



September 2021

CLIMATE RESILIENCE

Options to Enhance the Resilience of Federally Funded Roads and Reduce Fiscal Exposure



A Century of Non-Partisan Fact-Based Work

Why GAO Did This Study

Changes in the climate pose a risk to the safety and reliability of the U.S. transportation system, according to the 2018 *Fourth National Climate Assessment*. Congress authorized about \$45 billion per year in federal funding for roads through 2021 and appropriated about \$900 million per year in disaster assistance for fiscal years 2016 through 2020. In 2013, GAO included *Limiting the Federal Government's Fiscal Exposure by Better Managing Climate Change Risks* on its High-Risk List. Enhancing climate resilience—acting to reduce potential losses by planning for climate hazards such as extreme rainfall—can help manage climate risks.

GAO was asked to review climate resilience efforts for federally funded roads. This report examines (1) FHWA's climate resilience efforts and (2) options to further enhance them. GAO reviewed FHWA documents and a non-generalizable sample of projects that used FHWA's climate resilience resources, analyzed the content of 53 reports and pieces of legislation to identify options, interviewed stakeholders and agency officials, and analyzed options and FHWA efforts using GAO's October 2019 *Disaster Resilience Framework*.

What GAO Recommends

Congress should consider providing direction to FHWA to implement one or more options to enhance the climate resilience of federally funded roads. GAO also is making one recommendation that the Department of Transportation (DOT) consider these options when prioritizing climate resilience actions. DOT concurred with this recommendation.

View [GAO-21-436](#). For more information, contact J. Alfredo Gómez at (202) 512-3841 or gomezj@gao.gov.

CLIMATE RESILIENCE

Options to Enhance the Resilience of Federally Funded Roads and Reduce Fiscal Exposure

What GAO Found

During the last decade, the Federal Highway Administration (FHWA) undertook targeted efforts to encourage states to enhance the climate resilience of federally funded roads, such as by developing agency policy, providing technical assistance, and funding resilience research. GAO identified projects in four states that planned or made resilience enhancements using FHWA's resources. For example, Maryland used FHWA resources to raise a bridge by about 2 feet to account for projected sea level rise. Such efforts show the potential to enhance the climate resilience of federally funded roads on a wider scale.

GAO identified 10 options to further enhance the climate resilience of federally funded roads through a comprehensive literature search and interviews with knowledgeable stakeholders (see table). Some of these options are similar to recommendations made previously by GAO. Each option has strengths and limitations. For example, adding climate resilience requirements to formula grant programs could compel action but complicate states' efforts to use federal funds.

Options to Further Enhance the Climate Resilience of Federally Funded Roads

1. Integrate climate resilience into Federal Highway Administration policy and guidance.
2. Update design standards and building codes to account for climate resilience.
3. Provide authoritative, actionable, forward-looking climate information.
4. Add climate resilience funding eligibility requirements, conditions, or criteria to formula grant programs.
5. Expand the availability of discretionary funding for climate resilience improvements.
6. Alter the Emergency Relief (ER) program by providing incentives for, or conditioning funding on, pre-disaster resilience actions.
7. Expand the availability of ER funding for post-disaster climate resilience improvements.
8. Establish additional climate resilience planning or project requirements.
9. Link climate resilience actions or requirements to incentives or penalties.
10. Condition eligibility, funding, or project approval on compliance with climate resilience policy and guidance.

Source: GAO analysis of literature and interviews with knowledgeable stakeholders. | GAO-21-436

Implementing multiple options offers the most potential to improve the climate resilience of federally funded roads, according to knowledgeable stakeholders and GAO's analysis using the *Disaster Resilience Framework*, a guide for analyzing federal disaster and climate resilience efforts. This *Framework* states that integrating strategic resilience goals can help decision makers focus on a wide variety of opportunities to reduce risk. FHWA officials said that they likely would need additional authority from Congress to act on some, or a combination of, options and that the most effective way for Congress to ensure its priorities are implemented for any option is to put it in law. The most recent authorization of federal funding for roads covers fiscal year 2016 through fiscal year 2021, which ends on September 30, 2021. This provides Congress with an opportunity to improve the climate resilience of federally funded roads and better ensure they can withstand or more easily recover from changes in the climate. Providing FHWA with additional authority to implement one or more of the options could enhance the climate resilience of more—or all—federally funded roads.

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Abbreviations

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| AASHTO | American Association of State Highway and Transportation Officials |
| ADOT | Arizona Department of Transportation |
| C.F.R. | Code of Federal Regulations |
| CMIP | Coupled Model Intercomparison Project |
| CRS | Congressional Research Service |
| DeIDOT | Delaware Department of Transportation |
| DNREC | Delaware Department of Natural Resources and Environmental Control |
| DOT | U.S. Department of Transportation |
| ER | Emergency Relief |
| FAST Act | Fixing America's Surface Transportation Act |
| FHWA | Federal Highway Administration |
| I-5 | Interstate 5 |
| MDOT SHA | Maryland Department of Transportation State Highway Administration |
| NCHRP | National Cooperative Highway Research Program |
| NHS | National Highway System |
| NIST | National Institute of Standards and Technology |
| SR | State Route |
| STIP | Statewide Transportation Improvement Program |
| TRB | Transportation Research Board |
| U.S.C. | United States Code |
| USGCRP | U.S. Global Change Research Program |
| USGS | U.S. Geological Survey |
| VDOT | Virginia Department of Transportation |
| WSDOT | Washington State Department of Transportation |

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September 22, 2021

Congressional Requesters

Changes in the climate pose a risk to the safety, efficiency, and reliability of the U.S. transportation system, according to the 2018 *Fourth National Climate Assessment*.¹ This includes the ability of roads to serve as safe routes for evacuation and emergency services during disasters. Disaster costs also are projected to increase as extreme weather events become more frequent and intense due to climate change—as observed and projected by the U.S. Global Change Research Program and the National Academies of Sciences, Engineering, and Medicine. For example, extreme rainstorms may wash out roads before the end of their expected lifespans.² Climate-related damages to paved roads in the United States could cost up to an estimated \$20 billion per year by the end of the century, under some projected scenarios reported in the 2018 *Fourth National Climate Assessment*.³ Increasing demand for transportation services that emit greenhouse gases and contribute to climate changes may further increase these risks.

The projected impact of climate change on U.S. roads is a key source of federal fiscal exposure because of the size of the federal government’s investment in roads and states’ increasing reliance on the federal government for disaster assistance. The Federal Highway Administration (FHWA), within the U.S. Department of Transportation (DOT), is responsible for administering the federal-aid highway program. The “federal-aid highway program” is an umbrella term for a collection of

¹The Global Change Research Act of 1990, Pub. L. No. 101-606, § 103, 104 Stat. 3096, 3098, directed the President to establish the U.S. Global Change Research Program (USGCRP). USGCRP facilitates collaboration and cooperation across its 13 federal member agencies to advance understanding of the changing Earth system and maximize efficiencies in federal global change research. USGCRP most recently released a National Climate Assessment in 2018. See USGCRP, *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, vol. 2 (Washington, D.C.: 2018).

²For the purposes of this report, we generally use the term “road” to refer to transportation assets including roads, bridges, and their supporting infrastructure.

³USGCRP, *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, vol. 2 (Washington, D.C.: 2018).

FHWA-administered formula and nonformula grant programs that provide federal funding for roads. This program primarily funds highway planning and construction activities for approximately 110,000 active federally funded projects. Two statutes authorize approximately \$45 billion per year for the federal-aid highway program for fiscal years 2016 through 2021.⁴ A majority of the federal-aid highway program funding is distributed to states in accordance with formulas set by law (formula grant programs). Much of the remaining funding is distributed by FHWA through a variety of congressionally authorized nonformula grant programs for which applicants are awarded grants based on program-specific criteria (discretionary programs). One such discretionary program is FHWA's Emergency Relief program. The program makes federal disaster assistance available to states to repair or reconstruct roads that have suffered serious damage as a result of a natural disaster or catastrophic failures from other external causes.⁵ This program was appropriated an average of about \$900 million per year for fiscal years 2016 through 2020.⁶ Since 2005, federal funding for disaster assistance more broadly has totaled at least \$524 billion, as we stated in our report on the nation's fiscal health in March 2021.⁷

⁴The [Fixing America's Surface Transportation Act](#) (FAST Act), Pub. L. No. 114-94, § 1101, 129 Stat. 1312, 1322 (2015), authorized federal surface transportation funding for fiscal years 2016 through 2020, and was extended through 2021 by the [Continuing Appropriations Act, 2021 and Other Extensions Act](#), Pub. L. No. 116-159, div. B, tit. I, § 1101, 134 Stat. 709, 725 (2020).

⁵FHWA's Emergency Relief program is funded by a permanent annual authorization of \$100 million from the Highway Trust Fund, along with supplemental appropriations from the general fund. 23 U.S.C. § 125. See also e.g., Bipartisan Budget Act of 2018, Pub. L. No. 115-123, 132 Stat. 64, 102; Additional Supplemental Appropriations for Disaster Relief Act, 2019, Pub. L. No. 116-20, 133 Stat. 871, 895. As described in FHWA's Emergency Relief Manual, to be considered for Emergency Relief funding, either the President must make a major disaster declaration under the Stafford Act, 42 U.S.C. § 5170, or the governor of the state must issue an emergency or disaster proclamation and FHWA must concur with that declaration.

⁶There have not yet been any supplemental appropriations for FHWA's Emergency Relief program in fiscal year 2021 as of August 2021.

⁷This funding consists of obligations for disaster assistance from 2005 through 2014 totaling about \$278 billion and select appropriations for disaster assistance from 2015 to 2020 totaling \$246 billion. GAO, *The Nation's Fiscal Health: After Pandemic Recovery, Focus Needed on Achieving Long-Term Fiscal Sustainability*, [GAO-21-275SP](#) (Washington, D.C.: Mar. 23, 2021).

Since 2013, in recognition of the federal government’s significant stake in managing climate-related disaster impacts, GAO has included *Limiting the Federal Government’s Fiscal Exposure by Better Managing Climate Change Risks* in its High-Risk List.⁸ We and others have recommended enhancing climate resilience to help limit the federal government’s fiscal exposure to climate change because investing in resilience can reduce the need for far more costly steps in the future.⁹ Enhancing climate resilience means taking actions to reduce potential future losses by planning and preparing for potential climate hazards, such as extreme rainfall, sea level rise, and drought.¹⁰ For roads, this can mean making design changes (e.g., using heat resistant materials or widening drainage structures), moving roads (e.g., to higher ground or further inland), or selecting nature-based solutions (e.g., building sand dunes or restoring

⁸We added *Limiting the Federal Government’s Fiscal Exposure by Better Managing Climate Change Risks* to GAO’s High-Risk List in 2013. The High-Risk List identifies federal program areas that are at high risk of vulnerabilities to fraud, waste, abuse, and mismanagement or most in need of transformation. See GAO, *High-Risk Series: An Update*, [GAO-13-283](#) (Washington, D.C.: Feb. 2013) and *High-Risk Series: Dedicated Leadership Needed to Address Limited Progress in Most High-Risk Areas*, [GAO-21-119SP](#) (Washington, D.C.: Mar. 2, 2021).

⁹For example, see GAO, *Climate Change: Opportunities to Reduce Federal Fiscal Exposure*, [GAO-19-625T](#) (Washington, D.C.: June 11, 2019); *Climate Change: Selected Governments Have Approached Adaptation through Laws and Long-Term Plans*, [GAO-16-454](#) (Washington, D.C.: May 12, 2016); and National Research Council of the National Academies, *America’s Climate Choices: Panel on Adapting to the Impacts of Climate Change*, *Adapting to the Impacts of Climate Change* (Washington, D.C.: 2010).

¹⁰The National Academies defines resilience as the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events. We reported in May 2016 that two related sets of actions can enhance climate resilience by reducing risk. These are climate change adaptation and pre-disaster hazard mitigation. In general, the term “adaptation” is used by climate change professionals, and “pre-disaster hazard mitigation” is employed by the emergency management community, often to speak about the same thing: becoming better prepared for climate change impacts. Adaptation is defined as adjustments to natural or human systems in response to actual or expected climate change. Pre-disaster hazard mitigation refers to actions taken to reduce the loss of life and property by lessening the impacts of adverse events. It applies to all hazards, including terrorism and natural hazards such as health pandemics or weather-related disasters. In this report, we use the term “climate resilience” for consistency and to encompass both sets of actions as they relate to addressing climate risks. The National Academies, Committee on Increasing National Resilience to Hazards and Disasters and Committee on Science, Engineering, and Public Policy, *Disaster Resilience: A National Imperative* (Washington, D.C.: 2012); [GAO-16-454](#); and GAO, *Climate Resilience: A Strategic Investment Approach for High-Priority Projects Could Help Target Federal Resources*, [GAO-20-127](#) (Washington, D.C.: October 23, 2019).

wetlands). A survey of state departments of transportation published in 2018 by the National Academies found that most survey respondents were working in some capacity to incorporate resilience into transportation management programs, but were struggling to implement resilience practices into physical road projects.¹¹ Illustrating this emerging focus on climate resilience, recent proposed reauthorization bills for the federal-aid highway program included provisions to improve the climate resilience of federally funded roads.¹²

You asked us to consider what actions could be taken to enhance the climate resilience of federally funded roads.¹³ This report examines: (1) efforts FHWA has made to enhance the climate resilience of federally funded roads during the past 10 years, and (2) the strengths and limitations of options to further enhance the climate resilience of federally funded roads, according to knowledgeable stakeholders and relevant literature. We also provide information on how we used GAO's *Disaster Resilience Framework* to evaluate the extent to which each of the options identified in this report could enhance the climate resilience of federally funded roads.¹⁴

¹¹Forty state DOTs participated in the National Academies' survey. See National Academies of Science, Engineering, and Medicine, Transportation Research Board, National Cooperative Highway Research Program (NCHRP), *NCHRP Synthesis 527: Resilience in Transportation Planning, Engineering, Management, Policy, and Administration: A Synthesis of Highway Practice* (Washington, D.C.: 2018).

¹²For example, The Surface Transportation Reauthorization Act of 2021, S. 1931, 117th Cong. (May 27, 2021), would reauthorize the federal-aid highway program with, among other things, a new program that would provide funding for resilience improvements through formula funding and competitive grants over 5 years. It also would allow the use of Emergency Relief funding for protective features designed to mitigate the risk of recurring damage or the cost of future repairs from extreme weather events, flooding, or other natural disasters. The INVEST in America Act, H.R. 3684, 117th Cong. (June 4, 2021), would, among other things, create a new pre-disaster mitigation program. It also would require consideration of resilience during the transportation-planning process.

¹³We reported our preliminary observations on actions FHWA has taken to encourage states to enhance the climate resilience of federally funded roads and options to further enhance the climate resilience of federally funded roads in May 2021. See GAO, *Physical Infrastructure: Preliminary Observation on Options for Improving Climate Resilience of Transportation Infrastructure*, [GAO-21-561T](#) (Washington, D.C.: May 13, 2021).

