MS4 Permit). WRCOG developed a step by step framework to provide tools for planning, financing, implementing, and operating off-site and regional stormwater management facilities to meet stormwater regulations where it is not feasible to fully meet these requirements within a development site. Use of these off-site stormwater facilities is allowed under the Alternative Compliance program in the MS4 Permit.[44]

2.3 Procedural Barriers

Another challenge to implementing climate resilient infrastructure strategies within the public right-of-way includes often conflicting jurisdiction regulations, codes, ordinances, and standards from various levels (local through Federal) due to differing priorities of various project elements. For example, often during design and implementation of stormwater Low Impact Development (LID) Best Management Practices (BMPs), site distance setbacks, tree spacing, and LID landscape requirements may have differing and conflicting requirements to meet code or to meet specific design requirements. Based on a study of removal of institutional barriers to LID adoption, "Several barriers have generally slowed and hampered greater LID adoption. Bureaucratic inertia involving the entrenchment of prevailing conventional practices, institutional structures, and regulatory shortfalls are the prime barriers preventing a broad shift in stormwater management philosophy. Of these, regulatory structure is the most critical barrier."[45] Additional complications also can occur near the public right-of-way boundary where non-congruent public land uses and maintenance requirements may hinder implementation or maintenance of strategies.

Potential solutions to overcome these policy barriers include the following:

- Discussions with jurisdictional plan check reviewers and Capital Improvement Plan implementation teams on past issues.
- Developing a matrix of development ordinances, regulations, standards, and policies impacting strategy implementation (e.g. tree spacing, utility corridor placement/setbacks) and then identify conflicts and required changes.
- Agency coordination meetings during project planning to identify and resolve design and implementation issues.
- Interdepartmental coordination and leadership at top levels of local government.[46]

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[44] Land Use, Transportation, and Water Quality Planning Framework, prepared for Southern California Association of Governments (SCAG) in partnership with WRCOG, March 2016.

[45] A Review of Low Impact Development Policies: Removing Institutional Barriers to Adoption, Commissioned and Sponsored by California State Water Resources Control Board Stormwater Program and the Water Board Academy, prepared by Low Impact Development Center, December 2007.

[46] Barriers to Low Impact Development. Prepared by the Local Government Commission for the Southern California Stormwater Monitoring Coalition, September, 2012. http://www.lgc.org/wordpress/docs/resources/water/barriers-low-impact-development.pdf

2.4 Community and Agency Outreach

Engaging with the local community, relevant agencies, and the private sector is both integral to the success of future projects and has the potential to provide creative inputs to the project development process. Not conducting community outreach and not holding community engagement opportunities could lead to future opposition to the project due to groups feeling marginalized and not included. Additionally, authentic outreach leads to a better-informed, locally appropriate project outcome. Community outreach and engagement should not be considered a formality in the project development process, but instead should strive to facilitate meaningful engagement with a broad swath of community members across the public and private sectors.

During the early stages of planning, it is important to engage with community groups and local agencies that may play a part in the project development or project success. For WRCOG/SBCTA it may be important to be in discussion with the Regional Water Quality Control Boards across Santa Ana, San Diego, and the Colorado River Basin, local municipal services departments, and relevant community-based organizations (CBOs).

Further, strategies for community engagement should be well-tailored toward the local context and inclusive of a diverse range of residents and community groups. Examples of inclusive strategies include producing multilingual outreach materials, hosting community engagement meetings at a variety of dates and times to appeal to a wider audience, and hosting community engagement meetings that are accessible by public transit services. California has a guide to community engagement for projects that address climate change and provides suggestions on engagement and information sharing strategies.[47]

In addressing climate risks and potential adaptation strategies, it is important to engage in specific dialogue with the community regarding increasing threats associated with a warming planet, as well as how those conditions may directly impact system facilities and/or users in the region. A meeting initiated to address this concern, and its inclusion in local planning/response efforts could include the following elements:

[47] https://www.ca-ilg.org/sites/main/files/file-attachments/cc_and_public_participation.pdf

1. Climate Change and Changing Conditions in Our Community – An Overview
    a. Review summary material from CalAdapt on projected temperature, precipitation and wildfire risks in the region
    b. Discuss local community perspectives/experiences with climactic effects
        i. Temperature
        ii. Precipitation
        iii. Landslide
        iv. Wildfires
2. Risks in Our Community
    a. Review GIS data of locations where flooding, landslides, and/or wildfires may increase
    b. Outline how increasing temperatures may increase and what the effects may be to the region
        i. Impacts to transit riders
        ii. Impacts to roadway facility design
    c. Discuss consequences if facilities were to be impacted
        i. Safety
        ii. Health
        iii. Loss of Access
        iv. Additional Travel Costs
3. Opportunities to Adapt
    a. Discuss optional design responses possible in areas with noted risks and or traveler impacts
4. Incorporating Risk and Climate Change into Facility Decision-Making and Investments
    a. Outline the basic processes
    b. Discuss implementation in the region

3. CLIMATE RESILIENT TRANSPORTATION INFRASTRUCTURE STRATEGIES

The following chapter discusses different transportation infrastructure strategies and ancillary measures that are applicable for the WRCOG/SBCTA region. Each strategy includes a description and discussion of applicability and constraints. The icons presented in Table 1 indicate the hazard types the strategies address and the climate types where the strategy can be applied.

Table 1. Hazard and Climate Type Icons

Hazard Type	Extreme Heat	Extreme Cold	Wildfire	Severe Storms/ Flooding
Climate Type	Valley	Mountain	Desert	

Table 2 provides a summary of the strategies discussed in Section 3.1 below.

Table 2. Climate Resilient Infrastructure Strategies

Category	Strategy	Hazard Type(s)	Climate Type(s)
General	Understand and Address Consequences of Exceeded Design Events Exceeded		
Drainage, Wildlife and Multi-Use Crossing Infrastructure Design	Adjust Discharge Projections Based on Confidence Interval and/or Future Precipitation Projections		
	Appropriately Size Culverts for Burned and Bulked Flows		
	Choose Appropriate Drainage Material for Wildfire Prone Areas		
	Remove Post-Wildfire Debris		
	Prevent Bridge Scour		

Category	Strategy	Hazard Type(s)	Climate Type(s)
Ground Cover	Install Tree Wells		
	Install Bioretention Areas and Swales		
Roadway	Adjust Asphalt Binder Grade Based on Future Temperature Projections		
	Install Permeable Pavement		
Transit	Install Shade Protection at Transit Stops		
	Examine Temperature Trends and Projections and Maintain Rail Accordingly		
Key Facilities	Provide Defensible Space around Critical Assets		
	Offer Cooling Centers		
Evacuation Planning and Emergency Response	Enhance Emergency Response Planning and Practice for Hazard Events		
	Designate Evacuation Plan and Routes		
	Implement Transportation Design Strategies for Evacuation Routes		
	Implement Transportation Operations Strategies for Evacuation Events		
Additional Strategies	Implement Land Use Planning Strategies along the Transportation Corridor		
	Implement Site Design Principles		

3.1 General

3.1.1 UNDERSTAND AND ADDRESS CONSEQUENCES OF EXCEEDED DESIGN EVENTS

Transportation assets are typically designed to withstand certain design events. A design event defines (as an estimate) the probability or frequency of recurrence of a particular design parameter, such as a storm event within a range of severity or seismic event under a certain magnitude. In this example, the storm severity or earthquake magnitude range is selected for design based on its probability of exceedance or average recurrence interval. The design event is typically selected based on the risk tolerance for the facility, established by general agency policy. Design events can be exceeded over the service lives of these assets, given the uncertainties inherent in estimation techniques, changing land use patterns, etc. Given statistical probabilities alone there is a 63% chance that at least one 100-year event occurs over a 100-year service life. Table 3 shows different probabilities of occurrence based on different service life lengths and event recurrence intervals.

Table 3. Probability of Extreme Event Occurrence by Service Life and Recurrence Interval

Length of Service (years)	Frequency – Recurrence Interval				
	10-year	25-year	50-year	100-year	500-year
1	10%	4%	2%	1%	0.2%
10	65%	34%	18%	10%	2%
25	93%	64%	40%	22%	5%
50	99%	87%	65%	39%	10%
75	100%	95%	78%	53%	14%
100	100%	98%	87%	63%	18%

Source: FHWA HEC-17 Table 6.2

It is important for practitioners to understand the consequences of when an asset's design events are exceeded. This includes information about what magnitudes of hazards could substantially affect an asset. Magnitude, in this case, could refer to a flood elevation, discharge rate, temperature threshold, etc. It also includes information about how the asset itself could be affected, outlining such information as asset disruption - estimating timing and asset damage to include estimated extent and repair costs. This information can be documented so that staff involved with managing the asset over its lifecycle are aware of, and can plan for, these consequences. Ideally, if this understanding of consequences is established during the design process, an asset can be designed to minimize excessive damage and disruption costs of instances when design events are exceeded. Through this approach, an asset's design can also take uncertainties inherent in current design inputs, such as climate conditions, into consideration.

"Designing for resilient performance and behavior under adverse conditions does not imply designing for larger discharges ... Resilience implies understanding what happens when events occur that are other than the design flow." – FHWA HEC-17

Some design standards require analyzing a check event, which refers to an event that exceeds the design event.[48] This forces the designer to look at consequences of instances when the design event is exceeded. One simple way to implement this adaptation strategy is to require that designs use check events to determine broader impacts of certain events and enable a dialogue on risk when considering possible consequences. However, a more comprehensive analysis, beyond just the analysis of a single design event and a single check event, may be warranted given the expected changes associated with climate change.

Transportation managers should also require designers to provide the results of these risk/consequence analyses so that the information can be available to inform decisions regarding future operations and maintenance.

This strategy of assessing consequences as a part of design efforts can apply to all areas within the WRCOG/SBCTA region. While in the past it has traditionally been employed for addressing flood hazards, it is a useful strategy for other hazards of concern (e.g. wildfire, landslide, etc.).

[48] For example, see https://flh.fhwa.dot.gov/resources/design/pddm/Chapter_07.pdf

3.2 Drainage, Wildlife and Multi-Use Crossing Infrastructure

3.2.1 ADJUST DISCHARGE PROJECTIONS BASED ON CONFIDENCE INTERVALS AND/OR FUTURE PRECIPITATION PROJECTIONS

Bridges, culverts, and drainage infrastructure are designed based on assumptions of the hydrology of the natural environments that they interact with. Typically, these assumptions are based on past observations of precipitation, runoff, and discharge (e.g., streamflow) rates.

Existing practice often involves designing to discharge rates that are developed using historical discharge rates. Historical discharge rates can be observed directly, or they can be estimated using, among other factors, historical precipitation observations across a watershed that drains into an asset's location. NOAA Atlas 14 is a commonly used source for estimates of gridded precipitation rates organized by duration and frequency. These can be downloaded at NOAA's Precipitation Frequency Data Server.[49]

However, if precipitation patterns change, or even if historical estimates contain errors, then assets can be under-designed; that is, they fail to meet their normal design standards. As a minimum adaptive design strategy, practitioners can and should use confidence limits of historical precipitation or discharge rates, to help account for this issue. NOAA Atlas 14 provides these confidence limits in documentation typically applied by design engineers.

Furthermore, practitioners can analyze projected future precipitation patterns during design. These projections can be obtained from downscaled global climate data like the LOCA (Locally Constructed Analogues) Data generated by the Scripps Institution of Oceanography[50] to assess changes in projected precipitation patterns to adjust the discharge rates used in design criteria and hydraulic analysis. Ideally, these future projections should also include confidence intervals to help account for uncertainty in the projections. The Cal-Adapt tool provides downloadable projected extreme precipitation values and confidence intervals for different locations across California.[51]

The FHWA Hydraulic Engineering Circular No. 17, 2nd Edition (HEC-17), entitled Highways in the River Environment – Floodplains, Extreme Events, Risk, and Resilience, is a helpful reference for applying these methods.[52] Chapter 7, discusses different levels of discharge analysis with step-by-step guidance for each level. The levels, ranging from less to more analytically intensive are:

- Level 1: Use historical discharges and analyze future changes qualitatively
- Level 2: Use historical discharges with confidence limits and analyze future changes qualitatively
- Level 3: Use historical discharges with confidence limits and quantitative future precipitation projections
- Level 4: Use projected discharges with confidence limits

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49 https://hdsc.nws.noaa.gov/hdsc/pfds/
50 http://loca.ucsd.edu/
51 http://cal-adapt.org/tools/extreme-precipitation/
52 https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=16&id=162

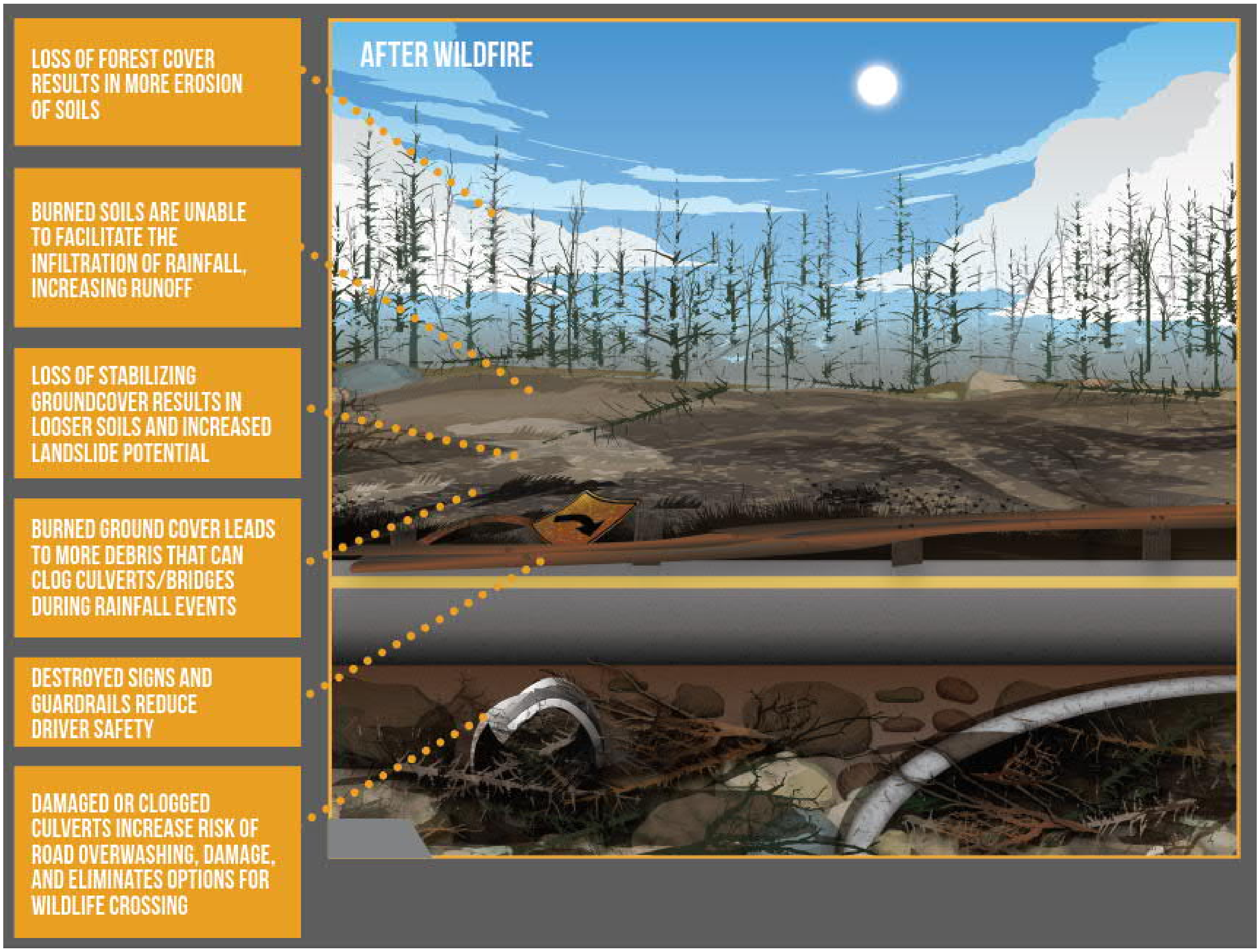
- Level 5: Use projected discharges with confidence limits and expanded evaluations, such as custom site-specific projections in land use and climate

This strategy can apply to all areas within the WRCOG/SBCTA region that are exposed to flood risks. One potential strategy constraint is limited capacity to apply novel or different methodologies due to limited resources and training. Another is that, in cases where design discharges increase, there may be an increased capital cost of infrastructure, despite potential savings in operations and maintenance costs over the service lives of these assets.

3.2.2 APPROPRIATELY SIZE CULVERTS FOR BURNED AND BULKED FLOWS

Debris flows can clog culverts and flood roads threatening the transportation system, particularly following wildfires, (FHWA, 2017). Fires impact a watershed in several ways, one of which is the potential to produce sediment/debris flows. The sediment/debris flows are caused by surface erosion from rainfall runoff and land sliding due to rainfall infiltration into the soil. Fires generally reduce the infiltration and storage capacity of soils, which increases runoff and erosion (Caltrans HDM). The behavior of flood flows varies depending on the concentration of sediment in the mixed flow. Mass movement of rock, debris and soil is the main source of 'bulked' flows. These 'bulked' flows may result in volumes of runoff and debris that overwhelm the design capacity of a roadway culvert if it has not been properly sized or designed to accommodate the 'bulked' flows. Bulking factors are applied to peak (clear water) flow rates to obtain a total or bulked peak flow which provides a safety factor in the sizing of culverts.

Figure 4 - Post Wildfire Schematic



Source: Caltrans Climate Change Vulnerability Assessment Summary Report, District 8, 2019

Both the Riverside County Hydrology Manual[53] (Section F) and the San Bernardino County Detention Basin Design Criteria[54] reference the United States Army Corps of Engineers' (USACE) Method (Tatum Method)[55] for determining bulked flows for use in appropriately sizing detention basins, debris basins, and culverts. The Riverside County Hydrology Manual also references use of the Los Angeles County Department of Public Works (LADPW) Flood Control District Method[56] for determining single storm event debris production and bulking factor rates.

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53 Riverside County Hydrology Manual, http://rcflood.org/downloads/Manuals/Hydrology-Manual-20180814.pdf
54 San Bernardino County Detention Basin Design Criteria, http://www.sbcounty.gov/Uploads/lus/PW/DETENTIONBASINDESIGN.pdf
55 USACE, "A New Method of Estimating Debris-Storage Requirements for Debris Basins," 1963.
56 Los Angeles County Department of Public Works, "Sedimentation Manual," 2006.
https://dpw.lacounty.gov/wrd/publication/engineering/2006_sedimentation_manual/Sedimentation%20Manual-Second%20Edition.pdf

There are two general methods for accommodating debris: 1) passing debris through the culvert, or 2) upstream interception. Engineered mitigation strategies for increases in stormwater volume and peak flows due to debris include:

- Design of new culverts using appropriate bulking factor.
- Retrofit of existing culvert capacity through enhanced inlet design.
- Increasing existing culvert capacity through replacement or addition of a culvert barrel(s).).
- Construction of sediment/debris capture mechanism at, or upstream of, the culvert entrance (inlet riser pipe, desilting/debris basin).

Appendix F of the LADPW Sedimentation Manual provides guidance on the design of closed conduits carrying bulked flow. To adequately determine methods for debris control, an evaluation of the characteristics of debris within flood flows must be made. An assessment of potential damage due to debris clogging, if protection is not provided, should be performed prior to design, considering potential for drainage basin susceptibility to wildfire and debris production. The FHWA Hydraulic Engineering Circular No. 9, "Debris-Control Structures"[57], shows types of debris control structures and provides a guide for selecting the type of structure suitable for various debris classifications. A thorough investigation of upstream and downstream conditions is often required to reveal what adverse effects there may be with increasing the capacity or velocity of existing cross drainage. Additionally, direct or indirect removal of sediment from flows may increase the potential for scour downstream of culverts.