¹⁴GAO, *Disaster Resilience Framework: Principles for Analyzing Federal Efforts to Facilitate and Promote Resilience to Natural Disasters*, [GAO-20-100SP](#) (Washington, D.C.: Oct. 2019).

To address the first objective, we reviewed documents describing FHWA resilience research, tools, and policies as well as federal laws and regulations related to resilience. We also interviewed FHWA officials and representatives from the American Association of State Highway and Transportation Officials (AASHTO) and the Transportation Research Board of the National Academies about FHWA's resilience efforts. In addition, to understand how recipients of federal funding for roads used FHWA's programs, tools, and policies, we collected information on project sites from four states—Arizona, Delaware, Maryland, and Washington State—that we identified as having used FHWA's resilience resources, as well as climate change projection information, to plan or implement physical resilience enhancements on federally funded roads.¹⁵ Such enhancements could include raising bridges to account for projected sea level rise or flooding. We identified these projects by first reviewing project descriptions for all of the resilience research pilot projects funded by FHWA. Next, we obtained referrals from knowledgeable parties for additional projects that might meet our search criteria. Using this methodology, we identified 27 planning organizations and state departments of transportation (DOTs) around the United States that were likely to have begun or completed physical resilience enhancements on federally funded roads using FHWA's resilience resources and climate change projection information. We contacted these 27 organizations to confirm whether they had any projects that met all of our search criteria. We found seven projects in four states that met all of our search criteria. Findings from our reviews of these projects are not generalizable to all federally funded road projects.

To address the second objective, we reviewed relevant literature and interviewed knowledgeable stakeholders. Specifically, we conducted a literature search for (1) reports on transportation infrastructure resilience or funding that proposed or described options that could be used to enhance the climate resilience of federally funded roads and (2) proposed and enacted legislation that included examples of incentives or requirements to consider resilience for federally funded projects. We then analyzed the content of 53 relevant reports and pieces of legislation and distilled examples of options from this literature into a preliminary list of high-level options grouped by location in existing FHWA funding and program structures. We later added options to the list based on suggestions provided by knowledgeable stakeholders during interviews.

¹⁵We completed site visits in person with one state (Arizona), and gathered information on project sites from the remaining states by phone and email (Delaware, Maryland, and Washington State) due to COVID-19 pandemic travel restrictions.

To identify knowledgeable stakeholders, we used the results of the literature search to identify potential stakeholders with knowledge of both climate resilience and federal funding for roads. We continued to ask each knowledgeable stakeholder we interviewed to recommend other knowledgeable stakeholders who might meet our criteria. To select the 34 knowledgeable stakeholders we spoke with, we primarily considered type of expertise, relevance of published work, and referrals from other stakeholders we interviewed as criteria. To describe the options' strengths and limitations, we synthesized perspectives from 19 semi-structured interviews with 34 knowledgeable stakeholders and used our prior work and other relevant literature to provide additional context to stakeholder perspectives. The specific areas of expertise varied among the stakeholders we interviewed, so not all of the stakeholders commented on all of the interview questions we asked. Interviewees included representatives from AASHTO, officials from several state DOTs, former DOT officials, and stakeholders from academic institutions, research organizations, think tanks, and consultancies. We also interviewed FHWA officials about the various options and included their statements on the extent to which the agency could implement these options under its existing authority.

To identify the extent to which each of these options could enhance the climate resilience of federally funded roads, we compared the available options with FHWA's current climate resilience efforts using our *Disaster Resilience Framework*.¹⁶ We published the *Disaster Resilience Framework* in 2019 to serve as a guide for analysis of federal actions to promote resilience to natural disasters and address the actual and anticipated effects of climate change. This *Framework* can be used to identify opportunities to address gaps in federal efforts by, for example, supporting identification of options to address government-wide challenges that are of a scale and scope not addressed by existing programs. In this report, we used the *Disaster Resilience Framework* to identify the positive effects achievable by implementing options to further enhance the climate resilience of federally funded roads in comparison to current FHWA efforts. We present detailed examples of how we applied the *Disaster Resilience Framework* in appendix III. For additional details on our scope and methodology, see appendix I.

We conducted this performance audit from July 2019 to September 2021 in accordance with generally accepted government auditing standards.

¹⁶[GAO-20-100SP](#).

Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

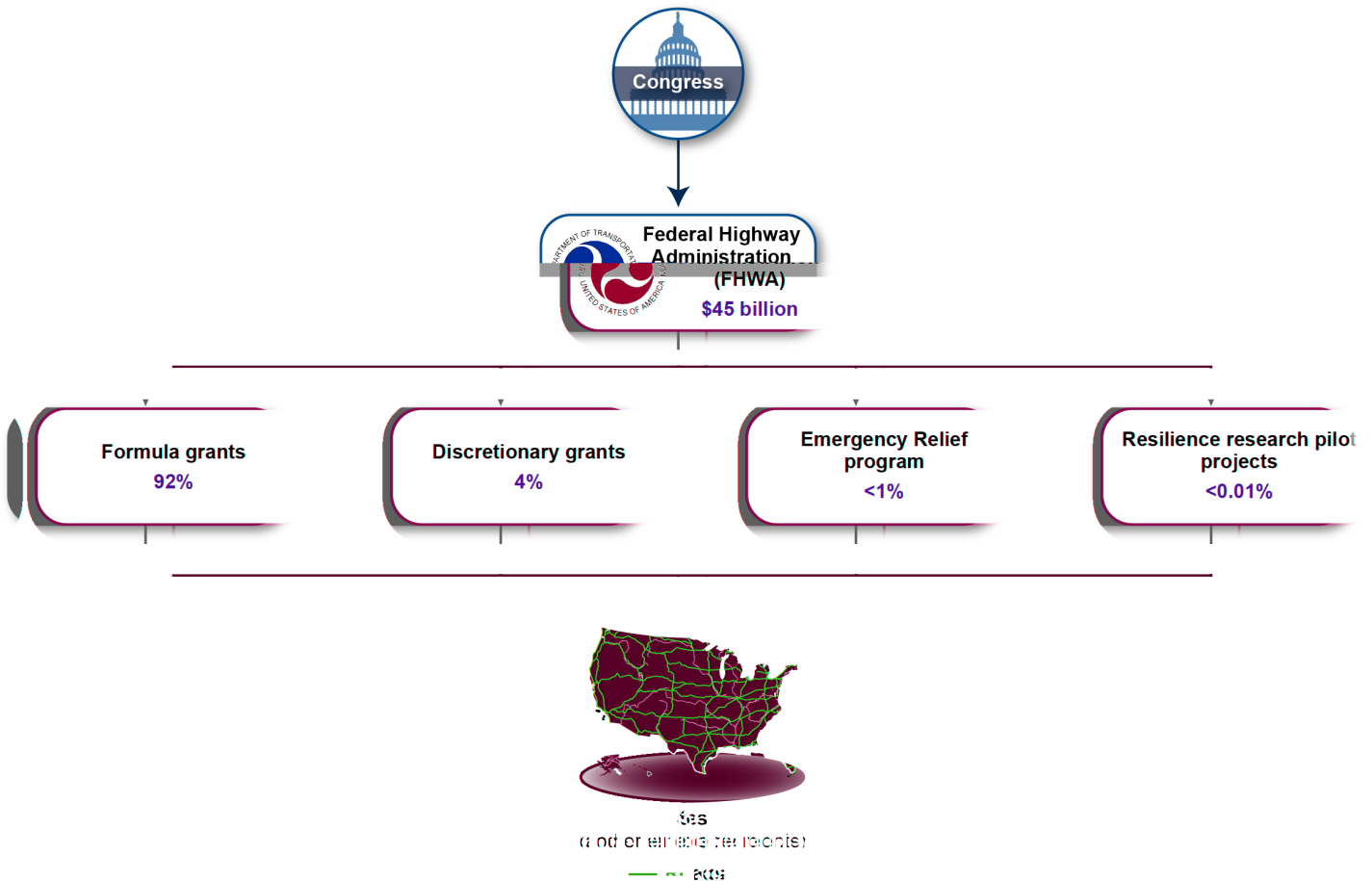
This section describes (1) the federal role in funding roads; (2) Executive Order 14008, *Tackling the Climate Crisis at Home and Abroad*; (3) climate resilience as a risk management strategy to reduce federal fiscal exposure; and (4) GAO's *Disaster Resilience Framework*.

Federal Role in Funding Roads

Most roads and bridges are locally or state owned and operated. The federal role is primarily to administer funding for roads while providing oversight and technical assistance. Congress authorizes how much federal funding is available each fiscal year; FHWA administers the distribution of funding to states; and states prioritize how to use federal funding in accordance with laws and regulations (see figure 1).¹⁷ About 1 million of the nation's 4 million miles of roads are eligible for federal aid—including the approximately 220,000-mile National Highway System, of which the nearly 49,000-mile Interstate Highway System is a part.

¹⁷We use the term "states" throughout, because the vast majority of federal funding for roads is distributed to and used by states. However, federal funding can go to entities other than states. For the federal-aid highway programs generally, "state" is defined as any of the 50 U.S. states, the District of Columbia, and the Commonwealth of Puerto Rico. 23 U.S.C. § 101(a)(26). However, the definition of state varies in some specific circumstances. For example, the Emergency Relief program defines "state" to also include the Virgin Islands, Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands. 23 U.S.C. § 125(f).

Figure 1: Federal Funding Process for Roads



Source: GAO analysis of FHWA program data. GAO-21-214-26.

Note: The \$45 billion amount reflects average annual authorizations for the federal-aid highway program for fiscal years 2016 through 2021. The percentages for program types are based off of that \$45 billion amount. Percentages do not add to 100 because funding for FHWA administration expenses, federal lands and tribal transportation grants, and other transportation research funding are not shown. Also, this figure does not reflect additional supplemental appropriations for the Emergency Relief program.

Congress. Congress enacts multi-year legislation to authorize funding for the federal-aid highway program. This funding includes a series of formula and discretionary grant programs. In the most recent multi-year reauthorization, Congress authorized approximately \$45 billion per year

for the federal-aid highway program for fiscal years 2016 through 2020.¹⁸ This funding was recently extended through the end of fiscal year 2021.¹⁹ In addition, Congress has authorized additional funding for roads to the Emergency Relief program through supplemental appropriations. States can receive federal funding through the following means:

- **Formula grants.** Congress authorizes federal funding for roads in multi-year legislation to be distributed to states in accordance with formulas set in statute. About 92 percent of federal funding authorized for the federal-aid highway program in the most recent reauthorization were apportioned to states by statutory formula. These formula grant programs include the National Highway Performance Program, the Surface Transportation Block Grant Program, the Highway Safety Improvement Program, the Congestion Mitigation and Air Quality Improvement Program, Metropolitan Planning, the National Highway Freight Program, and the Railway-Highway Crossing Program. Among these, the National Highway Performance Program and the Surface Transportation Block Grant Program receive the most funding. The National Highway Performance Program is the largest of the federal-aid highway programs. It supports improvement of the condition and performance of the National Highway System, including interstates and nearly all other major highways. The Surface Transportation Block Grant Program provides flexible funding to address state and local transportation needs. It has the broadest project eligibility and can be used on any federal-aid highway, bridge projects on any public road, transit capital projects, and on routes for nonmotorized transportation. Congress authorizes a single amount for each year for all the formula grant programs combined. That amount is then apportioned among the states based on statutory formulas. Those apportioned amounts are further divided among the formula grant programs. Once this funding is apportioned and divided among the programs, states may obligate the funds for eligible activities on eligible roads.
- **Discretionary grants.** Congress also authorizes funding for the highway program through a variety of discretionary grant programs. FHWA awards grants to applicants based on the conditions specific to

¹⁸Fixing America's Surface Transportation Act, Pub. L. No. 114-94, § 1101, 129 Stat. 1312, 1322 (2015).

¹⁹Continuing Appropriations Act, 2021 and Other Extensions Act, Pub. L. No. 116-159, div. B, tit. I, § 1101(b), 134 Stat. 709, 725 (2020).

each program. These conditions—including eligibility and selection criteria—may be established by law or regulation. For example, Congress has created the National Scenic Byways Program to offer grants and technical assistance to states and Indian tribes for projects that, among other things, protect scenic, historical, recreational, cultural, natural, and archaeological resources in an area adjacent to scenic byways. Through discretionary grants, Congress or DOT can establish desired goals or outcomes, such as improving the condition of critical infrastructure, enhancing economic competitiveness, or reducing fatalities. Congress has not previously authorized a discretionary grant program specific to climate change or resilience.

- **Emergency Relief program.** Congress authorizes up to \$100 million annually to repair or reconstruct highways, roads, and trails seriously damaged or destroyed by natural disasters or catastrophic failures from other external causes.²⁰ FHWA provides assistance to states applying for funds and conducts oversight to determine eligibility and ensure that federal requirements are met. Congress also regularly provides funds to the Emergency Relief program from general revenues through supplemental appropriations.²¹ A total of about \$4.5 billion in such additional funding has been made available for the Emergency Relief program beginning in fiscal year 2016.

²⁰Congress has provided funds for highway emergency relief since at least 1938 and, since 1972, has authorized \$100 million annually in “contract authority” for FHWA’s Emergency Relief program to be paid from the Highway Trust Fund. 23 U.S.C. § 125. As described in FHWA’s Emergency Relief Manual, to be considered for Emergency Relief funding either the President must make a major disaster declaration under the Stafford Act or the governor of the state must issue an emergency or disaster proclamation and FHWA must concur with that declaration. See also 23 C.F.R. § 668.111(c). FHWA’s Emergency Relief program regulations define policies for the program and the eligibility requirements for selecting projects. These regulations state that Emergency Relief funds are not intended to correct preexisting deficiencies or duplicate assistance available under another federal program or compensation from insurance or other sources. 23 C.F.R. § 668.105(b), (e). The program is not intended to pay for “betterments,” projects that change the function or character of the highway facility, such as expanding road capacity. However, FHWA may determine that betterments are eligible for program funding if they pass a benefit-cost test that weighs their cost against the prospective cost to the Emergency Relief program for potentially chronic future repairs.

²¹E.g., Additional Supplemental Appropriations for Disaster Relief Act, 2019, Pub. L. No. 116-20, tit. IX, 133 Stat. 871, 895; Bipartisan Budget Act of 2018, Pub. L. No. 115-123, tit. XI, 132 Stat. 64, 102.

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- **Resilience research pilot projects.** In 2010, FHWA started funding resilience research pilot projects under its statutory research authorities, according to FHWA officials.²² FHWA provided funding to states and other organizations to conduct vulnerability assessments and develop resilience enhancement options for roads.

FHWA. FHWA supports state and local governments in the design, construction, and maintenance of the nation’s highway system through financial and technical assistance under the federal-aid highway program. For example, FHWA distributes block grant funding to the states in accordance with formulas set in law, approves state surface transportation improvement programs and applications for Emergency Relief funding, and oversees state programs to monitor the effective and efficient use of federal funds.