This strategy can be used in parallel with the preceding strategy (Adjust Discharges Based on Confidence Intervals and/or Future Precipitation Projections) to better account for the risks/uncertainty inherent in climate change. It can apply to all areas within watersheds that are exposed to wildfires. Capital funding for retrofitting existing infrastructure can be a strategy constraint, though, like the preceding strategy, long-term savings in maintenance and disruption costs can make this strategy worthwhile. It is most straightforward to apply this strategy when new culverts are already being designed and installed, as marginal costs are likely to be relatively limited compared to the overall project.

3.2.3 CHOOSE APPROPRIATE DRAINAGE MATERIAL FOR WILDFIRE PRONE AREAS

In wildfire prone areas, selection of the materials used for storm drain and culvert construction is critical. Use of fire-resistant materials such as reinforced concrete pipe and steel should be specified in wildfire prone areas. Consideration should be given to replacement of existing plastic culvert pipe inlet structures (plastic flared end sections) with concrete headwalls in wildfire prone areas. This strategy applies to all areas susceptible to wildfires.

[57] FHWA, Debris Control Structures, Evaluation and Countermeasures, Third Edition, 2005. https://www.fhwa.dot.gov/engineering/hydraulics/pubs/04016/hec09.pdf

Figure 5 - Metal Pipe and Concrete Headwall Post-Fire

Source: Caltrans Climate Change Vulnerability Assessment Summary Report, District 8, 2019

3.2.4 REMOVE POST-WILDFIRE DEBRIS

Post-wildfire debris removal is a longer-term recovery strategy to reduce the severity of post-fire flooding events, which can be exacerbated by post-wildfire debris flows. This strategy encourages longer-term removal of potentially dangerous debris following a wildfire event to defend transportation assets. While often implemented outside the transportation right-of-way, transportation managers can be involved in implementation to help prevent system impacts.

Reduced vegetation following a wildfire can serve to increase the velocity of flooding events, and further, post-wildfire debris that have not be removed may cause damage to life and property by stripping vegetation in its path, exerting greater pressure and force onto key assets and property, damaging infrastructure, and clogging drainage infrastructure, bridges, and culverts.[58] Additionally, wildfires destabilize hillslopes and weaken tree roots, decreasing the stabilization of vegetation rooted in these areas over time.[59]

58 https://ca.water.usgs.gov/wildfires/wildfires-debris-flow.html
59 https://link.springer.com/article/10.1186/s40677-018-0099-z

Key actions for post-wildfire debris removal include:

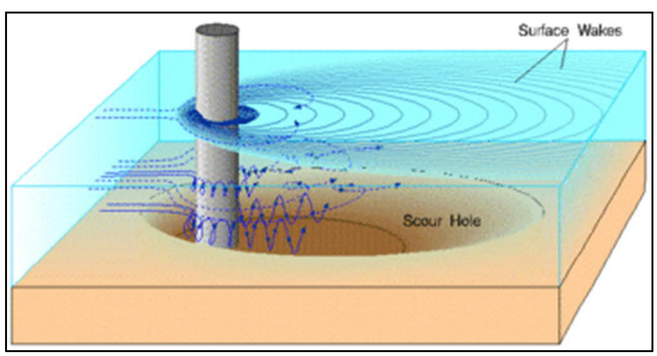
- Employing best-available monitoring and data collection to identify areas susceptible to future debris flows.
- Employing best-available data to predict future debris flows.
- Establishing and continuing to maintain barriers, such as riprap, in areas determined to be susceptible to future debris flows.
- Reforesting immediately following a wildfire event.
- Utilizing Cal Recycle and California Environmental Protection Agency guidance to properly transport and dispose of debris.[60]

The post-wildfire debris removal strategy can be applied in all areas of the WRCOG/SBCTA region prone to wildfire, particularly the mountainous and forested environments. One challenge associated with this action is the need to continuously be vigilant with monitoring and removing post-wildfire debris. Areas may need to be monitored for years after an event. Furthermore, coordination with property owners and other stakeholders is often required for implementation.

3.2.5 PREVENT BRIDGE SCOUR

Bridge scour is the removal of sediment such as sand and gravel from around bridge abutments or piers. Scour, caused by swiftly moving water, can scoop out scour holes, compromising the integrity of a structure. Bridges over waterways should be evaluated to determine their vulnerability to scour and, if needed, design phase mitigations or in-place scour countermeasures for protection. Except for bridges across lined or hardened channels, most waterways can be expected to experience scour over a bridge's design life. From a climate resiliency standpoint, original design considerations (i.e. – design storm assumptions) may change over the bridge design life due to climatic change (more precipitation) and associated changes in the magnitude and frequency of large runoff events, as well as watershed condition changes after a wildfire.

Figure 6 - Bridge Scour Examples (Source: FHWA)



Per FHWA, the added cost of making a bridge less vulnerable to scour is small when compared to that of the total cost of failure, which can be two to three times the original cost of the bridge.[61] FHWA recommends that scour evaluations be conducted for new and existing bridges by an interdisciplinary team of hydraulic, geotechnical, and structural engineers to provide guidance for the design of new bridges and existing bridges. Potential changes in watershed or climatic conditions should also be considered when evaluating bridge scour potential. Bridges with scourable beds should withstand the effects

[60] https://www.calrecycle.ca.gov/disaster/wildfires
[61] FHWA, https://www.fhwa.dot.gov/engineering/hydraulics/policymemo/t514023.cfm

of scour from a superflood (a flood exceeding the 100-year flood) without failing, and all existing bridges should be evaluated for the risk of failure from scour during the occurrence of a superflood on the order of magnitude of a 500-year flood. A plan of action should be developed for existing bridges determined to be scour critical. The following FHWA design documents are used for the scour analysis and countermeasure design for bridges:

- FHWA Hydraulic Engineering Circular (HEC) 18: Evaluating Scour at Bridges[62]
- FHWA HEC-23: Bridge Scour and Stream Instability Countermeasures Experience, Selection and Design Guidance[63]

Additionally, the design of new bridge projects should be evaluated using the following references from FHWA for design considerations and channel stability assessments[64]:

- FHWA Hydraulic Engineering Circular No. 14, Hydraulic Design of Energy Dissipators for Culverts and Channels[65]
- FHWA Publication No. FHWA-HRT-05-072, Assessing Stream Channel Stability at Bridges in Physiographic Regions[66]

This strategy applies to riverine environments in the region. Capital costs are a strategy constraint.

3.3 Ground Cover

Ground cover plays an important role in making transportation systems more resilient to impacts. Depending on the climate, ground cover should consist of native and drought tolerant plant types, be resilient in extreme heat (and cold, depending on the region), provide shade protection (in the case of trees), and/or provide erosion control protection for flooding events.

For enhanced climate resiliency, Low Impact Development (LID), stormwater quantity and quality treatment control perspectives tree wells, bio-infiltration, bioretention/biofiltration areas and swales are typical strategies that can be implemented within various locations within the roadway right-of-way and employ native/drought tolerant plants, mulch, or rock cover. These features are typically included under Green Infrastructure (GI) strategies. GI captures rainfall, cools buildings and pavement, and creates natural pathways for wildlife. GI includes LID techniques, which mimic nature to capture and treat stormwater as close to the source as possible. When implemented, GI creates living green streets that capture, store, and infiltrate stormwater to treat it as a resource and improve the local and regional environment. These elements are described in more detail below. Local or regional water efficient and fire-resistant landscape guidance documents may be utilized for selection of appropriate vegetation such as the Riverside County Transportation and Land Management Agency's Comprehensive Landscape Guidelines and Standards, and the Riverside County Guide to California Friendly Landscaping.

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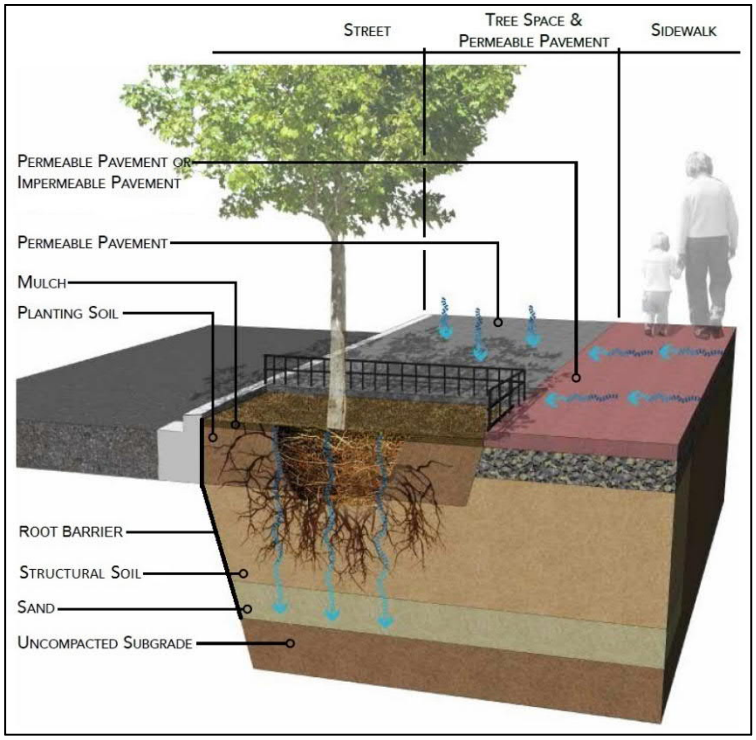
62 FHWA HEC-18, https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=17&id=151
63 FHWA HEC-13, https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=23&id=142
64 County of Riverside, Low Impact Development: Guidance and Standards for Transportation Projects for the Santa Ana Region County Co-Permittees, http://rcflood.org/downloads/NPDES/Documents/SA_WQMP/EXHIBIT%20D.pdf
65 FHWA HEC-14, http://www.fhwa.dot.gov/engineering/hydraulics/pubs/06086/hec14.pdf
66 FHWA, http://www.fhwa.dot.gov/publications/research/infrastructure/hydraulics/050 72/05072.pdf

3.3.1 INSTALL TREE WELLS

Trees are a powerful resiliency and green streets tool due to their ability to intercept water on leaves, slowly deliver it to the mulch and soil, absorb it through root systems, and transpire it as water vapor directly back to the atmosphere. Trees make a streetscape feel welcoming, help manage stormwater, and reduce the urban heat island effect by providing shade. Trees improve air quality, natural habitat, the human environment, and well-being. Tree planting in wildfire prone areas, and along designated evacuation routes should consider defensible space setbacks from buildings and critical assets (See Section 3.6.1 for discussion on defensible space).

Figure 7 - Tree Well



Source: County of San Diego Green Infrastructure Guidelines, 2019

This strategy is applicable in areas where trees are found, typically anywhere aside from desert or chaparral biomes. A potential constraint is that trees in a congested right-of-way are confined to small planting areas where they struggle to reach a mature size or live a long life. Using Structural Soil, Structural Cell, or Suspended Sidewalk techniques, soil volumes and space for tree roots to grow uninhibited can be greatly increased. These techniques also allow for more water and air to reach the tree roots. Surface and subsurface features near a tree well can include the following:

- Permeable Paver: Permeable pavers allow water to infiltrate into the soil to be used by the trees.
- Mulch: Shredded hardwood layer to retain water and trap pollutants.
- Planting Soil: Un-compacted soil mix allows root growth when used in open areas, with structural cells, or suspended sidewalks.
- Structural Soil: Supports pavement and allows root growth.
- Sand: Acts as a drainage layer for excess stormwater (when needed).
- Un-compacted Subgrade: Existing soil where stormwater may infiltrate.

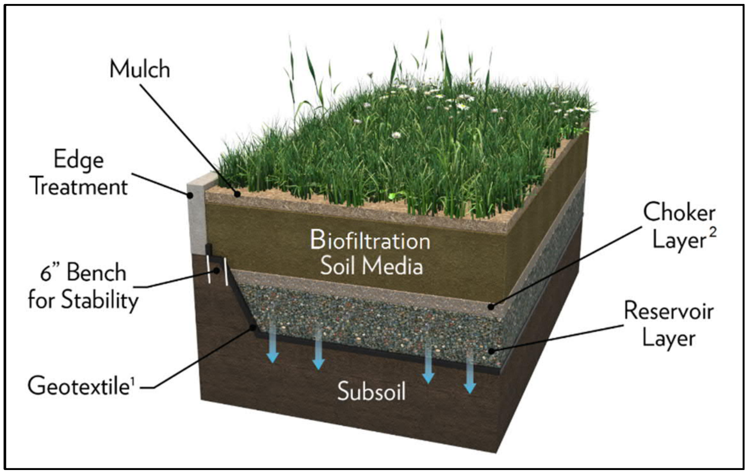
3.3.2 INSTALL BIORETENTION AREAS AND SWALES

Bio-infiltration, bioretention, and biofiltration areas and swales use the natural functions of plants, mulch, and soils to remove pollutants and slow stormwater runoff. The strategy uses storage, sediment capture, and biological processes to clean the water. These mimic processes that occur in nature before water reaches waterways. The rainwater is held in the planting bed until it infiltrates into the ground or evaporates. The entire system can fit into small spaces, making it adaptable to tree spaces along the road, planter boxes, curb extensions, medians, roundabouts, and open areas.

Typical ground cover and subsurface components of a bioretention area and swales include:

- Mulch: Shredded hardwood layer to retain water and trap pollutants.
- Biofiltration Soil Media: A specific blend of soil, compost, and sand to retain and drain water and support plant growth.
- Choker Layer: Sand and gravel to prevent engineered soil media from migrating into the reservoir.
- Reservoir Layer: Stone to hold excess water until it infiltrates.
- Geotextile: Prevents existing soil from migrating into the engineered soil media and stone reservoir layer.
- Underdrain (where needed).).
- Un-compacted Subgrade: Existing soil where stormwater infiltrates.

Figure 8 - Bioretention Section



Source: County of San Diego Green Infrastructure Guidelines, 2019

This strategy is applicable in areas that are prone to flooding events. One constraint is that implementation is often needed in tandem with traditional gray infrastructure to fully address flood risks.

3.4 Roadway

3.4.1 ADJUST ASPHALT BINDER GRADE BASED ON FUTURE TEMPERATURE PROJECTIONS

Roadway pavement can be either concrete or asphalt mix, with the choice dependent on various conditions. One element of asphalt pavement design is the selection of the pavement binder, which ties together the aggregate materials in asphalt. Selecting the appropriate and recommended pavement binder is dependent, in part, on both high and low temperature. At the State level, Caltrans uses two specific parameters:[67]

- Low temperature – The mean of the absolute minimum air temperatures expected over a pavement's design life.
- High temperature – The mean of the average maximum temperatures over seven consecutive days.

Figure 9 - Freeze & Thaw Impacts on Pavement

Binders must be selected so that pavement integrity is maintained under both extreme cold conditions (which leads to contraction) and high heat (which leads to expansion). The American Association of State Highway and Transportation Officials (AASHTO) provides further guidance on how temperature can be incorporated into pavement design.[68] FHWA's LTPPBind tool helps agencies investigate binder grades based on climate inputs.[69]

With higher expected temperatures in the study region, practitioners can adjust the asphalt binder grades based on observed changes in temperature and on forecasted future changes in temperature over the expected service life of the asphalt. The temperature-related metrics that serve as inputs for binder grade selection can be identified. They can then be updated based on these observed and expected changes in those metrics over time.

Figure 10 - High Temperature Impacts on Pavement

This strategy can apply to all areas within the WRCOG/SBCTA region. One constraint of this strategy is that it can be relatively costly to use higher quality asphalt binder, however, as with pervious strategies, implementing the

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67 Caltrans Climate Change Vulnerability Assessment, http://www.dot.ca.gov/transplanning/ocp/vulnerability-assessment.html
68 AASHTO Mechanistic-Empirical Pavement Design Guide, https://fenix.tecnico.ulisboa.pt/downloadFile/563568428712666/AASHTO08.pdf
69 FHWA LTPPBind Online, https://infopave.fhwa.dot.gov/Tools/LTPPBindOnline

strategy can also reduce maintenance costs overtime.

3.4.2 INSTALL PERMEABLE PAVEMENT

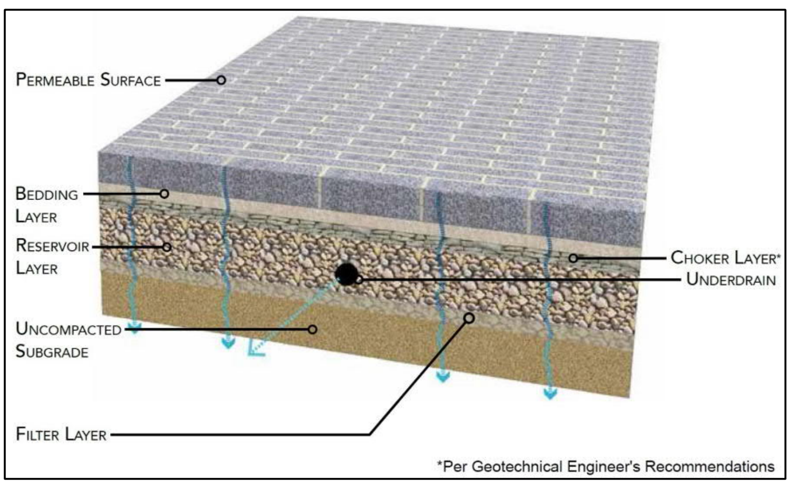
Permeable pavements refer to concrete or asphalt pavements composed with materials that make them relatively pervious to water. By capturing stormwater that would otherwise flow across road surfaces, permeable pavements can reduce peak flows, lessen the strain on drainage systems, and recharge groundwater, where it can be filtered naturally by the soil.[70]

Most pervious concrete and porous asphalt pavements are used to manage stormwater in “low-traffic, low-speed applications, such as shoulders or parking lots”, though there is research underway for higher load applications. They tend to have higher initial cost compared to the traditional impermeable alternatives. Permeable pavements also need to be regularly maintained so that they remain pervious. That said, permeable pavements can save on costs of conveying and treating stormwater.

The Caltrans Pervious Pavement Design Guidance provides more detail on permeable pavements and their use cases.[71]

This strategy can be applied to relatively low traffic roads in the WRCOG/SBCTA region that experience high stormwater runoff.

Figure 11 - Permeable Pavement (Source: County San Diego, 2019)



Source: County of San Diego Green Infrastructure Guidelines, 2019

70 FHWA Toward Sustainable Pavement Systems: A Reference Document (Chapter 6), https://www.fhwa.dot.gov/pavement/sustainability/hif15002/chapters/hif15002_06.pdfhttps://www.fhwa.dot.gov/pavement/sustainability/hif15002/chapters/hif15002_06.pdf

71 Caltrans Pervious Pavement Design Guidance, https://dot.ca.gov/programs/design/hydraulics-stormwater

3.5 Transit

3.5.1 INSTALL SHADE PROTECTION AT TRANSIT STOPS

Shade protection at transit stops is an architectural strategy transportation planners can utilize to improve conditions for riders and accessibility to transit stops in extreme heat, exacerbated by the urban heat island effect.[72] Shade protection allows pedestrians to remain cooler while waiting for and transferring between transit services. Shade protection can be implemented at the transit stop and along nearby walkways that transit riders rely on to access transit services. Shade protection at transit stops can be paired with efforts to increase the availability of technology innovations, such as electric vehicle (EV) charging stations. Figure 12 displays an example of a shaded transit stop in Santa Monica, CA.

Figure 12 - Shaded Transit Stop, Big Blue Bus, Santa Monica, CA

Several actions can be taken to improve shade protection at transit stops, including:[73]

- Building shaded canopies at transit stops
- Planting trees at and surrounding transit stops
- Developing a list of canopy trees adapted to future climate conditions
- Developing and incentivizing tree-shading ordinances for transit stops
- Referring to Caltrans' Complete Streets toolbox and guidance[74]

Shade protection at transit stops can be adopted in all areas of the WRCOG/SBCTA region. One of the limitations of the efficacy of this strategy is that riders might have to travel long distances to access transit throughout the WRCOG/SBCTA region, which means that providing shade in concentrated areas might not do much in the way of reducing the impacts of extreme heat for riders.