FHWA uses a decentralized organizational structure to administer the federal-aid highway program. In this decentralized structure, oversight and administration of the program is largely delegated to FHWA’s 52 state division offices. Through its division offices, FHWA engages in a range of activities to encourage the effective and efficient use of federal-aid highway funding and assist states in progressing projects through construction to improve the highway system. To accomplish these tasks, FHWA works with states to identify issues, develop and advocate solutions, approve and obligate project funding for eligible activities, and provide technical assistance and training to state DOTs. To ensure that states comply with federal laws and regulations, FHWA’s division offices conduct oversight of federally funded projects and review state DOT capacity and systems used to administer approved projects.

FHWA and the state divide or share project-level oversight. FHWA uses a risk-based approach to decide how to divide stewardship and oversight responsibilities with the state. For projects where both FHWA and the state share oversight responsibilities, the respective responsibilities are generally mapped out in a state-specific Stewardship and Oversight Agreement and in Stewardship and Oversight Plans for individual projects. Generally, FHWA performs more oversight responsibilities on Interstate Highway Projects and other projects on the National Highway System than on projects that are not on the National Highway System, according to FHWA officials.

²²23 U.S.C. § 503(b)(3)(C)(xv).

States. Under the federal-aid highway program, states select which projects are funded and are generally responsible for overseeing project development and construction. To receive federal transportation funding, at least once every 4 years, each state is required to prepare a Statewide Transportation Improvement Program (STIP), which lists the surface transportation projects within the state for the next 4 years. For urbanized areas, defined in statute as areas with a population of 50,000 or more, states must coordinate planning activities with metropolitan planning organizations—federally recognized organizations representing local governments that lead transportation-planning activities in metropolitan areas. In non-metropolitan areas, states must work in consultation with affected local officials with responsibility for transportation. Once the STIP is approved by FHWA, the state generally selects which projects in the STIP will be implemented. Emergency Relief funds are not planned and programmed through the STIP; instead, projects on federal-aid highways for each eligible event must be approved by FHWA.

**Executive Order 14008,
*Tackling the Climate Crisis
at Home and Abroad***

Executive Order 14008, *Tackling the Climate Crisis at Home and Abroad*, states that it is the policy of the administration to deploy the full capacity of federal agencies to, among other things, combat climate change and implement a government-wide approach that increases resilience to the impacts of climate change.²³ Executive Order 14008, issued January 27, 2021, established the National Climate Task Force to organize and deploy this government-wide approach, and it made the Secretary of Transportation a task force member. The order directs Climate Task Force members, to the extent permitted by law, to prioritize action on climate change in their policy-making and budget processes, in their contracting and procurement, and in their engagement with state, local, tribal, and territorial governments; with workers and communities; and with leaders across all sectors of the economy. The order also directs agencies, including DOT, to submit a climate action plan that describes steps the agency can take with regard to its facilities and operations to bolster adaptation and increase resilience to the impacts of climate change, submit annual progress reports on the plan, and make action plans publicly available. Per the order, these action plans should describe the agency's climate vulnerabilities and plans to use the power of procurement to ensure that government installations, buildings, and facilities are climate-ready. In preparing the action plans, agencies should seek to increase the federal government's resilience against supply chain

²³86 Fed. Reg. 7619 (Feb. 1, 2021).

disruptions. Agencies are in the process of implementing Executive Order 14008.

Climate Resilience as a Risk Management Strategy to Reduce Federal Fiscal Exposure

Enhancing climate resilience can be a risk management strategy to reduce federal fiscal exposure. Numerous studies have concluded that climate change poses risks to many environmental and economic systems and creates a significant fiscal exposure to the federal government. For example, according to the 2018 *Fourth National Climate Assessment*, the continued increase in the frequency and extent of high-tide flooding due to sea level rise threatens America's trillion-dollar coastal property market and public infrastructure, with cascading impacts on the larger economy. The assessment also noted that an increase in the number of hot days projected to reach sustained temperatures above 90 degrees would make 5.8 million miles of paved roads susceptible to increased rutting, cracking, and buckling.²⁴ We added *Limiting the Federal Government's Fiscal Exposure by Better Managing Climate Change Risks* to our High-Risk List in 2013, and we most recently updated this list in March 2021.²⁵ We have reported that government-wide action is needed to reduce federal fiscal exposure in areas including, but not limited to, the federal government's roles as (1) insurer of property and crops; (2) provider of disaster aid; (3) owner or operator of infrastructure; (4) leader of a strategic plan to coordinate federal efforts; and (5) provider of data and technical assistance to state and local decision makers such as transportation engineers.

We have previously reported that enhancing climate resilience can help reduce federal fiscal exposure.²⁶ Enhancing climate resilience entails a continuous risk management process, according to the *Fourth National Climate Assessment*. Specifically, individuals and organizations become aware of and assess risks and vulnerabilities from climate and other drivers of change, take actions to reduce those risks, and learn over time. In December 2016, we reported on a risk management strategy that can help guide federal climate resilience efforts. Enterprise risk management is a forward-looking management approach that can help federal

²⁴USGCRP, *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, vol. 2 (Washington, D.C.: 2018).

²⁵[GAO-21-119SP](#).

²⁶For example, see [GAO-20-127](#) and [GAO-21-119SP](#).

agencies identify, assess, and manage risks, such as preparing for and responding to natural disasters.²⁷ In our December 2016 report, we identified six essential elements of enterprise risk management: (1) aligning the enterprise risk management process to goals and objectives, (2) identifying risks, (3) assessing risk, (4) selecting a risk response based on risk appetite, (5) monitoring risks to see whether risk responses are successful, and (6) communicating and reporting on risks. For example, prioritizing the federal response to risk requires considering both the likelihood of the risk and the impact of the risk on an agency's mission.

Many current and future climate-change impacts require immediate actions; therefore, climate resilience efforts need to be focused where urgent action is needed, according to the National Academies.²⁸ While it will not be possible to eliminate all risks associated with climate change, if the nation prioritizes federal climate risk management activities—such as climate resilience projects—it may be possible to minimize negative impacts and maximize the opportunities associated with climate change, according to the National Academies. Some agencies have made efforts to manage climate change risk within existing programs and operations—a concept known as “mainstreaming”—and these efforts may convey climate resilience benefits. For example, an agency planning to build a seawall to protect a coastal facility might build it higher to account for rising sea level projections. According to the *Fourth National Climate Assessment*, a significant portion of climate risk can be addressed by mainstreaming, which can provide many climate resilience benefits.

GAO's Disaster Resilience Framework

We have previously reported that the federal government has primarily funded disaster resilience projects in the wake of disasters—when

²⁷GAO, *Enterprise Risk Management: Selected Agencies' Experiences Illustrate Good Practices in Managing Risk*, [GAO-17-63](#) (Washington, D.C.: Dec. 1, 2016). According to OMB Circular A-123, federal leaders are responsible for implementing management practices that identify, assess, respond, and report on risk. The circular directs federal agencies to implement enterprise risk management to better ensure their managers are effectively managing risks that could affect the achievement of agency strategic objectives. Enterprise risk management is an effective agency-wide approach to addressing the full spectrum of an organization's risks as an interrelated portfolio, rather than addressing risks only within silos.

²⁸National Research Council of the National Academies, *America's Climate Choices: Panel on Adapting to the Impacts of Climate Change, Adapting to the Impacts of Climate Change* (Washington, D.C.: 2010).

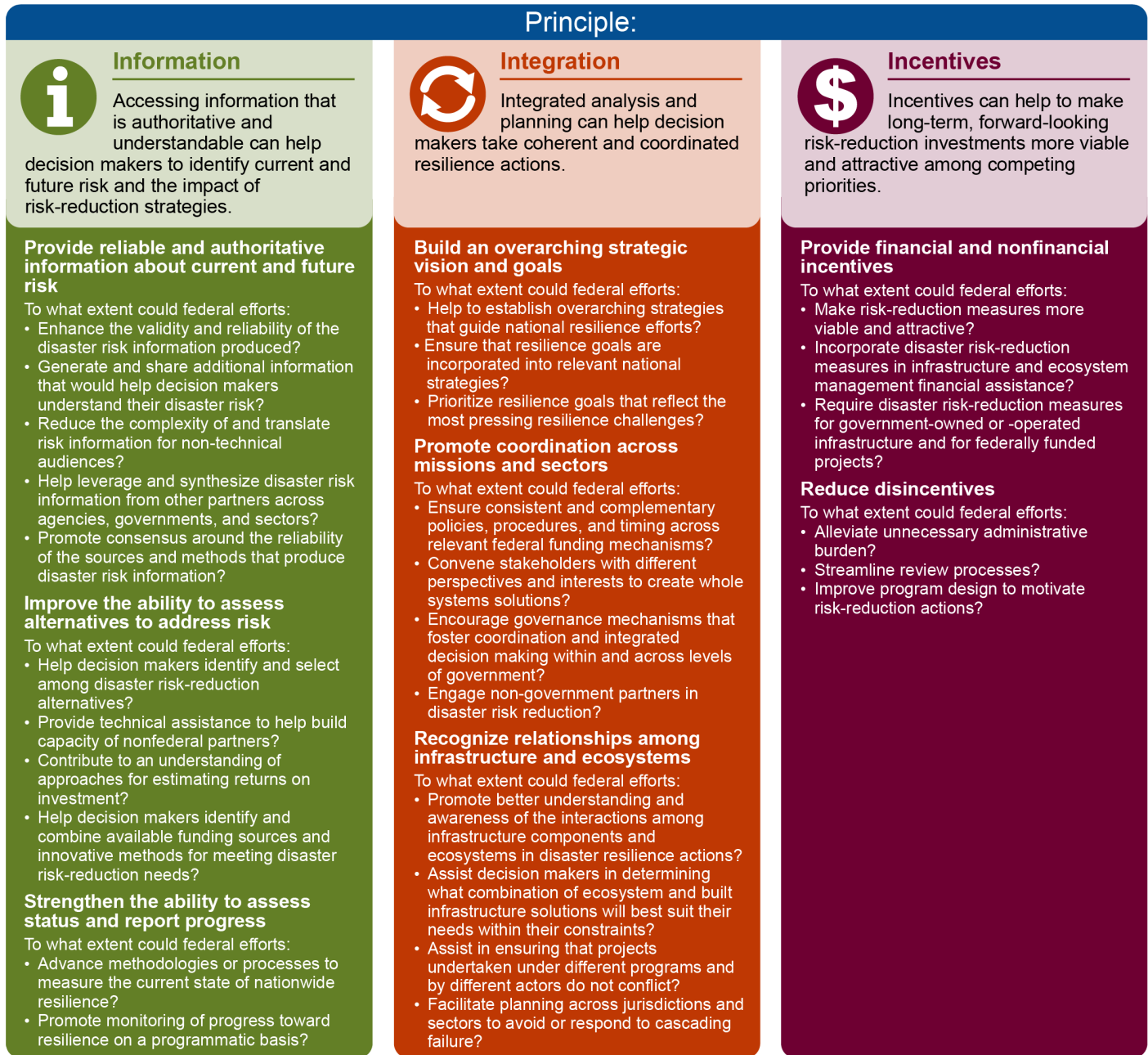
damages have already occurred and opportunities to pursue future risk reduction may conflict with the desire for the immediate restoration of critical infrastructure.²⁹ In October 2019, we issued the *Disaster Resilience Framework* to serve as a guide for analysis of federal actions to facilitate and promote resilience to natural disasters and changes in the climate.³⁰ According to the *Framework*, investments in disaster resilience are a promising avenue to address federal fiscal exposure because such investments offer the opportunity to reduce the overall impact of disasters.

The *Framework* is organized around three guiding principles—information, integration, and incentives—and a series of questions that can help identify opportunities to enhance federal efforts to promote disaster resilience (see figure 2). For example, incentives can help make long-term, forward-looking risk-reduction investments more viable and attractive among competing priorities. Under this principle, the *Framework* asks to what extent federal efforts could require disaster risk-reduction measures for federally funded projects or could make risk-reduction measures more viable and attractive.

²⁹See [GAO-20-100SP](#) and GAO, *Hurricane Sandy: An Investment Strategy Could Help the Federal Government Enhance National Resilience for Future Disasters*, [GAO-15-515](#) (Washington, D.C.: July 30, 2015).

³⁰[GAO-20-100SP](#).

Figure 2: GAO's Disaster Resilience Framework



Source: GAO. | GAO-21-436

These principles can be applied to any federal effort—post-disaster, pre-disaster, and outside the traditional disaster preparedness and recovery domain—to help federal agencies and policy makers consider what kinds of actions to take if they seek to promote and facilitate disaster risk reduction. Users of the *Disaster Resilience Framework* can consider its principles and questions to analyze any type of existing federal effort, identify gaps in existing federal efforts, or consider the federal role. Specifically, this *Framework* can be used to identify opportunities to address gaps in federal efforts, for example, by supporting identification of options to address government-wide challenges that are of a scale and scope not addressed by existing programs. Because not all parts of the *Framework* will be relevant for every effort, users also can adapt the principles to the specific circumstances of the effort they are considering by applying portions of the *Framework*.

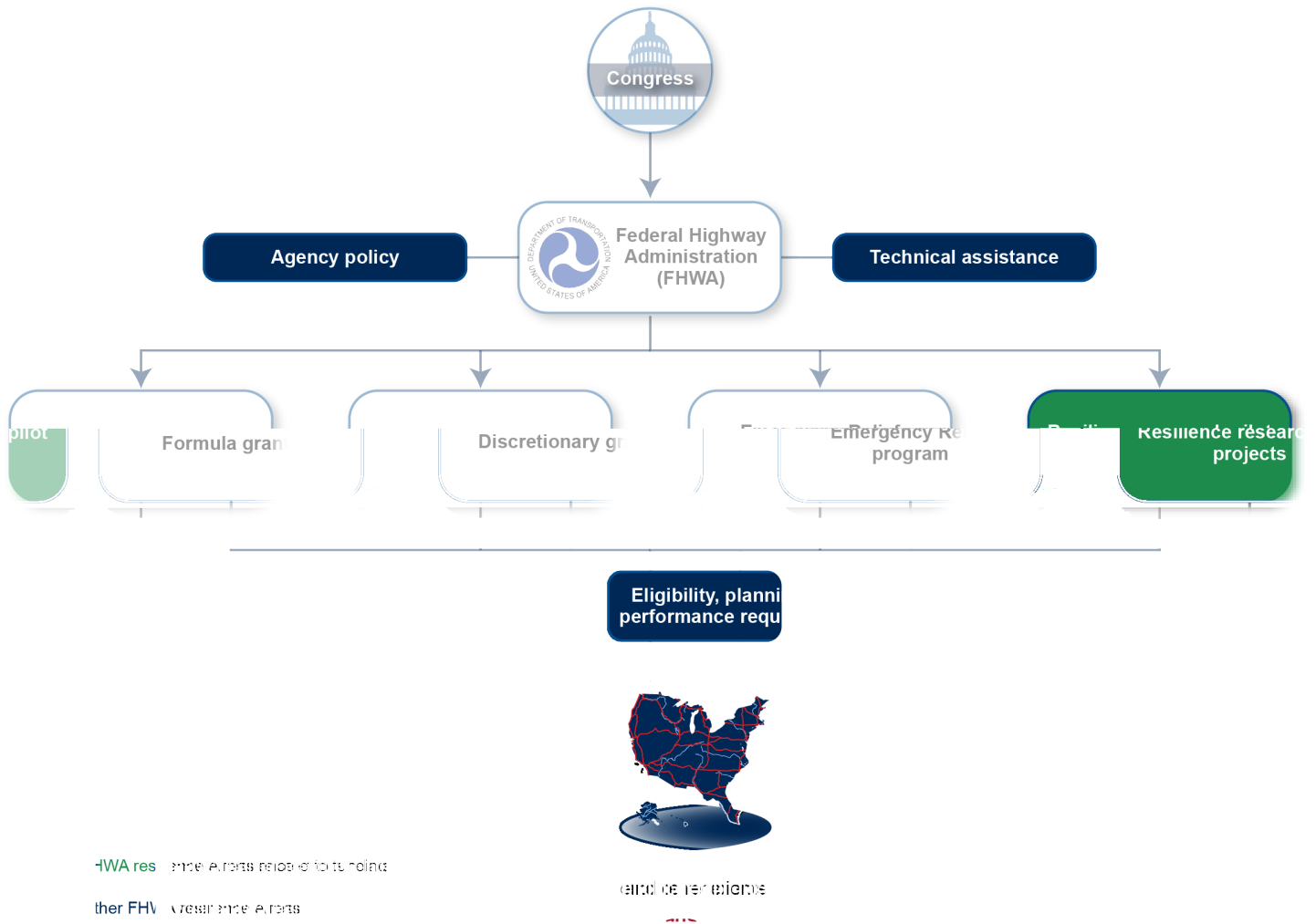
FHWA’s Efforts Show the Potential to Enhance the Climate Resilience of Federally Funded Roads

During the last 10 years, FHWA undertook targeted efforts to encourage states to enhance the climate resilience of federally funded roads by developing agency policy, providing technical assistance to states, administering resilience research funding, and clarifying funding eligibilities and federal requirements. These efforts show the potential to enhance the climate resilience of federally funded roads on a wider scale.

FHWA’s Targeted Climate Resilience Efforts Include Developing Policy, Providing Technical Assistance, Funding Resilience Research, and Clarifying Eligibilities and Requirements

FHWA’s primary role in enhancing the climate resilience of federally funded roads has been to support states that wish to take action. FHWA’s targeted efforts to promote climate resilience include: (1) developing agency policy; (2) providing technical assistance to help states use climate projection information and assess vulnerabilities; (3) co-funding resilience research pilot projects; and (4) clarifying existing funding eligibilities and relevant federal requirements for projects that enhance resilience. These efforts are relatively new, according to FHWA officials. See figure 3 for a depiction of how FHWA’s current climate resilience efforts fit within the federal funding process for roads.

Figure 3: Federal Highway Administration Climate Resilience Efforts within the Federal Funding Process for Roads



Note: We focus on FHWA climate resilience efforts. In certain circumstances, states may also use federal funds provided through formula grants, discretionary grants, and the Emergency Relief program to improve the resilience of federally funded roads. However, FHWA officials told us that they do not systematically track states' resilience efforts.

Developing Policy

During the last 10 years, FHWA developed agency policy on improving the resilience of the nation's roads. Specifically, in 2014, FHWA issued FHWA Order 5520 to implement its statutory responsibilities and comply with the now-rescinded Executive Order 13653 and a DOT policy

statement on climate change adaptation.³¹ FHWA officials told us that they continue to implement FHWA Order 5520.³² This order aims to integrate climate risk considerations into FHWA planning, operations, policies, and programs. The policy discusses FHWA responsibilities for doing so. For example, the policy states that FHWA staff will develop and provide technical assistance, research, and outreach, and will encourage the development and use of transportation-specific vulnerability assessment and adaptation tools.

Providing Technical Assistance

During the last 10 years, FHWA also provided states with technical assistance aimed at improving the climate resilience of federally funded roads. This assistance focused on developing tools that states can use to evaluate vulnerabilities and resilience options and to integrate climate change information into road projects. FHWA encourages use of these tools by hosting webinars and other information-sharing events. During these events, FHWA provides guidance on using its tools, and states share their experiences using them. FHWA has solicited feedback from states on ways to improve its assistance.

FHWA developed several tools for evaluating vulnerabilities and resilience options. For example, the *Vulnerability Assessment and Adaptation Framework* describes steps that states can take to identify vulnerable roads and provides guidance for incorporating assessment results into transportation-planning processes.³³ Certain FHWA technical manuals also help engineers assess climate risks and mitigation options in riverine and coastal environments.³⁴ In addition, an FHWA report synthesizing approaches to addressing resilience in project development

³¹See *Preparing the United States for the Impacts of Climate Change*, Exec. Order No. 13,653, 78 Fed. Reg. 66,819 (Nov. 1, 2013); and U.S. Department of Transportation, *Policy Statement on Climate Change Adaptation*, June 2011.

³²Federal Highway Administration, *FHWA Order 5520: Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events*, (Washington, D.C.: Dec. 15, 2014).

³³Federal Highway Administration, *Vulnerability Assessment and Adaptation Framework*, 3rd ed., FHWA-HEP-18-020, (Washington, D.C.: December 2017).

³⁴See Federal Highway Administration's *Hydraulic Engineering Circular 17: Highways in the River Environment – Floodplains, Extreme Events, Risk and Resilience*, 2nd ed., FHWA-HIF-16-018 (Washington, D.C.: June 2016) and *Hydraulic Engineering Circular 25: Highways in the Coastal Environment*, 3rd ed., FHWA-HIF-19-059, (Washington, D.C.: January 2020).

identifies ways that road project implementers can, among other things, conduct economic analyses to identify the most efficient options, understand tradeoffs between options, and justify resilience investments.³⁵

FHWA also developed several tools for integrating climate change information into road projects. For example, the Vulnerability Assessment Scoring Tool helps states rank order their roads based on their vulnerability to specific climate stressors. In addition, the Coupled Model Intercomparison Project Climate Data Processing Tool allows road project managers and engineers to download climate projection information, such as frequencies of extreme precipitation events, for each of the 30,000-square mile grids in which they have assets. The tool uses climate projection information from the World Climate Research Programme. Through this and other FHWA tools, FHWA officials have attempted to connect road project managers with publicly available climate projection information developed by other organizations and federal agencies.

Funding Resilience Research

During the last 10 years, FHWA supported the development of vulnerability assessments and resilience enhancement options for roads by funding resilience research. Specifically, FHWA co-funded more than 50 resilience research pilot projects to: assess vulnerabilities and options for improving resilience; evaluate the potential for nature-based features, such as wetlands, to protect coastal assets; and develop approaches for integrating climate resilience into asset management and other processes. According to FHWA officials, the grants have varied in size—from about \$38,000 to \$300,000. As of July 2021, FHWA had awarded a total of \$7.2 million in resilience research grant funds to state departments of transportation, metropolitan planning organizations, and other organizations.

Virginia and Oregon provide two examples of how states have used these grants. The Virginia Department of Transportation (VDOT) used its grant to identify which assets are most exposed to climate risks using FHWA's draft *Risk Assessment Model*.³⁶ VDOT also used its grant to assess interactions between climate factors (e.g., sea level rise) and non-climate factors (e.g., economic conditions). For example, the project team

³⁵Federal Highway Administration, *Synthesis of Approaches for Addressing Resilience in Project Development*, FHWA-HEP-17-082, (Washington, D.C.: July 2017).

³⁶The Federal Highway Administration used its draft *Risk Assessment Model* to develop the *Vulnerability Assessment and Adaptation Framework*.

Clarifying Eligibilities and Requirements

analyzed the interaction between economic downturns and governments' abilities to implement climate change response measures. The Oregon Department of Transportation used its grant to develop green infrastructure resilience-enhancement designs to mitigate storm impacts and erosion along coastal U.S. Highway 101 and analyze their potential effectiveness. Design options included cobble beaches, artificial dunes, and planted terraces.

FHWA shared the information that grantees collected during their research. For example, FHWA hosted webinars and organized informational peer exchanges to share project results. Participants also published final study reports covering topics such as the work they did, the challenges they faced, and the lessons they learned. These reports are published on FHWA's public web site.³⁷

FHWA also clarified eligible uses of federal funds and resilience requirements and is taking steps to implement relevant laws and regulations. For example, in 2013, FHWA updated its Emergency Relief guidance.³⁸ This guidance now states that the design and construction of repairs should consider long-term resilience. It also calls for state DOTs to evaluate proposed replacements' resilience and consider incorporation of cost effective features that will make the replacements resilient and reduce the risk of future damage. FHWA also distributed a memorandum in 2019 advising states on how projects funded through the Emergency Relief program can incorporate resilience enhancements.³⁹ In addition, FHWA disseminated a memorandum explaining that federal funds can be used for projects that protect existing or new roads—if the protections are adequately justified.⁴⁰ See table 1 for *United States Code* and *United States Code of Federal Regulations* citations related to enhancing the resilience of federally funded roads.

³⁷See <https://www.fhwa.dot.gov/environment/sustainability/resilience/pilots/>.

³⁸Federal Highway Administration, *Emergency Relief Manual* (Washington, D.C.: May 31, 2013). FHWA officials told us that states have used federal and Emergency Relief funds to implement resilience improvements and that these funds have led to increased resilience on certain facilities.

³⁹Federal Highway Administration, *Integration of Resilient Infrastructure in the Emergency Relief Program* (Washington, D.C.: Oct. 11, 2019).

⁴⁰Federal Highway Administration, *Eligibility of Activities to Adapt to Climate Change and Extreme Weather Events Under the Federal-Aid and Federal Lands Highway Program*, (Washington, D.C.: Sept. 24, 2012).

Table 1: United States Code (U.S.C.) and Code of Federal Regulations (C.F.R.) Citations Related to Enhancing the Resilience of Federally Funded Roads

| U.S.C./C.F.R. Entry | Description |
|-------------------------------|--|
| 23 U.S.C. § 119(d)(1)(B), (C) | Funds apportioned to states through the National Highway Performance Program of the federal-aid highway program may be used for projects on eligible facilities that construct, replace, rehabilitate, preserve, and protect bridges and tunnels on the National Highway System. ^a Protection measures for bridges include: scour countermeasures, ^b seismic retrofits, impact protection measures, security countermeasures, and protection against extreme events. Protection measures for tunnels include: impact protection measures, security countermeasures, and protection against extreme events. |
| 23 U.S.C. § 133(b)(9) | Funds apportioned to states through the Surface Transportation Block Grant Program of the federal-aid highway program may be used for the protection of bridges and tunnels on public roads. ^c Protection efforts may include: painting, scour countermeasures, ^b seismic retrofits, impact protection measures, security countermeasures, and protection against extreme events. |
| 23 U.S.C. § 503(b)(3)(C)(xv) | The Secretary of Transportation must carry out highway and bridge infrastructure research and development activities, which may include conducting studies to enhance the resilience of physical infrastructure systems to changes in climate. |
| 23 U.S.C. § 135(d)(1)(I) | Each state must provide for consideration and implementation of projects, strategies, and services that will improve the resiliency and reliability of the transportation system and reduce or mitigate storm water’s impacts on surface transportation, in the statewide transportation-planning process. |
| 23 U.S.C. § 134(h)(1)(I) | Each metropolitan planning organization must provide for consideration of projects and strategies that will improve the resiliency and reliability of the transportation system and reduce the impact of storm water on surface transportation, in the metropolitan transportation-planning process. |
| 23 C.F.R. § 515.7(b) | When developing risk-based asset management plans, states must establish a process for conducting life-cycle planning for their assets. The life-cycle planning process should include: future changes in demand as well as information regarding current and projected environmental conditions inclusive of extreme weather events, climate change, and seismic activity. |
| 23 C.F.R. pt. 667 | State departments of transportation (DOT) must evaluate roads, highways, and bridges that have, on more than two occasions, required repair or reconstruction because of emergency events. The results from these evaluations should be used to determine if reasonable alternatives can be developed to: (1) decrease the amount of federal funds spent on repairs (2) increase public safety and enhance human and environmental health, and (3) ensure transportation needs, as determined by the state DOT, are met. |

Source: GAO summary of laws and regulations related to resilience. | GAO-21-436

^aThe National Highway Performance Program provides support for the condition and performance of the National Highway System (NHS) for the construction of new facilities on the NHS, and ensures that investments of federal-aid funds in highway construction are directed to support progress toward the achievement of performance targets established in a state’s asset management plan for the NHS.

^bScour is the erosion of a streambed or bank material due to flowing water. 23 C.F.R. § 650.305.

^cAs described by FHWA, the Surface Transportation Block Grant Program provides flexible funding that may be used by states and localities for projects to preserve and improve the conditions and performance on any federal-aid highway, bridge, and tunnel projects.

FHWA is taking steps to implement relevant laws and regulations. For example, FHWA officials told us that they are implementing the Repeatedly Damaged Facilities rule, which requires that states conduct statewide evaluations to determine if there are any reasonable alternatives to roads that have required repair and reconstruction on two

or more occasions due to emergency events, such as natural disasters.⁴¹ The rule specifies that the evaluation include identification and consideration of any alternative that will mitigate, or partially or fully resolve, the root cause of the recurring damage—and consider the risk of recurring damage and cost of future repair under current and future environmental conditions.⁴² The agency disseminated guidance advising states on the rule in late 2018 and plans to periodically review the extent to which states are complying with this rule.⁴³

Another regulation requires states to establish a process for establishing asset management plans. The process shall, among other things, identify risks to the National Highway System.⁴⁴ Risks identified are to include risks associated with current and future environmental conditions, such as climate change, as well as risks identified through evaluations of repeatedly damaged facilities.⁴⁵ FHWA officials told us that FHWA has developed guidance that addresses life-cycle planning and funded resilience pilots that focus on integrating resilience into states' asset management programs. However, FHWA has not yet established criteria for how asset management plans should address resilience alternatives for repeatedly damaged assets. In addition, FHWA officials said that the agency does not yet have a clear understanding of how states are integrating resilience information into their asset management plans.

FHWA's Climate Resilience Efforts Show the Potential to Enhance the Climate Resilience of Federally Funded Roads

FHWA's climate resilience efforts, as implemented in specific projects, show the potential to enhance the climate resilience of federally funded roads. Specifically, we identified projects in four states—Arizona, Delaware, Maryland, and Washington State—that used FHWA resilience resources and climate projection information to plan or implement

⁴¹23 C.F.R. § 667.1.

⁴²23 C.F.R. § 667.3.