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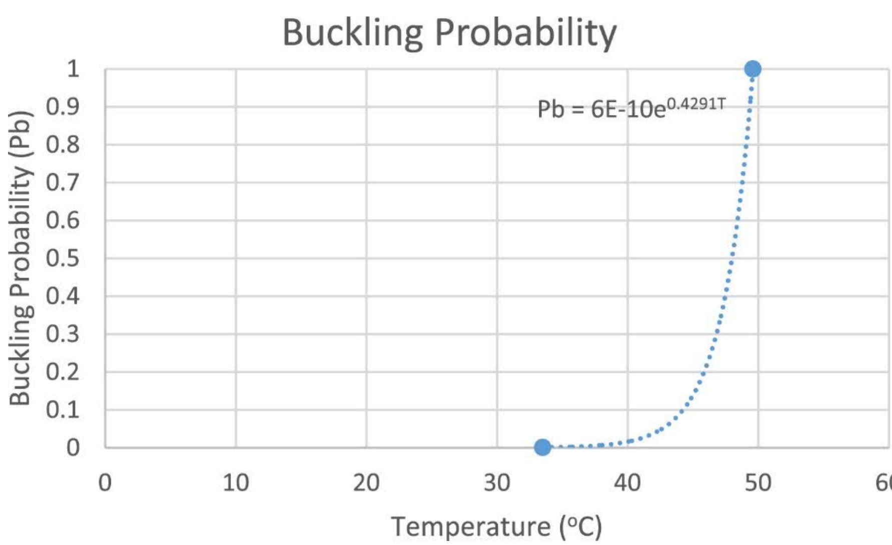
72 http://arccacalifornia.org/roadmap-to-resilience/
73 http://arccacalifornia.org/roadmap-to-resilience/
74 http://www.dot.ca.gov/transplanning/ocp/docs/Complete-Streets-Elements-Toolbox.pdf; http://www.dot.ca.gov/pd/pdq/2018_PDQ_Summer_CompStreet.pdf

3.5.2 EXAMINE TEMPERATURE TRENDS AND PROJECTIONS AND MAINTAIN RAIL ACCORDINGLY

Examining temperature trends and projections and maintaining rail accordingly is a long-term strategy that transportation agencies can employ in response to the impacts of climate change. This strategy requires an acute understanding of the rail system and rail engineering.

Figure 13 - Relationship Between Temperature and Probability of Rail Buckling



Climate induced changing temperature trends can put stress on railways that may cause track buckling.[75] Rail is at risk of buckling when rail experiences prolonged exposure to temperatures at or below the zero-stress temperature (ZST)[76], which is the temperature at which the rail is not under stress and can maintain its integrity. Prolonged exposure to temperatures above or below the ZST places stress on the rails, causing the rail to contract or expand. Under high temperatures when the rail over expands, it is prone to buckling. Figure 13 depicts the generalized relationship between temperature and the probability of rail buckling.[77] It is important to note that ZST thresholds are not universal and contingent on the type of rail. Further, ZST for a certain type of rail can change and be re-set over the lifetime of the rail.

Rail buckling can result in either delays in service or derailments, which are expensive. From 2005 to 2013, there were 249 Federal Railroad Administration (FRA)-reportable derailments which cumulatively cost roughly $84 million in damages.[78] Deploying strategies to effectively examine temperature trends and projections can be a way to appropriately monitor stress to rail assets, which can help inform safe decision-making.

Setting up an effective rail temperature monitoring program is the first step in defending against rail buckling along transportation assets. When there is sufficient data established to inform decision-making, several strategies can be employed to defend against rail buckling and subsequent derailments, which include both short term and long-term strategies listed below.

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[75] https://www.arema.org/files/library/2013_Conference_Proceedings/Best_Practice_Guidelines_for_CWR_Neutral_Temperature_Management.pdf
[76] Also referred to as Neutral Rail Temperature (NRT) and Rail Neutral Temperature (RNT)
[77] https://www.sciencedirect.com/science/article/pii/S0967070X16308198
[78] https://www.arema.org/files/library/2014_Conference_Proceedings/Rail_Temperature_Prediction_Model_as_Tool_to_Issue_Advance_Heat_Slow_Orders.pdf

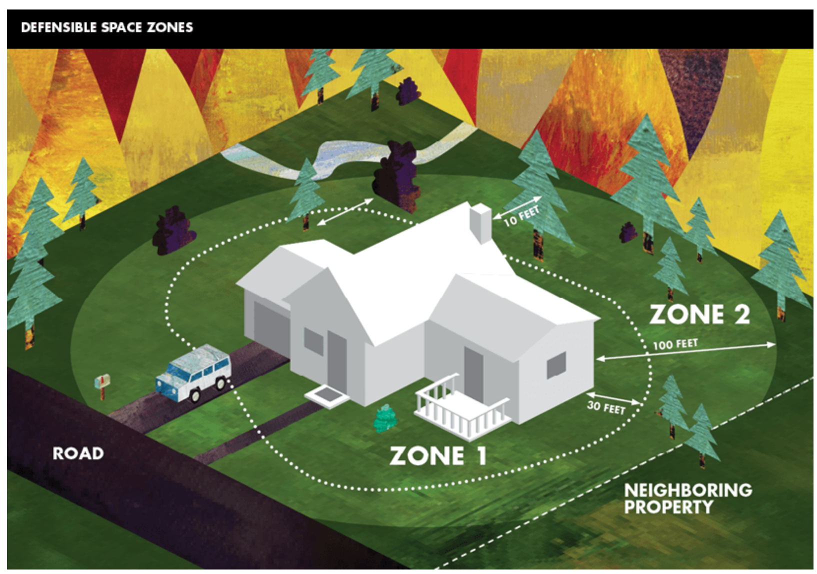
- Short-term strategies:
  - Monitor, record, and evaluate rail integrity
  - Issue rail slow/stop orders based on predicted rail stress
- Long-term strategies:
  - Perform ZST adjustments over the lifecycle of the asset
  - Incorporate future temperature changes into ZST adjustments to build resilience
  - Establish policies for when to perform ZST adjustments based on temperature fluctuations

Examining and monitoring temperature trends and maintaining rail accordingly can be applied to all areas of the WRCOG/SBCTA region. The difficulty with this strategy is that it requires continuous data collection and monitoring. Further, available data might not always provide accurate readings of daily highs for rail temperature.

3.6 Key Facilities

3.6.1 PROVIDE DEFENSIBLE SPACE AROUND CRITICAL ASSETS

Figure 14 - Defensible Space Zones



Defensible space is a strategy for transportation planners to reduce the risk of structural damage to transportation assets in the event of a wildfire. Applying this strategy both reduces the risk of fire hazard and enables firefighters to defend the asset.[79]

The California Public Resources Code 4291 requires that any person in California who "owns, leases, controls, operates, or maintains a building or structure in, upon, or adjoining a mountainous area, forest-covered lands, brush-covered lands, grass-covered lands, or land that is covered with flammable material" to maintain defensible space around the respective structure or asset.[80] Cal Fire advises a two-zone strategy of defensible space as displayed in Figure 14.[81] Zone 1 should consist of a 30 foot area surrounding the perimeter of the asset, where all debris, vegetation, and tree branches are removed. Zone 2 should extend to 100 feet surrounding the perimeter of the asset, where strategies such as creating horizontal and vertical spacing between vegetation and general landscape maintenance should be employed. Providing defensible space

[79] https://ucanr.edu/sites/safelandscapes/files/93415.pdf
[80] CA Public Resources Code 4291 http://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?sectionNum=4291.&lawCode=PRC
[81] http://www.readyforwildfire.org/Defensible-Space/

is a strategy that can be widely applied and is an especially important strategy for critical structures and evacuation routes and major roadways.

To effectively establish defensible space around an asset, local transportation practitioners can plan for and conduct the following maintenance activities:

- Maintain a buffer of at least 100 feet around the asset
- Remove vegetation that is prone to igniting quickly in the event of a fire
- Plant fire-resistant vegetation around the asset in Zone 2
- Disperse trees and shrubs to reduce the ability for fire to spread
- Ensure there is horizontal and vertical separation between plants to eliminate ladder fuels
- Remove all tree branches lower than 6 feet off the ground
- Build and maintain hardscapes such as granite paths and stone walls
- Adhere to regular landscaping maintenance

Maintaining defensible space can be applied in all areas of the WRCOG/SBCTA region and can be particularly effective in the mountainous and forested environments. One constraint is that this strategy requires removing and refining the area around the facility or roadway year-round, which requires resources and coordination. This can be both costly and time consuming, and resources may limit the ability for the WRCOG/SBCTA to continuously and effectively maintain defensible space around assets.

3.6.2 OFFER COOLING CENTERS

Establishing cooling centers is a strategy in response to human health hazards associated with high-heat conditions. Ensuring that community members have access to cooling centers is integral to their success, which in turn will require engagement with transportation system managers and planners. Key to implementation and use of cooling centers is providing resilient transportation networks to facilitate access in times of extreme heat.

Cooling centers are air-conditioned public locations where individuals can retreat to keep cool during high-heat and extreme heat days. Heat and extreme heat can pose a risk to public health and can lead to both heat-induced disease and, at times, death.[82] Establishing cooling centers is a low-cost means of providing shelter and reducing exposure to extreme heat, particularly for vulnerable and low-income populations. Traditionally, cooling centers are established in public buildings, although there are examples of outdoor cooling centers such community pools.

There are several complimentary strategies that can help bolster the efficacy and awareness of the cooling centers, which include:

- Developing a community strategy for extreme heat and heat waves.
- Conducting community outreach about the locations and hours of cooling centers.
- Providing heat alerts to the community.

82 https://www.cdc.gov/climateandhealth/docs/UseOfCoolingCenters.pdf

- Developing multi-lingual communication materials about cooling centers.
- Providing free or reduced rate public transportation to and from cooling centers to facilitate access.
- Utilizing community centers that serve a multi-functional purpose.

The California Office of Emergency Services has produced a Cooling Center Checklist to help guide communities on how to establish well-equipped cooling centers. The criteria are listed in Table 4.