⁴³Federal Highway Administration, *Questions and Answers Regarding Implementation of 23 CFR Part 667: Periodic Evaluation of Facilities Repeatedly Requiring Repair and Reconstruction Due to Emergency Events*, (Washington, D.C.: Nov. 26, 2018).

⁴⁴23 C.F.R. § 515.7 (c)(1).

⁴⁵23 C.F.R. § 515.7(c)(1).

Arizona

St. David Bridge, State Route 80

Location: St. David, Arizona

Federal funding: Approx. \$7.5 million from the federal-aid highway program's Surface Transportation Block Grant Program.

Why Arizona Department of Transportation (ADOT) is making resilience enhancements: (1) to address severe erosion (shown below, top) due to the convergence of two rivers at the project site, which removes soil around the bridge and may reduce the life cycle of the bridge (shown below, bottom) and (2) to address concerns that the bridge could be overtopped during a 50-year storm event.



Planned Resilience Enhancements: ADOT plans to reduce the number of bridge spans subject to erosion and deepen the bridge's vertical supports.

Source: GAO analysis of information from U.S. Geological Survey (USGS) and ADOT. Photos: USGS (top) and ADOT (bottom). | GAO-21-436

physical resilience enhancements on federally funded roads.⁴⁶ These selected projects illustrate the potential that FHWA's current efforts—and climate resilience efforts more broadly—have to help improve the resilience of the nation's roads. We provide brief descriptions of the projects below and more detailed descriptions in appendix II.

The Arizona Department of Transportation (ADOT) used resilience research funds from FHWA, with a state match, to study ADOT's vulnerabilities to weather and natural hazards, including climate change, and how to integrate science-based decision-making about climate stressors into asset management processes, with a particular focus on developing infrastructure life-cycle planning and risk-management methodologies. In addition, for the three sites we visited in Arizona—the St. David Bridge, the Gila River Bridge on State Route (SR) 79, and the Gila River Bridge on Interstate 10—ADOT used FHWA's Coupled Model Intercomparison Project Climate Data Processing Tool to download project-level climate projection information, such as frequencies of very hot days and future precipitation trends, for the 30,000-square mile area in which the assets are located.

Using funds from the federal-aid highway program, ADOT also obtained more granular data needed to make engineering decisions about how to improve the climate resilience of these sites. For example, ADOT officials used federal-aid highway program funds to obtain data on average stream flows and depths during storms events—and to analyze how the components of the St. David Bridge (e.g., the bridge spans)⁴⁷ could deteriorate under various long-term climate scenarios. This information

⁴⁶We completed an in-person site visit to Arizona and gathered information on project sites from the remaining states (Delaware, Maryland, and Washington State) by phone and email due to COVID-19 pandemic travel restrictions. We identified seven projects in these states that used FHWA resilience resources and climate projection information to plan or implement physical resilience enhancements on federally funded roads. We identified these projects by first reviewing project descriptions for resilience research pilot projects funded by the Federal Highway Administration. Next, we obtained referrals from stakeholder organizations for additional projects that might meet our search criteria. Using this methodology, we identified 27 planning organizations and state DOTs that were likely to have begun or completed physical resilience enhancements on federally funded roads using federal funding, FHWA's resilience resources, and climate projection information. We contacted these 27 organizations to confirm whether they had any projects that met all of our search criteria. We found seven projects that met our search criteria. Findings from our reviews of these seven resilience projects are not generalizable and do not imply that only seven projects exist nationwide. See appendix I for additional information about our methodology.

⁴⁷A bridge span is a section of the bridge's superstructure that carries traffic.

and analysis informed decisions about redesigning the bridge, which has reached the end of its service life. ADOT officials decided to reduce the number of bridge spans subject to erosion and deepen the bridge's vertical supports to enhance its resilience to anticipated hydrologic conditions at the site. For additional information about why and how ADOT planned resilience enhancements at the three sites we visited in Arizona, see appendix II.

Delaware

The Delaware Department of Transportation (DelDOT) also benefited from FHWA resilience research funding and resilience tools. Specifically, project implementers for a project on Delaware State Route 1—a major access route to state beaches and tourist facilities—applied for and received FHWA resilience research funding to document vulnerabilities and a rationale for addressing them with green infrastructure techniques. They did so because the site floods and closes to traffic a few times every year, and DelDOT engineers hoped to address flooding associated with high-tide and wind events. They thought that green infrastructure techniques could enhance drainage capacity. DelDOT officials used their grant funds to hire consultants to help them reconcile available data sets and incorporate climate change information into specific site assessments. They also used FHWA's *Vulnerability and Adaptation Assessment Framework* to identify which resources and data they would need to design a resilience project in a coastal location. Ultimately DelDOT officials decided on a combination of gray infrastructure (e.g., repairing a rock wall) and green infrastructure (e.g., building a sand dune levee and tidal marsh) improvements for the site. See figure 4 for a photograph of flooding along Delaware State Route 1 near Seashore State Park and a rendering of the resilience enhancements implemented at the project site in Dewey Beach. For additional information about why and how DelDOT planned resilience enhancements on SR 1, see appendix II.

Figure 4: Flooding (Left) and Resilience Enhancements Made (Right) on Delaware State Route 1



Source: Delaware Department of Transportation (2017 and 2018). Photo is from 2017 and the rendering was published in 2018. | GAO-21-436

Maryland

Reconstruction, U.S. Route 113

Location: Snow Hill, Maryland

Federal funding: Approximately \$64 million from the National Highway Performance Program.

Why the Maryland Department of Transportation State Highway Administration (MDOT SHA) made resilience enhancements here: MDOT SHA replaced a 2-lane highway with a divided 4-lane highway and new bridge to improve safety, as this roadway experienced more fatal accidents than comparable roads. However, the project area is expected to experience 2 feet of sea level rise, and hydraulic analyses indicated that the new bridge would be overtopped under these conditions. This is a designated emergency route, so ensuring that sea level rise would not compromise it was paramount.

Resilience enhancements made: MDOT SHA raised the new bridge and its approaches by approximately 2 feet.



Source: GAO analysis of information from MDOT SHA.
Photo: MDOT SHA. | GAO-21-436

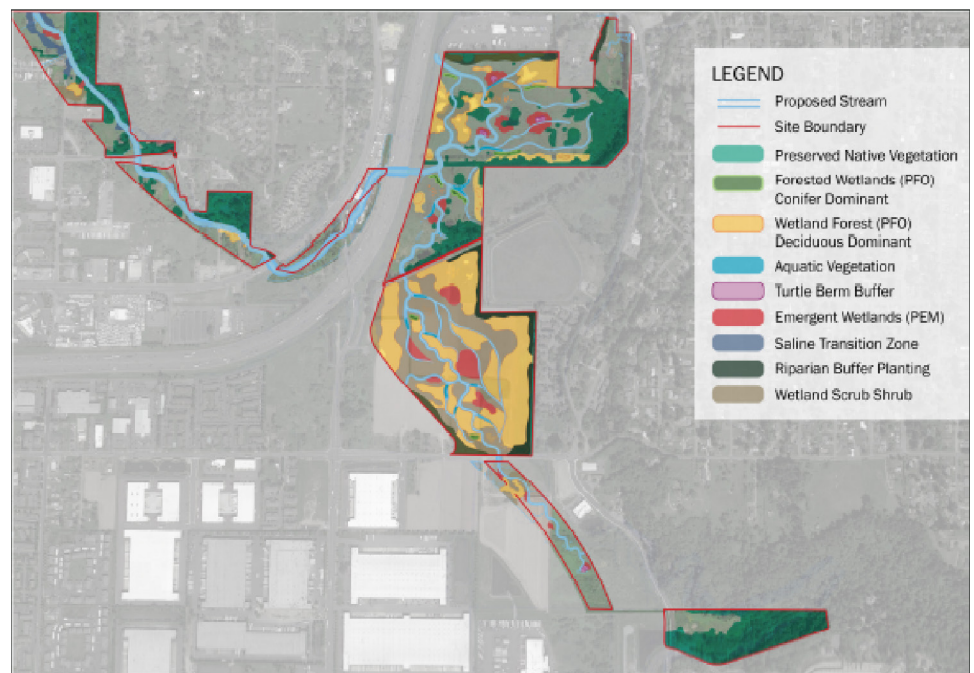
The Maryland Department of Transportation State Highway Administration (MDOT SHA) benefited from FHWA resilience research funding and other resilience resources when designing the two projects we reviewed, U.S. Route 113 in Snow Hill and MD 261 in North Beach. For example, MDOT SHA used resilience research funds to prepare a statewide assessment report of how climate changes could affect the state's roads. MDOT SHA's report contained tables reflecting projected changes in sea level rise for many Maryland counties. These data drove the project implementers for MD 261 to raise the bridge at the project site by approximately 2 feet. In another example, project implementers for U.S. Route 113 used FHWA guidance on how to project future sea levels for road projects. Based on this guidance, they determined that they would need to raise both the new bridge planned for the site and the approaches to the bridge by about 2 feet. For additional information about why and how MDOT SHA planned resilience enhancements on U.S. Route 113 and MD 261, see appendix II.

Washington State

Officials from the Washington State Department of Transportation (WSDOT) used an FHWA resilience tool to help them design a resilience enhancement to the future interchange area for Interstate 5 (I-5). WSDOT is investing about \$750 million to connect SR 167 to I-5 to improve the movement of goods to and from the Port of Tacoma. Relatively flat topography makes the project area vulnerable to flooding during even moderate storms, which can cause lane closures and congestion on this critical commercial route. Therefore, project implementers were committed to including design features in the project to protect the state's investment against future flooding. They used FHWA's Coupled Model Intercomparison Project Climate Data Processing Tool to confirm that the

project's planned green infrastructure elements—including extensive wetland restoration, stream restoration, and floodplain storage elements—would accommodate projected future flooding. Figure 5 shows design plans for the project. For additional information about why and how WSDOT planned resilience enhancements at the project site, see appendix II.

Figure 5: Design Plan for Restoring Streams, Wetlands, and Floodplains in the Future Interchange Area for Interstate 5 and Washington State Route 167



Source: Washington State Department of Transportation. | GAO-21-436

Options to Further Enhance the Climate Resilience of Federally Funded Roads Have Strengths and Limitations, and Implementing Multiple Options Offers the Most Potential

We identified 10 options to further enhance the climate resilience of federally funded roads based on a comprehensive review of relevant literature and interviews with knowledgeable stakeholders. Each of these options has strengths and limitations, according to knowledgeable stakeholders and relevant literature. FHWA officials said they would not comment on the strengths and limitations of these options but said the options include both actions that FHWA might undertake on its own and those that might require congressional action. According to the officials, FHWA would likely need additional congressional direction or authority to implement some options, but FHWA could likely implement aspects of some options under existing law. However, these officials told us that their authority to implement the options may depend on the specific policy proposal. GAO has not evaluated to what extent FHWA could implement these options without congressional action. Implementing multiple options could incorporate the strengths and address the limitations of the different options, and offers the most potential to improve the climate resilience of federally funded roads, according to knowledgeable stakeholders we interviewed, literature we reviewed, and our analysis of the options using our October 2019 *Disaster Resilience Framework*.⁴⁸ This *Framework* can be used to identify opportunities to address gaps in federal efforts by, for example, supporting identification of options to address government-wide challenges that are of a scale and scope not addressed by existing programs. Our comparison of the 10 options to further enhance the climate resilience of federally funded roads and FHWA's current climate resilience efforts using the information, integration, and incentives principles of the *Disaster Resilience Framework* shows how each option, if implemented, could further enhance the climate resilience of federally funded roads.⁴⁹

Each Option to Further Enhance the Climate Resilience of Federally Funded Roads Has Strengths and Limitations

We identified 10 options to further enhance the climate resilience of federally funded roads through FHWA-administered programs, such as by integrating climate resilience into federal funding for roads, based on a comprehensive review of relevant literature and interviews with knowledgeable stakeholders (see figure 6). Each of these options has strengths and limitations, according to knowledgeable stakeholders and

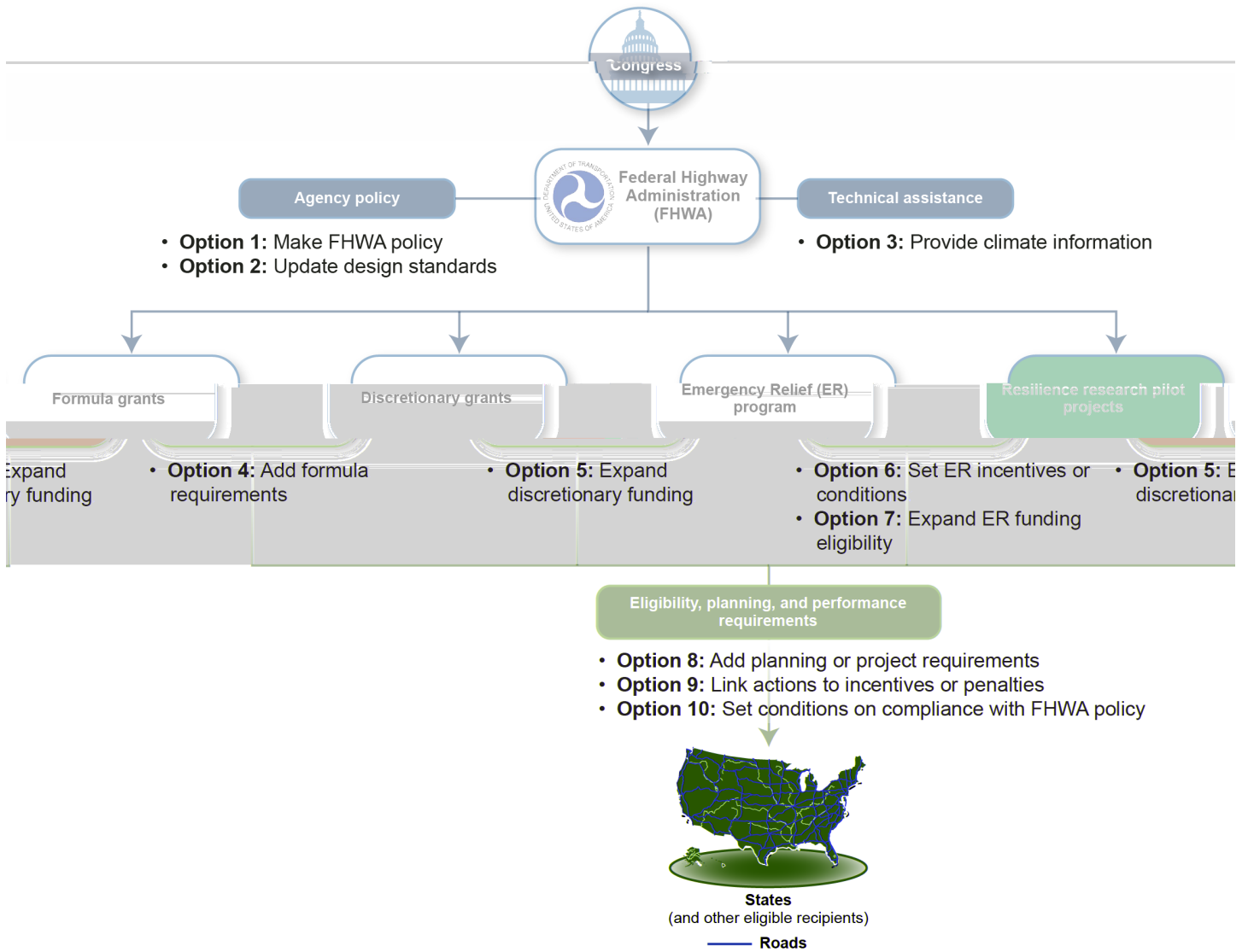
⁴⁸[GAO-20-100SP](#).