Table 4. Cooling Center Criteria[83]

Important Criteria	Suggested Criteria
• Air conditioning or equivalent (temperature maintained at 79°) • Accessible to people with access and functional needs / ADA compliant • Ample seating appropriate to the jurisdiction • Public restrooms accessible to people with access and functional needs • Access to potable water (drinking fountain, etc.) • Access to 911 services (payphone) • Publicly advertised • Parking access • Proximity to public transit	• Back-up generators • Secure, facility has security service • Communications, phone (including TDD/TTY), internet access, sign-language interpreters • Child friendly with materials for children to play with while at the cooling center • Medical personnel such as nurses and/or aides • 24-hour, 7 days a week operation • Large capacity • Personnel assistance services for people with access and functional needs • Available televisions, books, games • Transportation for those lacking their own, including wheelchair accessible services • Follow-up procedures for those in need of additional services (health care, social services, etc.) • Area for pets • Veterinary resources available if needed

Potential locations for cooling centers could include hospitals, schools, and churches. Establishing cooling centers and facilitating transportation to these locations can be applied to all areas of the WRCOG/SBCTA region. Research on cooling centers suggests that the strategy is not foolproof to getting individuals out of the heat. Particularly, cooling centers might carry a stigma that these locations are reserved for the homeless, lower income populations, and the elderly, deterring wide use. Other barriers to use include transportation access, a fear of leaving home, and an inability to leave pets behind. These barriers, however, can be addressed through a comprehensive and well-targeted cooling center communication and implementation strategy.

[83] https://www.caloes.ca.gov/PlanningPreparednessSite/Documents/ExcessiveHeatContingencyPlan2014.pdf

3.7 Evacuation Planning and Emergency Response

3.7.1 ENHANCE EMERGENCY RESPONSE PLANNING AND PRACTICE FOR HAZARD EVENTS

Transportation managers can greatly increase the resiliency of the transportation system by having a clear plan and concept of operations for hazard events, such as wildfires, floods, storms, and slope failures. This plan should be coordinated across other agencies and stakeholders. It may be a part of a city or county emergency operations plan that covers all sectors.

Practitioners should be tied into the San Bernardino County Emergency Operations Plan (EOP)[84], the Riverside County EOP, or both, depending on their location. There is also a Riverside County EOP Template[85] that local jurisdictions can use for developing their own EOPs. At the State level, the State of California Emergency Plan (SEP) [86] and Standardized Emergency Management System (SEMS)[87] are essential references. At the national level, the National Response Framework (NRF)[88] and National Incident Management System (NIMS)[89] are key resources as well. FHWA's primer on Concept of Operations (CONOPS) for emergency response outlines important emergency planning and operations considerations specifically for transportation managers.[90]

Figure 15 - Evacuation Stakeholders

Source: FHWA Using Highways for No-Notice Evacuations, Ch. 5

Transportation planners can bolster their preparedness through several activities highlighted in these resources. Examples of best practices include:

- Clear communication plan for coordination between agencies across jurisdictions, with adjacent municipalities or counties, and overarching organizations, such as Cal OES, Caltrans, and Cal Fire. It

84 http://cms.sbcounty.gov/portals/58/Documents/Emergency_Services/Emergency-Operations-Plan.pdf
85 https://www.rivcoemd.org/Programs/Preparedness/Plans
86 https://www.caloes.ca.gov/PlanningPreparednessSite/Documents/California_State_Emergency_Plan_2017.pdf
87 https://www.caloes.ca.gov/cal-oes-divisions/planning-preparedness/standardized-emergency-management-system
88 https://www.fema.gov/media-library/assets/documents/117791
89 https://www.fema.gov/national-incident-management-system
90 https://ops.fhwa.dot.gov/publications/evac_primer_nn/chap5.htm

should cover communication with emergency services personnel and other sectors involved with emergency management, in addition to within the transportation sector.

- Command structures and transfer of command protocols for hazard events.
- Multiple and redundant modes of communication, including plans for when communications and power grids are offline.
- Paper guidebooks and maps for relevant staff for reference in case of communication and power grid failures.
- Clearly defined roles for staff, with planned redundancy in these roles. If there are not enough in-house personnel available, it may be helpful to form on-call or on-demand agreements with contracted labor for emergency events.
- Cross-agency emergency response drills and training.
- Resources such as water, food, and fuel need to be provided to those involved in coordinating evacuations.
- Multiple notification systems for public, including text, landline phone calls, traditional media, social media, sirens, etc. Multilingual communications are essential. Opt-in notification systems typically do not provide enough coverage.
- Public awareness programs about evacuation and other emergency best practices.
- Location-specific evacuation plans.

This strategy applies to all areas within the WRCOG/SBCTA region. One potential strategy constraint is limited staff and funding resources for extensive planning and coordination. Also, given that emergency operations are typically an intermittent activity without a regular schedule, it can fall out of focus within an agency. Regular training and practice can refresh practitioners on emergency plans and concepts of operations.

3.7.2 DESIGNATE EVACUATION PLAN AND ROUTES

Evacuation planning is a subset of emergency response planning (see above) that requires knowledge of the transportation system and therefore heavy involvement from transportation managers. Designating evacuation routes and understanding how the network might be used in a hazard event is critical for preparedness.

Several aspects of the transportation network need to be understood for effective evacuation planning and route designation:

- Capacity of roadways and other infrastructure.
- High hazard risk locations, such as fire- or flood-prone areas and where people could be evacuated to if those hazards were to occur.
- Typical origin-destination numbers and patterns of travelers by time of day and mode.
- Understanding of potential origin-destination numbers patterns during hazard events at different times of day on different modes. This can be developed using a knowledge of typical numbers and patterns, high hazard risk areas, and where people would need to be evacuated to.

- Potential evacuee characteristics in addition to location, such as languages spoken and potential mobility restrictions.
- Understanding of which portions of the network would be susceptible to disruption from hazards (e.g., roadway blockage or bridge failure).
- Redundancy of the transportation network (i.e., availability of alternative routes).
- Expected roadway volumes and timing based on both typical and hazard origin-destination patterns. Include understanding of volumes and timings when vulnerable assets are disrupted.
- Locations of chokepoints, such as intersections/interchanges, road narrowing, etc.

Travel models are a helpful tool for understanding much of this information. That said, there are important limitations in how they can be used. Regional travel demand models often provide a good overall representation of travel user characteristics and patterns across a wide geographic area, but may not be as well suited for understanding precise timing of volumes and capacity constraints. Microsimulation models may have a higher temporal resolution and be better equipped to handle some of these issues, but they often cover much smaller geographic areas, which can limit their applicability for a large-scale evacuation effort.

After developing an understanding of how the transportation network might be used during an evacuation event, an evacuation plan can be developed. This plan can include actions for addressing potential vulnerabilities, such as capacity constraints, populations with special mobility needs, and asset failure points. These actions can cover both transportation operations and design (see next two strategies for examples).

The evacuation plan can also identify routes that are especially critical for evacuation. These evacuation routes are often roadways with relatively high capacities. Evacuation planning can focus on how to maximize the capacity and resiliency of these routes. While it is helpful to designate evacuation routes ahead of time, the routes used during a hazard event depend on the individual timing, location, and other circumstances of that event.

This strategy applies to all areas within the WRCOG/SBCTA region. To assist with implementing this strategy, one element of the Resilient IE Toolkit is a hazard and evacuation map for each WRCOG and SBCTA jurisdiction, which identifies a network of evacuation routes and provides hazard overlays, such as flood zones, to understand the route constraints which may be caused by certain hazard events.

3.7.3 IMPLEMENT TRANSPORTATION DESIGN STRATEGIES FOR EVACUATION EVENTS

This section refers to strategies that can be used in transportation asset design and long-term management to better equip these assets and the overall network for hazard events when they do occur. These strategies include[91]:

- Widening of roadways that serve as key evacuation routes.
- Median breaks and crossovers so that traffic can be redirected or contra flows strategies can be employed.

[91] Many of these are from https://ops.fhwa.dot.gov/publications/fhwahop13013/ch3.htm and https://ops.fhwa.dot.gov/publications/fhwahop08020/fhwahop08020.pdf

- Dynamic shoulder lanes that can be used for emergency vehicles or additional lanes.
- Maintenance of defensible space along key evacuation routes to minimize fire hazard (see strategy writeup below).
- Emergency pull-off or refuge areas.
- Cabling for intelligent transportation systems (ITS) and other technology that is resistant to hazards, such as flooding and fire.
- Tenth mile markers for assisting travelers and emergency responders with location, particularly when communications grids are down.
- Closed circuit television (CCTV) or similar systems to monitor traffic and debris. Provide redundancy in case of system disruption.
- Adaptive signal control (ASC) systems to adjust traffic lights and other signals to high volumes during hazard events. Provide redundancy in case of system disruption.
- Redundancy of Traffic Management Centers (TMCs), with contingency plans for loss of power and communications grids.

3.7.4 IMPLEMENT TRANSPORTATION OPERATIONS STRATEGIES FOR EVACUATION EVENTS

This section refers to short-term strategies in transportation system operations that can be used when hazard events occur. Some of these, such as signal adjustment or contra flow, typically require that necessary equipment be installed ahead of time. This installation of equipment is covered under the Transportation Design Strategies for Evacuation Events writeup.[92]

Operations strategies include:

- Adjust signals to direct traffic during evacuation events.
- Stock deployable signs and barriers to direct traffic.
- Designate shoulder lane or other lane for emergency vehicles.
- Establish contra flow lanes to handle uncharacteristically high traffic volumes during evacuation events. This strategy can require relatively long lead times and therefore may not be viable in no-notice or short-notice evacuation events.
- Coordinate release/timed evacuation from different locations in areas with heavy volumes and high potential for bottlenecks.
- Plan for closure of road lanes or ramps leading into hazard areas for civilians.
- Organize extra on-call maintenance support for debris clearing during events.
- Mobilize transit vehicles and drivers to transport evacuees.
- Establish temporary traffic control points staffed by emergency management personnel.