⁴⁹We used the *Disaster Resilience Framework* to identify the forward-looking positive effects achievable by implementing options to further enhance the climate resilience of federally funded roads in comparison to current FHWA efforts.

relevant literature.⁵⁰ Table 2 briefly summarizes the strengths and limitations of these options, each of which we discuss in more detail below.

⁵⁰We identified these options, provided examples of how these options could be implemented, and described their strengths and limitations based on a comprehensive review of relevant literature and 19 semi-structured interviews with knowledgeable stakeholders. When interviewing the stakeholders, we asked them to consider the options at a high-level, and to describe their strengths and limitations as they relate to limiting the federal government's fiscal exposure to climate change risks. To characterize knowledgeable stakeholder views, we defined "*some*" as 1 to 3 stakeholders, "*several*" as 4 to 9 stakeholders, and "*many*" as 10 or more stakeholders. We did not evaluate to what extent FHWA could implement these options without congressional action.

Figure 6: Options to Further Enhance the Climate Resilience of Federally Funded Roads



- FHWA resilience efforts related to funding
- Other FHWA resilience efforts

Source: GAO analysis of FHWA documents, relevant literature, and interviews with knowledgeable stakeholders. | GAO-21-436

Table 2: Strengths and Limitations of Options to Further Enhance the Climate Resilience of Federally Funded Roads

| Option | Strengths | Limitations |
|---|---|---|
| Option 1: Make Federal Highway Administration (FHWA) policy | | |
| Integrate climate resilience into FHWA policy and guidance. ^a | <ul style="list-style-type: none"> National policy can motivate action Clearly communicates FHWA priorities and expectations | <ul style="list-style-type: none"> Potential lack of long-term consistency and implementation May not reflect varying state capacities or risks |
| Option 2: Update design standards | | |
| Update design standards to account for climate change and resilience best practices. ^a | <ul style="list-style-type: none"> Updated codes, design standards, and related guidance can lead to broad uptake of best practices for climate resilience Removes information barrier to action | <ul style="list-style-type: none"> Depends on actions by non-governmental partners May be a slow process |
| Option 3: Provide climate information | | |
| Provide authoritative, actionable, forward-looking climate information. ^a | <ul style="list-style-type: none"> Facilitates informed decision-making Removes information barrier to action | <ul style="list-style-type: none"> Does not motivate or compel action Depends on actions by other federal entities |
| Option 4: Add formula requirements | | |
| Add climate resilience funding requirements, conditions, or criteria to formula funds. ^b | <ul style="list-style-type: none"> Compels action Mainstreams resilience into the majority of funding Distributes resilience funding broadly | <ul style="list-style-type: none"> Limits state flexibility and autonomy May not reflect varying state capacities or risks Formula funds may not address vulnerable roads that have many years left in their design life |
| Option 5: Expand discretionary funding | | |
| Expand the availability of discretionary funding for climate resilience improvements. ^a | <ul style="list-style-type: none"> Does not divert funding from other projects or create mandates Can support innovation through, for example, pilot programs or best practices research Could be used to target specific types of projects or areas of need Allows FHWA to define national priorities and expectations | <ul style="list-style-type: none"> Does not mainstream resilience or move it into standard practice Limits state flexibility and autonomy because FHWA decides what to prioritize May mismatch funding with risk because ability to write grants is not correlated with need May support politically influenced rather than broadly useful projects Creates administrative burdens for FHWA and states requesting funding May present transparency issues, given known challenges with discretionary grant programs |
| Option 6: Set Emergency Relief (ER) incentives or conditions | | |
| Alter the ER program by providing incentives for, or conditioning funding on, pre-disaster resilience actions. ^b | <ul style="list-style-type: none"> Incentivizes proactive approach in potential disaster areas Could incentivize states that haven't previously acted to invest in resilience | <ul style="list-style-type: none"> May not address resilience across the system of transportation assets and services Conditions may be waived when disasters hit Presents equity issues if ER funding is conditional rather than need-based May present monitoring challenges, given known issues with the ER program |

| Option 7: Expand ER funding eligibility | | |
|---|---|--|
| Expand the availability of ER funding for post-disaster climate resilience improvements. ^b | <ul style="list-style-type: none"> Incentivizes proactive approach to potential disaster areas Would support replacing or repairing roads to higher standards Would use post-disaster momentum to make resilience enhancements | <ul style="list-style-type: none"> May not address resilience across the system of transportation assets and services May not address long-term plans for highly vulnerable roads May provide an incentive to defer maintenance until disasters hit or to fund already planned projects May present monitoring challenges given known issues with the ER program |
| Option 8: Add planning or project requirements | | |
| Establish additional climate resilience planning or project requirements. ^a | <ul style="list-style-type: none"> Mainstreams resilience into planning processes May address resilience across transportation systems and communities May increase awareness of resilience issues | <ul style="list-style-type: none"> May take a long time to implement May not reflect varying state capacities or risks May lead to uneven implementation given varying state planning processes |
| Option 9: Link actions to incentives or penalties | | |
| Link climate resilience actions or requirements to incentives or penalties. ^b | <ul style="list-style-type: none"> Incentives motivate action Incentives can promote good practices Incentives could mitigate cost share and other fiscal challenges Penalties compel action | <ul style="list-style-type: none"> Incentives may be a slow approach to addressing climate risk Penalties may have unintended consequences Penalties may be difficult to enforce |
| Option 10: Set conditions on compliance with FHWA policy | | |
| Condition eligibility, funding, or project approval on compliance with climate resilience policy and guidance. ^b | <ul style="list-style-type: none"> Compels action Integrates resilience into the majority of funding | <ul style="list-style-type: none"> Limits state flexibility and autonomy May not reflect varying state capacities or risks May be difficult to track compliance |

Source: GAO analysis of information from literature and interviews with knowledgeable stakeholders. | GAO-21-436

Note: We identified these options and described their strengths and limitations based on a comprehensive review of relevant literature and 19 semi-structured interviews with knowledgeable stakeholders. Some strengths or limitations may be relevant to multiple options, but we reported overall themes as described by the knowledgeable stakeholders we interviewed. We did not evaluate to what extent FHWA could implement these options without congressional action. FHWA officials said they would not comment on the strengths and limitations of these options. According to the officials, generally speaking, FHWA would likely need additional congressional direction or authority to implement some options, but FHWA could likely implement aspects of some options under existing law. However, these officials told us that their authority to implement the options may depend on the specific policy proposal. FHWA officials also told us that they remain available to provide nonpartisan technical assistance when requested by Congress (e.g., technical opinions on how legislative decisions could affect the federal-aid highway program).

^aFHWA officials said that generally speaking, they could likely implement aspects of this option under existing law and said specific proposals would need to be evaluated.

^bFHWA officials said that generally speaking, they would likely need additional congressional direction or authority to implement this option and said specific proposals would need to be evaluated.

Option 1: Integrate Climate Resilience into FHWA Policy and Guidance

Integrating climate resilience into FHWA policy and guidance would have strengths and limitations, according to knowledgeable stakeholders and relevant literature. FHWA released a resilience policy in 2014 that focuses on FHWA responsibilities,⁵¹ but FHWA could do more with policy by establishing a high-level FHWA climate resilience policy that includes, for example, suggested steps or information on standards or best practices for states. FHWA could also provide technical climate resilience guidance on topics such as how states could incorporate climate projection information into road planning and design, or formal guidance on how states should implement laws and regulations relevant to resilience. According to FHWA officials, FHWA can make policy and provide additional guidance on resilience without additional statutory authority. However, FHWA officials told us that any FHWA guidance would be non-binding, and setting expectations or standards for states would go beyond making policy and could require regulatory or statutory changes.

- **Strengths.** National policy can motivate action, according to several stakeholders. It can also clearly communicate FHWA priorities and expectations, according to several stakeholders. For example, one stakeholder from a state DOT described this approach as an opportunity for FHWA to set national direction or a basic floor for standards that states could improve on. FHWA guidance on best practices could affect state processes by normalizing resilience into standard practices and influencing engineers and project design, according to several stakeholders. In another example, one stakeholder from a different state DOT said that because of its broad reach, FHWA is uniquely positioned to compile guidance by pulling together all of the practices being implemented nationwide. This stakeholder said that this guidance would be well received by states as a source of ideas.
- **Limitations.** One limitation of integrating climate resilience into FHWA policy and guidance is the potential lack of long-term consistency and implementation, according to several stakeholders. Specifically, FHWA priorities and expectations may fluctuate with political transitions if not included in regulation, according to these stakeholders. For example, one stakeholder from a state DOT told us that inconsistent guidance from federal agencies can create difficulties

⁵¹Federal Highway Administration, *FHWA Order 5520: Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events*, (Washington, D.C.: Dec. 15, 2014).

Option 2: Update Design Standards

for states. Another stakeholder told us that policy and guidance have limited clout without long-term, consistent regulations. FHWA policy or guidance also may not reflect varying state capacities or risks, according to several stakeholders. For example, some stakeholders said that some states are doing well figuring out resilience on their own, while others are not, and that there is a need for programs to train people in this field such as resilience training for engineers.

Updating design standards to account for climate change and resilience best practices would have strengths and limitations, according to knowledgeable stakeholders and relevant literature. FHWA could support the development of design standards for roads that account for future climate conditions and provide resilience best practices for withstanding these conditions and then incorporate these design standards into regulations.⁵² According to FHWA officials, FHWA alone cannot update design standards, because such design standards are developed by standards-developing organizations, such as professional engineering societies, and then incorporated into FHWA's regulations. Further, according to the officials, the industry has a lack of uniformity and standardized practices.

- **Strengths.** Updating design standards and related codes or guidance would remove an information barrier to action, and could lead to broad uptake of best practices for climate resilience, according to several stakeholders. For example, some stakeholders told us that design guidance, codes, and standards might provide clarity in terms of engineering and design, which states often cite as a barrier to integrating climate change considerations into design. In another example, one stakeholder from a state DOT told us that updated design standards would serve as a procedures manual for engineers to follow. Another stakeholder said such standards would help ensure that resilience is incorporated on a project-by-project basis.
- **Limitations.** Updating design standards may be a slow process—it can take a long time to develop standards at the federal level, according to several stakeholders and relevant literature. Developing

⁵²Design standards are technical guidelines that promote the safety, reliability, productivity, and efficiency of infrastructure. They are typically developed by standards-developing organizations through a formal, consensus-based process, and federal law and policies govern the participation of agency officials in their development. AASHTO develops design standards for highway and street design, in coordination with state DOTs and with the support of FHWA, and FHWA requires the use of certain AASHTO design standards by referencing them in regulations.

such standards also depends on actions by non-governmental partners such as the American Association of State Highway and Transportation Officials (AASHTO), according to several stakeholders and relevant literature. Some stakeholders told us that AASHTO—the most relevant non-governmental partner for highway design standards—is looking for resilience design criteria to incorporate into its design standards. In November 2016, we reported that selected standards-developing organizations, including AASHTO, generally have not used forward-looking climate information in design standards, building codes, and voluntary certifications; instead, they were relying on historical observations.⁵³ We recommended a government-wide approach, in which the National Institute for Standards and Technology (NIST), in consultation with USGCRP and the Mitigation Framework Leadership Group, convenes an ongoing government-wide effort to provide forward-looking climate information to standards organizations, such as AASHTO.⁵⁴

Option 3: Provide Climate Information

Providing authoritative, actionable, forward-looking climate information would have strengths and limitations, according to knowledgeable stakeholders and relevant literature.⁵⁵ FHWA has taken steps to help states use available climate information projections, such as by developing tools, but providing climate information is a broader issue for

⁵³See [GAO-17-3](#).

⁵⁴As of May 2021, NIST had not yet taken action to implement this recommendation, but in January 2021, NIST held a workshop aimed at connecting the U.S. building codes and standards development communities with agencies and organizations collecting and disseminating climate change information. NIST was founded in 1901 and is now part of the U.S. Department of Commerce. The NIST's mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve quality of life. The Mitigation Framework Leadership Group was created to strengthen the nation's disaster resilience by expanding mitigation awareness, coordination, and action. It coordinates mitigation efforts across the federal government and assesses the effectiveness of mitigation capabilities as they are developed and deployed across the nation.

⁵⁵Climate information may include information and analysis about observed climate conditions, information about observed climate impacts and vulnerabilities, and projections of what climate change may mean for local areas. Authoritative, actionable, forward-looking climate information refers to the best available, quality assured projections of future climate conditions at a geographic scale useful for planning and decision-making and in a format that can be translated into impacts at the local level.

which we previously recommended a government-wide solution.⁵⁶ This option could be implemented by having FHWA coordinate with other federal agencies or entities to provide locally or regionally downscaled climate information in a format that is accessible and actionable by transportation project managers or engineers. According to FHWA officials, FHWA has flexibility in providing technical assistance and would not need additional statutory authority to support the provision of climate information.

- **Strengths.** Providing authoritative, forward-looking climate information that is accessible and actionable for project planners and engineers at the local level would remove an information barrier to action and facilitate informed decision-making, according to several stakeholders and relevant literature. Project managers of some of the seven projects we reviewed said they found the climate information tools FHWA developed to help states to be useful. For example, some project managers cited FHWA's Coupled Model Intercomparison Project Climate Data Processing Tool, which allows road project managers to download climate projection information from authoritative sources for the 30,000-square mile grids in which they have transportation assets. Although project managers found FHWA's climate information tools helpful, they told us they relied on universities or consultants to complete the climate information analysis for their projects. In addition, we reported in November 2015 that though many federal efforts were underway, the climate information needs of federal, state, local, and private sector decision makers were not being fully met.⁵⁷ We also reported that decision makers might be unaware that climate information exists or be unable to use what is available.
- **Limitations.** Providing climate information would not move resilience into standard practice or motivate action on its own, according to several stakeholders and relevant literature. This option is not

⁵⁶See GAO, *Climate Information: A National System Could Help Federal, State, Local, and Private Sector Decision Makers Use Climate Information*, [GAO-16-37](#) (Washington, D.C.: Nov. 23, 2015). We recommended that the Executive Office of the President designate a federal entity to (1) develop and periodically update a set of authoritative climate change observations and projections for use in federal decision-making, which state, local, and private sector decision makers could also access to obtain the best available climate information; and (2) create a national climate information system with defined roles for federal agencies and nonfederal entities with existing statutory authority. As of December 2020, the office had not yet taken action to implement these recommendations.

⁵⁷[GAO-16-37](#).

something that FHWA can easily address on its own and depends on government-wide action by other federal entities, according to some stakeholders and relevant literature. For example, in November 2015, we recommended a government-wide approach to meeting the climate information needs of federal, state, local, and private decision makers, because we found that though many federal efforts were under way the climate information needs of these decision makers were not being fully met. We noted that the federal government's own climate information was fragmented across individual agencies that use the information in different ways to meet their missions. Specifically, we recommended that the Executive Office of the President designate a federal entity to (1) develop and periodically update a set of authoritative climate change observations and projects to help decision makers obtain the best available climate information, and (2) create a national climate information system with defined roles for federal agencies and nonfederal entities.⁵⁸

Option 4: Add Formula Requirements

Adding climate resilience funding requirements, conditions, or criteria to formula funds would have strengths and limitations, according to knowledgeable stakeholders and relevant literature. We identified three main ways to implement this option and add climate resilience funding requirements, conditions, or criteria to formula funds. First, this option could create a new formula program specifically to fund climate resilience improvements with a distribution formula using climate risk factors in each state as criteria. Second, this option could require federally funded road projects to plan for climate resilience as a condition of formula funding. For example, this could be a requirement that project plans and designs account for climate risk and resilience options or that project managers publicly post how forward-looking climate information was used for project planning and design decisions. Third, this option could require that a portion of formula funding be used for climate resilience improvements by setting aside or allocating a portion of formula funds based on, for example, progress toward climate resilience goals. According to FHWA officials, such changes to formula programs would need to be done by statute.

- **Strengths.** This option would compel action and mainstream resilience into the bulk of federal funding, according to several

⁵⁸GAO-16-37. As of December 2020, the office had not yet taken action to implement these recommendations.

stakeholders.⁵⁹ Several stakeholders told us it would be difficult to ensure states consider climate risk and resilience across the board without a mandate linked to formula funding. Additionally, this option would ensure that resilience funding is distributed broadly across the national highway system, according to some stakeholders. Furthermore, one stakeholder told us that the formula program is good at mandating broad national policies of national benefit.

- **Limitations.** Linking climate resilience to formula funds would limit state flexibility and autonomy, according to several stakeholders. For example, additional reporting requirements or other barriers can make it more complicated for states to use federal funding, according to some stakeholders. This option also may not reflect varying state capacities or climate risks, many stakeholders told us. For example, some stakeholders told us that states are simply not ready for this option because they first need additional guidance and climate information. However, some other stakeholders said these limitations could be managed, for example, if the funding requirements, conditions, or criteria were straightforward and accompanied by clear guidance, or accounted for variation in state climate risks. Another limitation, according to some stakeholders, is that this option would not address vulnerable roads that have many years left in their design life, because formula funds are generally only available to support planning and construction of new roads or roads nearing the end of their design life. For example, one stakeholder from a state DOT told us that many of that state’s existing roads could be subject to sea level rise and river flooding, but that neither formula-funded construction nor basic maintenance address these climate risks.

Option 5: Expand Discretionary Funding

Expanding the availability of discretionary funding for climate resilience improvements would have strengths and limitations, according to knowledgeable stakeholders and relevant literature. This option could be implemented by creating a new competitive discretionary grant program with climate resilience criteria, or by providing additional funding for resilience research pilot projects. For example, such funding could support research or projects on integrating climate resilience performance measures into the planning process. According to FHWA officials, legislation would be needed to establish a separate, stand-alone discretionary grant program focused on resilience. However, for existing discretionary grant programs, FHWA could add policy preferences and

⁵⁹To “mainstream” is to manage climate change risk within existing programs and operations.

evaluation criteria related to resilience, according to the officials. FHWA also could continue to fund resilience research projects under its statutory research authorities with Highway Research and Development funds.

- **Strengths.** Expanding the availability of discretionary funding would not divert funding from other projects or create mandates, according to several stakeholders. This option also can support innovation through pilot programs or best practices research, according to many stakeholders. For example, stakeholders told us that additional discretionary funding could help states explore emerging areas such as climate risk modelling and analysis, integration of climate information into the asset management process, resilience performance measures, project-specific engineering analysis, and nature-based solutions or other solutions with co-benefits. For example, one stakeholder from a state DOT told us that FHWA's resilience pilots have been the only way the state could further its resilience program. Discretionary funding can be used to target specific types of projects or areas of need, many stakeholders said, such as particularly vulnerable roads or populations. Finally, some stakeholders told us that expanding the availability of discretionary grant funding would allow FHWA to define national priorities and expectations for climate resilience, which could help states transition toward implementation.
- **Limitations.** Expanding the availability of discretionary funding may limit state flexibility and autonomy because FHWA decides what to prioritize with discretionary funding, according to some stakeholders. This option also does not mainstream climate resilience or move it into standard practice, according to many stakeholders. Additionally, several of these stakeholders told us that discretionary funding can be part of the solution, but discretionary grants are not enough on their own. For example, one stakeholder told us that discretionary grants typically fund larger projects and would not help states make small, low-cost resilience improvements across all projects. This option also may not match funding with risk because ability to write grants is not correlated with need, according to some stakeholders. Also, discretionary grants can end up supporting politically influenced rather than broadly useful projects, according to several stakeholders. Furthermore, the grant application and review process creates administrative burdens for FHWA and states, several stakeholders said. Finally, expanding discretionary funding may present transparency issues, given past challenges with these programs, according to several stakeholders and relevant literature. For example, in November 2017 we found some consistency and

transparency issues with DOT's application review and selection process for certain discretionary grant programs for highway and freight projects.⁶⁰ More recently, in June 2019 we found that DOT's process for reviewing applications for grants to fund projects under another discretionary grant program lacked consistency and transparency in aspects related to following up with applicants and evaluating applications.⁶¹

Option 6: Set Emergency Relief Incentives or Conditions

Altering the ER program by providing incentives for, or conditioning funding on, pre-disaster resilience actions would have strengths and limitations, according to knowledgeable stakeholders and relevant literature. The ER program could be altered by incentivizing pre-disaster resilience actions with, for example, a higher federal share or more flexibility in using federal funds.⁶² Receipt of ER funding also could be conditioned on whether states have taken specified pre-disaster resilience actions such as completing a statewide climate risk and resilience assessment. According to FHWA officials, eligibility and other terms and conditions for the ER program are determined by statute, so statutory changes would be necessary to implement this option.

- **Strengths.** Providing incentives for pre-disaster resilience actions would encourage a proactive approach to potential disaster areas, according to several stakeholders. This would include for states that have not previously taken actions to consider and invest in resilience, according to some stakeholders. For example, one stakeholder told us that the challenge from a state perspective is that the state never knows which road will fail, so it would be beneficial to have a systemic way in which FHWA integrates resilience into the ER program. Another stakeholder told us that targeted funds to support pre-disaster resilience actions would be helpful, since states may not currently

⁶⁰See GAO, *Discretionary Transportation Grants: DOT Should Take Actions to Improve the Selection of Freight and Highway Projects*, [GAO-18-38](#) (Washington, D.C.: Nov. 2, 2017). We made three recommendations to DOT, which remained open as of August 2021.

⁶¹See GAO, *Discretionary Transportation Grants: Actions Needed to Improve Consistency and Transparency in DOT's Application Evaluations*, [GAO-19-541](#) (Washington, D.C.: June 26, 2019). We made three recommendations to DOT, which remained open as of August 2021.

⁶²The "federal share" is the maximum share of an eligible road project's costs that the federal government will cover. Unless otherwise specified in the authorizing legislation, most projects will have an 80 percent federal share, but certain statutory provisions can modify a program's basic federal share. For example, in some cases the federal share increases to 100 percent for ER projects or certain safety projects.

have funding for such actions (e.g., to conduct engineering analyses for repeatedly damaged facilities). Conditioning ER funding on pre-disaster resilience actions would provide a strong incentive for states to take action, according to some stakeholders; however, several others thought disaster relief should not be conditional.

- **Limitations.** An incentive-based approach within the ER program may not address resilience across the system of transportation assets and services, according to several stakeholders. Such an approach also would not provide a reliable source of funding for ongoing resilience investment, according to some of these stakeholders. Several stakeholders agreed that conditioning ER funding on pre-disaster resilience actions would be problematic and could present equity issues if ER funding were conditional rather than need-based. Such conditions could be waived when disasters hit to provide immediate relief to those in need, thereby minimizing any fiscal risk-reducing incentive, some stakeholders said. At least one stakeholder commented that such conditions could be effective if FHWA gave states sufficient time and guidance to comply with clearly stated requirements by setting a requirement in the near term and enforcing the condition in the long term. This option could present monitoring challenges, given known issues with the ER program, according to several stakeholders and relevant literature. For example, in October 2019 we found accountability issues with some ER project decisions, including a lack of documentation requirements and instances of ER funding that was used for projects beyond the set timeframe for post-disaster emergency repairs.⁶³ According to FHWA officials, FHWA launched a data-reporting system for the ER program in 2020. As of April 2021, FHWA officials were still monitoring how this data reporting system was being implemented.

Option 7: Expand Emergency Relief Funding Eligibility

Expanding the availability of ER funding for post-disaster climate resilience improvements would have strengths and limitations, according to knowledgeable stakeholders and relevant literature. The ER program currently allows some damaged or destroyed assets to be repaired or reconstructed with resilience improvements if states can provide documentation that doing so is economically justified. This option could

⁶³Emergency repairs to minimize damage, protect facilities, or restore essential traffic are eligible to receive 100 percent federal reimbursement if they are accomplished within 180 days of the disaster. See GAO, *Highway Emergency Relief: Federal Highway Administration Should Enhance Accountability over Project Decisions*, [GAO-20-32](#) (Washington, D.C.: Oct. 17, 2019). We made two recommendations to DOT, both of which remained open as of August 2021.

be implemented by making ER funding available for additional post-disaster resilience improvements, such as expanding eligibility to include roads located near damaged, destroyed, or highly vulnerable roads, or expanding eligibility to repair or replace roads to higher standards. According to FHWA officials, eligibility and other terms and conditions for the ER program are determined by statute, so statutory changes would be necessary to implement this option.

- **Strengths.** Expanding the scope of the ER program could incentivize a proactive approach to potential disaster areas, according to several stakeholders. For areas or sites already hit by disasters, several stakeholders said this option would also use post-disaster momentum to support replacing or repairing roads to higher standards, which could help prevent paying to repair or replace the same road again after the next disaster. For example, one stakeholder from a state DOT told us that under the current program it is difficult to do anything better than in-kind replacements. Another stakeholder from a state DOT told us that expanding the availability of ER funding would be helpful because national emergency-level storms are not the only events causing problems; the combined effect of smaller, localized events are also damaging roads.
- **Limitations.** This option does not address resilience across the system of transportation assets and services or long-term plans for highly vulnerable roads, according to some stakeholders. For example, several stakeholders told us that approaches to emergency repairs should include considering the criticality of certain roads and prioritizing projects based on various risk factors. Some of these stakeholders noted that risk may be acceptable for some roads but not others, such as critical emergency service routes. Additionally, expanding the availability of ER funding may provide an incentive to defer maintenance until disasters hit or to fund already planned projects, according to several stakeholders. Finally, this option may present monitoring challenges given known issues with the ER program—which we describe above—according to several stakeholders and relevant literature.

Option 8: Add Planning or Project Requirements

Establishing additional climate resilience planning or project requirements would have strengths and limitations, according to knowledgeable stakeholders and relevant literature. There are some existing planning and project requirements related to resilience for federally funded roads. These include the requirement that states consider and implement projects, strategies, and services that will improve resiliency and reliability in the statewide transportation-planning process and the repeatedly

damaged facilities rule which requires states to conduct evaluations to determine if there are reasonable alternatives to repeatedly damaged roads, highways, and bridges. However, additional climate resilience planning or project requirements could be established, for example, by requiring states to further integrate climate resilience into the project planning or asset management processes or by requiring states to develop climate resilience performance metrics and track progress toward performance goals. According to FHWA officials, FHWA can add policy preferences and evaluation criteria to discretionary programs, so long as they are consistent with the statutory requirements establishing the grant program.

- **Strengths.** Establishing additional climate resilience planning or project requirements would mainstream resilience into planning processes, according to several stakeholders. There is a logical connection between long-term planning, asset management, and climate resilience, some stakeholders told us. For example, one stakeholder from a state DOT told us it is common sense to require that all state DOTs have a resilience plan in place. Another stakeholder told us that existing planning requirements related to resilience are not explicit about climate change, so strengthening these requirements could help ensure that recipients of federal funds are prepared to integrate resilience considerations into project development. This option may also help address resilience across the system of transportation assets and services, according to several stakeholders. Specifically, one stakeholder stressed the importance of understanding surrounding conditions for making good investments. For example, only elevating roads without taking additional measures can shift flood risks to surrounding businesses, this stakeholder said. Another stakeholder told us there are advantages to addressing resilience at the system level—not just asset by asset—and that planning is a way to achieve that. This stakeholder told us that some states already do climate vulnerability assessments at the system level. This option may also increase awareness of resilience issues, several stakeholders told us.
- **Limitations.** It may take a long time to implement new planning or project requirements, according to several stakeholders, and such requirements may not reflect varying state capacities or risks, according to some stakeholders. To mitigate these limitations, any climate resilience planning or project requirements would need to be flexible enough to accommodate local conditions, according to some stakeholders. Furthermore, there might be knowledge barriers to implementing any new requirements, and states may need additional

Option 9: Link Action to Incentives or Penalties

climate information, FHWA guidance, and an understanding of states' risks and vulnerabilities, several stakeholders told us. This option may also lead to uneven implementation given varying state planning processes, several stakeholders added.

Linking climate resilience actions or requirements to incentives or penalties would have strengths and limitations, according to knowledgeable stakeholders and relevant literature. State climate resilience actions or requirements could be linked to incentives—such as increased federal share or increased flexibility with funding—or penalties—such as withholding or reducing funding, imposing additional oversight or reporting requirements, or withholding project approval.⁶⁴ For example, incentives or penalties could be paired with requirements added to formula funding or the planning process, such as those described in other options above. According to FHWA officials, additional statutory authority would likely be necessary to implement this option.