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92 Many of these are from https://ops.fhwa.dot.gov/publications/evac_primer_nn/chap5.htm and https://ops.fhwa.dot.gov/publications/fhwahop08020/fhwahop08020.pdf

3.8 Additional Principles and Strategies

3.8.1 IMPLEMENT LAND USE PLANNING STRATEGIES ALONG THE TRANSPORTATION CORRIDOR

Land use planning can play a significant role in reducing current and future community risks associated with climate change, including enhancing prevention and preparedness and/or facilitating response and recovery in a community. Zoning regulations and ordinances can have significant impact on land use by dictating what developers and agencies can do on their properties, ideally advancing public health, safety, and welfare in the process. Other local government tools for influencing land use include subdivision regulations, development incentives, and building codes.

As extreme weather events and impacts of climate change take a larger toll on the SBCTA/WRCOG region, municipalities should be aware of the role that climate plays in defining their physical vulnerabilities. Through land use planning and vulnerability assessments, communities can identify the interdependencies among physical and social vulnerabilities and estimate the extent to which climate change may influence land use patterns. Results of the climate vulnerability studies should inform planners on how/what we build along the transportation corridor to achieve climate resiliency.[93] A central pillar of Resilient IE are the two subregional vulnerability assessments developed specifically for the WRCOG subregion and San Bernardino County. The subregional vulnerability assessment may provide sufficient information regarding local vulnerabilities or provide a solid foundation to build from to better understand local climate vulnerability.

In summary, land use planning can minimize risk in several ways such as:

- Prohibiting development in high-risk areas through zoning and overlay controls.
- Limiting the types of development in high to moderate risk areas for open space or recreation, reducing the potential impacts of natural hazard events.
- Applying appropriate development controls in moderate and lower risk areas such as setbacks and lot sizes, as well as maximum densities and site coverage.[94]

Prudent land use planning options along a transportation corridor include appropriate setbacks to provide defensible space, use of native/drought tolerant and fire-resistant landscaping and trees, limitations on overall watershed percentage of impervious areas, and adherence to stormwater regulations that limit quantity of runoff in post-development conditions.

3.8.2 IMPLEMENT SITE DESIGN PRINCIPLES

From a stormwater management perspective, the following site design principles should be evaluated and implemented where feasible:

- Minimize the impervious footprint of the site by constructing streets and sidewalks to the minimum required widths.
- Minimize soil compaction in landscaped areas. Landscape with native or drought-tolerant species.
- Disconnect impervious surfaces by dispersing runoff from impervious surfaces to pervious areas. To be considered 'disconnected' impervious areas should be designed to drain to a pervious area at least one-half their size.

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93 U.S. Climate Resilience Toolkit, https://toolkit.climate.gov/topics/built-environment/planning-and-land-use
94 Institute for Sustainable Resources. Bajracharya, Childs, Hastings. 2011. http://www.prres.net/Proceedings/..%5CPapers%5CBajracharya_Childs_Hastings_Climate_change_disaster_management_and_land_use_planning.pdf

- Design and construct street trees, rain gardens, rock gardens, and permeable pavements to effectively receive and infiltrate or retain runoff from impervious areas before it discharges to the storm drain or exits the right-of-way.

Climate resilient infrastructure features should not be designed to block sight distance for motorists from adjacent streets and driveways, create obstacles for pedestrians, impede the visibility and maintenance of traffic control devices and signs, or reduce or eliminate clear recovery area and minimum horizontal clearances from fixed objects.

4. PROCEDURES AND CASE STUDIES/DESIGN EXAMPLES

4.1 Design Procedure

Implementing resilient infrastructure within the transportation right-of-way requires several considerations to create amenities that are attractive while providing resistance to extreme heat/cold, fire resistance, and stormwater quantity reduction and quality improvement.

Implementation can be approached from evaluating the opportunities within each zone or component of the system, including median, traveled lane, bike lane, shoulder, parkway, sidewalk/pathway, slopes, drainage easements, rail/ballast/sub-ballast, and transit station. Each zone presents different opportunities, benefits, risks and technical design factors for strategy implementation. The following constraints should be understood and evaluated: right-of-way width, utilities, roadway or track geometry and slope, site distance, proximity to storm drain, maintenance access, pedestrian and vehicle safety, bike and parking lanes, etc.

The planning and design process should include the following components:

- Planning Stage:
  - Inventory and assess site conditions
  - Determine climate effects to be considered
  - Identify opportunities and constraints for climate resilient infrastructure implementation
  - Develop list of preliminary strategies and perform preliminary design
  - Conduct inter department, inter-agency, and community outreach
  - Perform ADAP-style assessment (as described in section 1.2)

- Design Stage:
  - Finalize design sizing and layout
  - Coordinate with landscape architect on landscaping
  - Coordinating with utilities
  - Develop operation and maintenance plan

Design considerations common to all the elements that should be evaluated from the planning stage through final design include the following:

- Vehicle and pedestrian safety and mobility (including ADA requirements)
- Site distance
- Parking requirements

- Street tree type and spacing requirements
- Interface with driveways
- Utilities and appurtenant structure locations
- Roadway geometrics - longitudinal and cross slope, width and length, turning requirements
- Structural integrity of adjacent traveled way (design to prevent subsurface infiltration or ponding under traveled way)
- Hydrologic design requirements
- Underdrain and overflow devices
- Proximity of storm drain
- Surrounding land use and sediment sources
- Low water use/drought tolerant and fire-resistant landscape
- Maintenance access
- 'Mid-block' pedestrian crossing potential
- Continual update of ADAP-style assessment (see section 1.2)

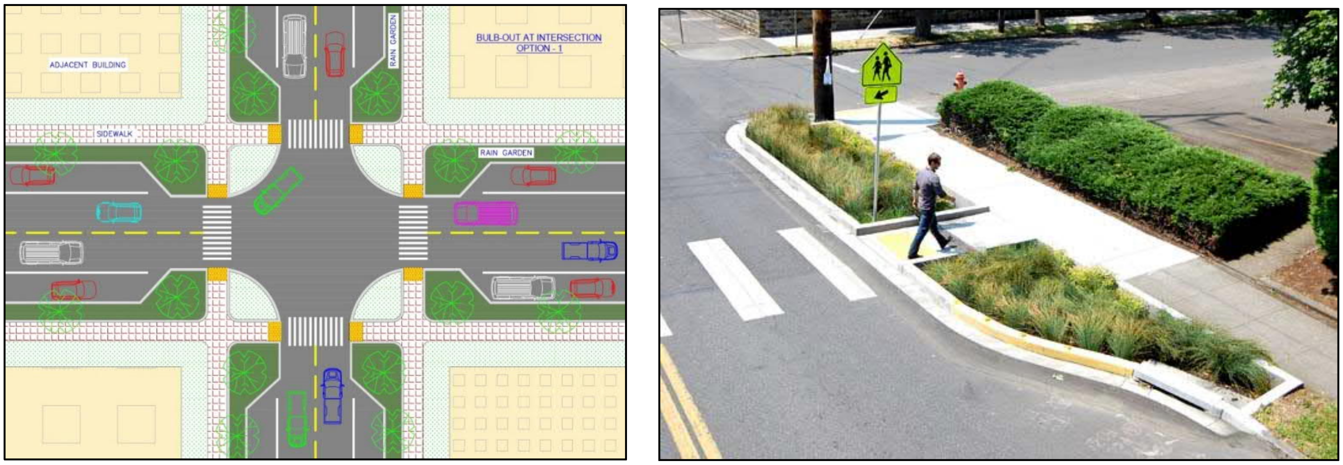
4.2 Design Examples

General design considerations and design elements for various locations within the right-of-way are presented below. Additional design examples are presented in Appendix A.

4.2.1 MEDIANS AND INTERSECTIONS

Medians and intersections (e.g. roundabouts or bulb-out at intersection) present opportunities for use of street trees, bioretention (e.g. rain gardens or rock gardens),), or permeable pavements. Bulb-outs provide traffic calming at intersections, increase pedestrian visibility, and decrease crosswalk lengths. Bulb-outs at intersections prevent motorists from parking too close to a crosswalk or from blocking a curb ramp. Motor vehicles parked too close to corners present a safety concern, since they block sight lines, obscure visibility of pedestrians and other vehicles, and make turning difficult for emergency vehicles and trucks. Bulb-outs are only appropriate where there is an on-street parking lane or shoulder and must not extend into bike lanes or travel lanes. The turning requirements of larger vehicles, such as fire trucks and school buses, require consideration in design.

Figure 16 - Bulb-out at Intersection



Source: County of San Diego Green Infrastructure Guidelines, 2019

Design elements common to medians and intersections include:

- Raised median:
  - Plant low water use/drought tolerant street trees and landscaping
  - Install permeable pavement
- Depressed median: Utilize roadway cross slope to direct stormwater runoff from impervious roadway elements to:
  - Street Trees
  - Planter Boxes
  - Vegetated Swale
  - Rock Swale

Figure 17 - Median Strategies

Source: County of San Diego Green Infrastructure Guidelines, 2019

4.2.2 TRAVELED WAY, BIKE LANE AND SHOULDER

The use of permeable pavements within the traveled way and bike lanes is not typically permitted. However, their use may be considered for low volume driving lanes in parking lots, private streets, alleys, and fire access roads. The use of permeable pavement in the shoulder/parking lane should be evaluated based upon adequate structural design and use of edge restraints.

Figure 18 - Traveled Way, Bike Lane, and Shoulder

Source: County of San Diego Green Infrastructure Guidelines, 2019

Curb extensions reduce overall street dimensions and provide traffic calming. Among other benefits, curb extensions provide added space for rain gardens. Curb extensions shall never encroach upon the traveled way or bike lanes. When existing tree roots are damaging adjacent curb, gutter, or pavement, curb extensions provide an excellent opportunity to preserve the tree and provide green infrastructure.

Careful survey of street parking impacts should be considered when locating curb extensions. Design elements for curb extensions include use of low water use/drought tolerant landscaping, permeable pavement and planter boxes.

Figure 19 - Curb Extension

Source: County of San Diego Green Infrastructure Guidelines, 2019

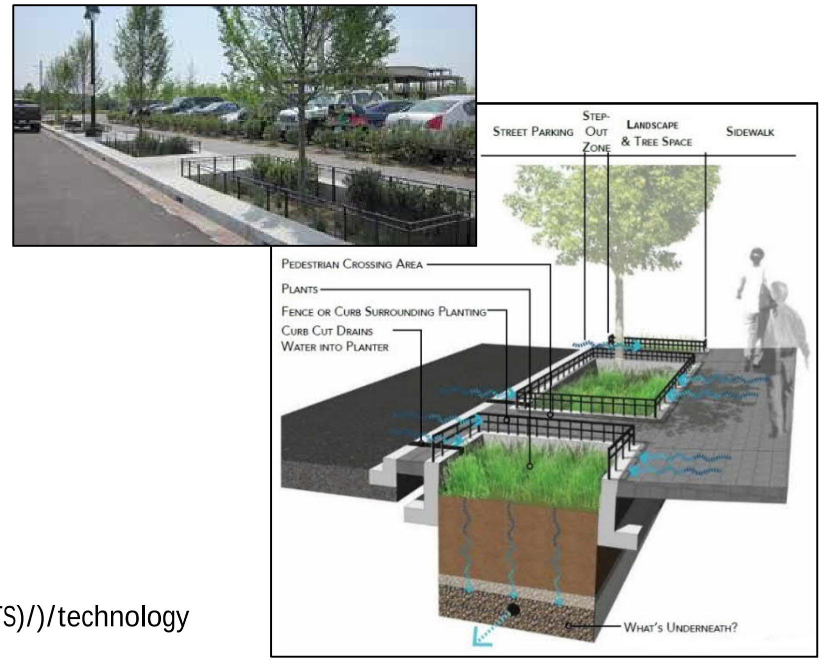
4.2.3 PARKWAY

The parkway including the tree space, planting strip, sidewalk, pathway, and other areas has numerous opportunities for climate resilient infrastructure implementation. Parkway design elements typically include:

- Landscape area: Street trees
- Planter boxes
- Curb extensions
- Bulb outs at intersections
- Swales (vegetated or rock)

- Sidewalk or trail:
  - Drain to adjacent landscaping
  - Drain to green street LID practice
  - Permeable pavement
- Other areas:
  - Filter Strip
  - Rock basin
- Other Strategies:
  - Transit stops (shade protection)
  - Intelligent Transportation System (ITS)/)/technology
  - Drainage infrastructure
  - Defensible space

Figure 20 - Green Street



Source: County of San Diego Green Infrastructure Guidelines, 2019

5. IMPLEMENTATION

This section provides guidance and references for strategy design, construction, maintenance, and costs associated with climate resilience planning and implementation.

5.1 Design and Construction

Several local and regional sources are available regarding engineering guidance, standard drawings, and specifications for climate resilient infrastructure strategies, including street trees, bioretention, swales, and pervious pavement (Riverside County, Caltrans, County of San Diego, City of Los Angeles, etc.).

- Riverside County, Low Impact Development: Guidance and Standards for Transportation Projects for the Santa Ana Region Riverside County Co-Permittees. http://rcflood.org/downloads/NPDES/Documents/SA_WQMP/EXHIBIT%20D.pdf
- Riverside County Design Handbook for Low Impact Development Best Management Practices. http://rcflood.org/NPDES/LIDBMP.aspx
- San Bernardino County Water Quality Management Plan. http://cms.sbcounty.gov/dpw/Land/WQMPTemplatesandForms.aspx
- National Cooperative Highway Research Program, Transportation Research Board, and National Research Council. Evaluation of Best Management Practices for Highway Runoff Control: Low Impact Development Design Manual for Highway Runoff Control. http://www.coralreef.gov/transportation/evalbmp.pdf

- Caltrans Pervious Pavement Design Guidance and Specifications. https://dot.ca.gov/programs/design/hydraulics-stormwater
- County of San Diego, BMP Design Manual, Appendix K: Guidance on Green Infrastructure https://www.sandiegocounty.gov/content/dam/sdc/dpw/WATERSHED_PROTECTION_PROGRAM/watershedpdf/Dev_Sup/County_BMPDM_App_K.pdf
- County of San Diego Green Infrastructure Resources

  https://www.sandiegocounty.gov/content/sdc/dpw/watersheds/DevelopmentandConstruction.html
- City of Los Angeles; LID Handbook, Forms and Educational Materials. https://www.lastormwater.org/green-la/low-impact-development/lid-documents/
- City of Los Angeles, Standard Plans http://eng2.lacity.org/techdocs/stdplans/s-400.htm
- Southern California Stormwater Monitoring Coalition: Low Impact Development Manual for Southern California: Technical Guidance and Site Planning Strategies. https://www.casqa.org/resources/lid/socal-lid-manual

5.2 Maintenance Guidance

Every strategy described in this Guidebook requires maintenance to help ensure long-term effectiveness. The feasibility of any technique will depend upon the level of maintenance resources available in the long-term and the level of expertise necessary to maintain the facilities. Project owners and operators must have the expertise and equipment necessary to maintain all aspects of the techniques selected for a project or have the resources to contract for the maintenance. Several techniques may require another public agency or department for proper maintenance. For example, maintenance of vegetated facilities may fall within a local landscape maintenance program. As such, the resources, equipment, and expertise available from other agencies may affect strategy feasibility. Several techniques may require consideration of existing source control programs, e.g., catch-basin cleaning or street sweeping.[95] Included with some of the references listed under the previous section, sample maintenance and inspection tables can be used to develop site specific operation and maintenance manuals. For example, San Diego County has a maintenance schedule document for a variety of strategies.[96]

5.3 Cost Information

Table 5 below summarizes infrastructure strategy unit cost data from the Green Values® National Stormwater Management Calculator.[97] These unit costs can be used for planning level determinations of installation and maintenance.

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[95] County of Riverside, Low Impact Development: Guidance and Standards for Transportation Projects for the Santa Ana Region County Co-Permittees, http://rcflood.org/downloads/NPDES/Documents/SA_WQMP/EXHIBIT%20D.pdf
[96] County of San Diego, https://www.sandiegocounty.gov/content/dam/sdc/dpw/WATERSHED_PROTECTION_PROGRAM/watershedpdf/Dev_Sup/GS_Maint_Sched_2019.pdf
[97] https://greenvalues.cnt.org/national/cost_detail.php

Table 5. Infrastructure Strategy Approximate Installation and Maintenance Unit Costs

Strategy	Unit Cost	Yearly Maintenance Cost	Comments
Infiltration, Bioretention*	$10-40 per square foot of bioretention surface area	$0.31-$0.61/sf	Lower end of unit cost range typical of unlined bioretention without underdrain. Higher end of unit cost range typical of lined bioretention with underdrain
Rain Garden	$5.15-$16.05/sf	$0.31-$0.61/sf	No comments
Planter Boxes	$0.55 - $24.50/sf	$0.04-$1.00/sf	No comments
Bioswales	$5.50 - $24.00/sf	$0.06-0.210/sf	No comments
Permeable pavement	Asphalt: $5.50-$8.13/sf Concrete: $5.50-$11.60/sf Grass/Gravel Pavers: $1.72-$6.00/sf Interlocking Concrete Pavers: $5.30-$12/sf	$0.09-$0.023/sf $0.09-$0.23/sf $0.015-$0.05/sf $0.01-$0.023/sf	No comments
Cistern	$0.61 - $2.88/gallon	$0.07/gallon	No comments

Notes: [1]From Water Environment Research Foundation BMP and LID Whole Life Cost Tools

In addition to the unit costs summaries above, the WRCOG Land Use, Transportation, and Water Quality Planning Framework[98] provides cost data and references for BMPs. Additionally, Water Environment Research Foundation (WERF) created costing spreadsheets that can be utilized to determine capital, maintenance, and whole life costs for a variety of infrastructure strategies.[99] More detailed LID BMP costs can be estimated during the design process using these cost spreadsheets, based on actual infrastructure strategy dimensions (length, depth) and features such as underdrains and liners.

6. CONCLUSION

This Guidebook is part of the larger Regional Climate Adaptation Toolkit for Transportation Infrastructure effort, also known as Resilient IE, a joint effort between WRCOG and SBCTA, funded by Caltrans. It complements the San Bernardino County Vulnerability Assessment, WRCOG Subregional Vulnerability Assessment, city-level climate-related transportation vulnerability/hazards and evacuation maps, and other products that are being developed as part of Resilient IE. The Guidebook also helps identify strategies that provide other benefits, such as the provision of alternative compliance stormwater facilities.

Extreme weather and climate conditions can heavily influence transportation and other forms of infrastructure. This infrastructure is designed to withstand these conditions to a certain extent, given current criteria-based design practices. Yet almost all the existing transportation infrastructure in the country, the state, and in the WRCOG/SBCTA region was originally designed under the assumption that these conditions remain relatively constant over time. Changing climate conditions, both observed and projected, are proving this assumption to be flawed and need to be appropriately considered to enable effective investments. Changing climate conditions

[98] Land Use, Transportation, and Water Quality Planning Framework, prepared for Southern California Association of Governments (SCAG) in partnership with WRCOG, March 2016.
[99] http://www.werf.org/c/KnowledgeAreas/Stormwater/ProductsToolsnonWERF/BMP_and_LID_Whole_Li.aspx

combine with development to increase the opportunity for physical damage to occur, and heighten the impact when a transportation facility is put out of service.

This Guidebook serves as a tool to help local practitioners make the transportation system more resilient to these changes. It is intended as a practical resource for jurisdictions on strategies, best practices, and methods for overcoming challenges and using climate resiliency tools in the context of changing patterns of extreme temperatures, heavy precipitation and flooding events, drought, and wildfires. It aims to address the diverse climate and terrain of the region and the needs specific to ensuring the long-term viability of the transportation system.

The Guidebook draws upon strategies that have been developed at the national and State levels. These strategies are tailored to the regional level for use by the intended audience of local jurisdictions, planners, and engineers within Western Riverside County and San Bernardino County. While many of these strategies require additional financial or other resource commitments for the planning process, when implemented can reduce maintenance and repair costs overtime, minimizing the cost requirements and improving reliability of the transportation system overall.