- **Strengths.** Incentives can motivate action and promote good practices, according to several stakeholders. Specifically, incentives such as federal share increases are definitely a motivating factor for states to take action, several stakeholders said. Furthermore, one stakeholder told us that an incentive-based approach would enable creative, bottom-up approaches and strategies. Incentives could also mitigate cost share and other fiscal challenges for states, according to some stakeholders. Penalties can compel action, according to several stakeholders and relevant literature. For example, in the past, penalties have been used to enforce certain national priorities related to safety and performance for roads, such as a minimum drinking age, the use of seat belts, and basic maintenance and paving condition. Regarding resilience for federally funded roads, one stakeholder said that because states might not take action if they are not required to do so, the federal government should reward states willing to invest in resilience and consider gradually removing assistance over time for any states not willing to invest in resilience.
- **Limitations.** Several stakeholders said that incentives on their own may be a slow approach to addressing climate risk. For example, one

⁶⁴The “federal share” is the maximum share of an eligible road project’s costs that the federal government will cover. Unless otherwise specified in the authorizing legislation, most projects will have an 80 percent federal share. States face penalties for failing to comply with certain program requirements established in law. For example, states must maintain a minimum drinking age of 21 or 8 percent will be withheld from their yearly apportionment.

stakeholder told us that because the federal government is investing money now for long-run infrastructure, it forgoes that potential benefit if resilience is optional and action is slow. Although penalties can compel action, several stakeholders agreed that incentives are preferable to penalties, in part because penalties can have unintended consequences, including worsening inequities among states if those with low capacity cannot meet requirements. Additionally, penalties could be challenging to enforce, according to several stakeholders. For example, one stakeholder noted that penalties that take away resources may be counterproductive when requiring states with limited resources to spend more on resilience. Some stakeholders emphasized that if there were penalties, the requirements would need to be very clear and FHWA would need to provide guidance to help states comply over time.

Option 10: Set Conditions on Compliance with FHWA Policy

Conditioning eligibility, funding, or project approval on compliance with climate resilience policy and guidance would have strengths and limitations, according to knowledgeable stakeholders and relevant literature. This option could be implemented, for example, by conditioning FHWA approval of formula funded projects on compliance with climate resilience policy or formal guidance on implementing laws and regulations relevant to resilience. According to FHWA officials, guidance itself is non-binding, so any conditions tied to compliance would need to be linked to a statutory or regulatory provision.

- **Strengths.** Setting conditions on eligibility, funding, or project approval could compel action, according to several stakeholders. It also could integrate resilience into the bulk of federal funding for roads, according to some stakeholders. For example, some stakeholders told us that tying funding to resilience actions is the only way to see states take resilience actions. Similarly, some stakeholders said that a policy with expectations or requirements for states may not compel action without enforcement mechanisms or consequences for noncompliance.
- **Limitations.** Setting conditions on eligibility, funding, or project approval may limit state flexibility and autonomy and may not reflect varying state capacities or risks, according to several stakeholders. It also may be difficult to track compliance, some stakeholders added. Several stakeholders told us that if FHWA were to require compliance, it would first need to very clearly communicate expectations with policy and guidance and then could progress toward withholding funds at some point in the future. For example, one stakeholder said it would be excessive to condition funding altogether rather than take an

incentive-based approach that increases or decreases funding depending on state actions. It also would be difficult to get states to comply unless requirements and related guidance were already fleshed out through the broader engineering community, this stakeholder said.

Implementing Multiple Options Offers the Most Potential to Further Enhance the Climate Resilience of Federally Funded Roads

Implementing multiple options could leverage the strengths and address the limitations of the different options, and offers the most potential to improve the climate resilience of federally funded roads, according to our analysis of the options using our October 2019 *Disaster Resilience Framework* and knowledgeable stakeholders we interviewed. Our *Disaster Resilience Framework* states that integrating strategic resilience goals can help decision makers work toward a common vision and help ensure focus on a wide variety of opportunities to reduce risk. The knowledgeable stakeholders we interviewed generally agreed that some of the options to further enhance the climate resilience of federally funded roads are mutually reinforcing given their relative strengths and limitations, and therefore that they would work best if more than one were implemented. For example, several stakeholders told us it would be difficult to add climate resilience planning or project requirements without providing more accessible and actionable climate information or design standards that specify how engineers should incorporate this information into their designs. Further, several stakeholders suggested that some of the options may be most effective when implemented sequentially. For example, some stakeholders suggested starting with a foundation of FHWA policy and guidance, working toward providing climate information and updating design standards, and then implementing formula conditions, criteria, or requirements. With such an approach, requirements or conditions could be specified in the near term but come into effect after states have been given climate information, standards, and guidance.

Furthermore, the January 27, 2021, Executive Order 14008, *Tackling the Climate Crisis at Home and Abroad*, states that it is the policy of the administration to deploy the full capacity of the federal government to, among other things, combat climate change and implement a government-wide approach that increases resilience to the impacts of climate change. The order directs agencies to submit a climate action plan that describes steps the agency can take with regard to its facilities and operations to bolster adaptation and increase resilience to the impacts of climate change, submit annual progress reports, and make action plans publicly available. While the order's full effect will not be known for some time and depends on sustained agency attention, it calls on the Secretary of Transportation, as a member of the National Climate

Task Force established by the executive order, to prioritize action on climate change in policy-making and budget processes, in contracting and procurement, and in engagement with state, local, tribal, and territorial governments, among other duties.

FHWA's efforts to improve the climate resilience of federally funded roads are relatively new, according to FHWA officials. As of July 2021, FHWA officials told us the agency had awarded a total of about \$7.2 million in resilience research grant funding to, among other things, help incorporate risk reduction measures into certain projects. In addition, we identified projects in four states—Arizona, Delaware, Maryland, and Washington State—that used FHWA resilience resources and climate projection information to plan or implement physical resilience enhancements on federally funded roads. Given the scale of the federal-aid highway program and the relative newness of resilience efforts, these projects illustrate the potential that FHWA's current efforts—and climate resilience efforts more broadly—have to help improve the resilience of the nation's roads. For fiscal years 2016 through 2021, Congress authorized approximately \$45 billion per year for the federal-aid highway program. Further, FHWA's Emergency Relief program was appropriated an average of about \$900 million per year for fiscal years 2016 through 2020. A survey of state departments of transportation published in 2018 by the National Academies found that most survey respondents were working in some capacity to incorporate resilience into transportation management programs but were struggling to implement resilience practices into physical road projects.

As discussed above, we identified 10 options to further enhance the climate resilience of federally funded roads based on a comprehensive review of relevant literature and interviews with knowledgeable stakeholders. Each of these options has strengths and limitations, according to knowledgeable stakeholders and relevant literature. Our comparison of the 10 options to FHWA's current efforts using the principles of our *Disaster Resilience Framework* shows how implementing each option could further enhance the climate resilience of federally funded roads. For example, the *Framework's* incentives principle states that incentives can help make long-term, forward-looking risk-reduction investments more viable and attractive among competing priorities. We compared the option to add formula requirements—by, for example, adding climate resilience funding requirements to formula funds—with FHWA's efforts to fund resilience research, using the *Framework's* incentives principle. We found that adding funding requirements could greatly help incorporate disaster risk-reduction measures into the bulk of federal assistance for roads. See appendix III for detailed information on

how each option could further enhance the climate resilience of federally funded roads.

The appropriate mix of options to enhance the climate resilience of federally funded roads is a policy choice that requires complex tradeoff decisions. These tradeoff decisions should be made with full information about the strengths and limitations of different options and involvement from stakeholders including states, localities, and nongovernmental entities. FHWA officials said that they could likely implement some of the options to further enhance the climate resilience of federally funded roads under existing law. For example, they said that FHWA could issue more guidance without additional authority. However, FHWA officials were hesitant to comment on which additional steps they would take, as the administration's climate change priorities are still under development. FHWA officials also said that they would likely need additional authority from Congress to act on some of the options or to implement a combination of options, and that the easiest way for Congress to ensure that its priorities are implemented for any option would be to put it in law. These officials also said they remain available to provide nonpartisan technical assistance when requested by Congress (e.g., technical opinions on how legislative decisions could affect the federal-aid highway program).

The most recent funding authorization for the federal-aid highway program covers fiscal year 2016 through fiscal year 2021, which ends on September 30, 2021—providing Congress with an opportunity to improve the climate resilience of federally funded roads. Adding requirements in reauthorizing legislation for FHWA to take additional action would provide FHWA with the authority and clear priorities to implement options to enhance the climate resilience of federally funded roads when the federal-aid highway program is reauthorized. These options present an opportunity to improve resilience in the nation's highway system and help ensure that federally funded roads and bridges can withstand or more easily recover from changes in the climate. Providing FHWA with additional direction or authority to implement one or more of the options could enhance the climate resilience of more—or all—federally funded roads, depending on the options exercised. This also represents a promising avenue to address federal fiscal exposure, as the options offer the opportunity to reduce the overall impact of disasters, based on our analysis using the 2019 *Disaster Resilience Framework*. Further, considering how to implement a variety of options to enhance the climate resilience of federally funded roads, such as the options identified in this report, could help FHWA meet its responsibilities under Executive Order 14008. This approach also would help states and other stakeholders work

toward a common vision and ensure a focus on a wide variety of opportunities to improve the climate resilience of federally funded roads and reduce federal fiscal exposure.

Conclusions

Climate-related damages to paved roads in the United States may cost up to an estimated \$20 billion annually by the end of the century, under some projected scenarios reported in the 2018 *Fourth National Climate Assessment*. FHWA has taken steps to encourage states to enhance the climate resilience of federally funded roads and could do more. We identified 10 options to further enhance the climate resilience of federally funded roads. Each of these options has strengths and limitations. Implementing multiple options could leverage their strengths and address their limitations and offers the most potential to improve the climate resilience of federally funded roads, as we found through an extensive analysis using our *Disaster Resilience Framework*, our review of related literature, and interviews with knowledgeable stakeholders. However, FHWA officials told us FHWA likely would need additional congressional direction or authority to implement some or a combination of options and that the most effective way for Congress to ensure that its priorities are implemented for any option would be to put it in law.

Legislation reauthorizing surface transportation funding offers an opportunity for Congress to add requirements for FHWA to take additional action, such as implementing specific options, to improve the resilience of federally funded roads. Specifically, providing FHWA with additional direction or authority to implement the options identified could enhance the climate resilience of more—or all—federally funded roads, depending on the options exercised. Furthermore, considering how to implement a variety of options to enhance the climate resilience of federally funded roads, such as the options identified in this report, could help the U.S. Department of Transportation and FHWA meet their responsibilities under Executive Order 14008 to prioritize action on climate change in policy-making and budget processes. Implementing a variety of options could help ensure that federally funded roads and bridges can withstand or more easily recover from changes in the climate, reducing the need for federal disaster assistance and limiting the federal government's fiscal exposure. However, deciding which options to implement requires complex tradeoff decisions. These decisions should be made after thoughtful consideration of the strengths and limitations of the different options—and with involvement from stakeholders including states, localities, and nongovernmental entities.

Matter for Congressional Consideration

As Congress considers reauthorizing legislation for the federal-aid highway program, it should consider providing direction or authority to the Federal Highway Administration to implement one or more of the options to enhance the climate resilience of federally funded roads identified in this report. (Matter 1)

Recommendation for Executive Action

The Secretary of the U.S. Department of Transportation should consider how the Federal Highway Administration (FHWA) plans to implement options to enhance the climate resilience of federally funded roads, such as the options identified in this report, when prioritizing actions on climate change in policy-making, as called for in Executive Order 14008. (Recommendation 1)

Agency Comments

We provided a draft of this report to DOT for review and comment. In its written comments, reproduced in appendix IV, DOT concurred with our recommendation to consider how FHWA plans to implement options to enhance the climate resilience of federally funded roads when prioritizing actions on climate change in policy-making, as called for in Executive Order 14008. DOT stated that protecting the nation's highway infrastructure is a priority for DOT and FHWA. DOT also stated that it is committed to increasing its effectiveness in ensuring that infrastructure is resilient enough to withstand climate change and extreme weather events that could otherwise disrupt the transportation network and require major reconstruction. DOT provided several examples of its ongoing efforts to help state DOTs and other stakeholders integrate climate resilience into their programs and projects.

We are sending copies of this report to the appropriate congressional committees, the Administrator of the U.S. Department of Transportation, and other interested parties. In addition, the report is available at no charge on the GAO website at <http://www.gao.gov>.

If you or your staff members have any questions about this report, please contact me at (202) 512-3841 or gomezj@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff members who made major contributions to this report are listed in appendix V.

A handwritten signature in black ink that reads "Alfredo Gómez". The signature is written in a cursive style with a large, stylized 'G'.

J. Alfredo Gómez
Director, Natural Resources and Environment

List of Requesters

The Honorable Eddie Bernice Johnson
Chairwoman
Committee on Science, Space, and Technology
House of Representatives

The Honorable Peter A. DeFazio
Chairman
Committee on Transportation and Infrastructure
House of Representatives

The Honorable Benjamin L. Cardin
Chairman
Subcommittee on Transportation and Infrastructure
Committee on Environment and Public Works
United States Senate

The Honorable Mikie Sherrill
Chair
Subcommittee on Environment
Committee on Science, Space, and Technology
House of Representatives

The Honorable Bill Foster
Chairman
Subcommittee on Investigations and Oversight
Committee on Science, Space, and Technology
House of Representatives

Appendix I: Objectives, Scope, and Methodology

This report examines (1) efforts that the Federal Highway Administration (FHWA) has made to enhance the climate resilience of federally funded roads during the past 10 years and (2) the strengths and limitations of options to further enhance the climate resilience of federally funded roads, according to knowledgeable stakeholders and relevant literature. To address these objectives, we reviewed agency documents, collected information on federally funded road projects, reviewed relevant literature, and interviewed agency officials and knowledgeable stakeholders. We also provide information on how we used GAO's *Disaster Resilience Framework* to evaluate the extent to which each of the options identified in this report could enhance the climate resilience of federally funded roads.¹

Describing FHWA's Climate Resilience Efforts

To describe the efforts that FHWA has made to enhance the climate resilience of federally funded roads during the past 10 years, we reviewed federal laws and regulations related to resilience, and we reviewed documents related to FHWA's resilience programs, tools, and policy. For example, we reviewed FHWA's *Vulnerability Assessment and Adaptation Framework*,² Hydraulic Engineering Circulars 17 and 25,³ and FHWA Order 5520.⁴ To better understand FHWA's resilience efforts, we also interviewed FHWA officials and representatives from the American Association of State Highway and Transportation Officials (AASHTO) and the Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine. We selected these organizations to interview because, based on their roles and areas of focus, we expected them to be knowledgeable about FHWA's role in enhancing the climate resilience of federally funded roads. Specifically, one of AASHTO's stated

¹GAO, *Disaster Resilience Framework: Principles for Analyzing Federal Efforts to Facilitate and Promote Resilience to Natural Disasters*, [GAO-20-100SP](#) (Washington, D.C.: Oct. 2019).

²Federal Highway Administration, *Vulnerability Assessment and Adaptation Framework*, 3rd ed., FHWA-HEP-18-020 (Washington, D.C.: December 2017).

³Federal Highway Administration, *Hydraulic Engineering Circular 17: Highways in the River Environment – Floodplains, Extreme Events, Risk and Resilience, Second Edition*, FHWA-HIF-16-018, (Washington, D.C.: June 2016); and *Hydraulic Engineering Circular No. 25: Highways in the Coastal Environment, Third Edition*, FHWA-HIF-19-059, (Washington, D.C.: Jan. 2020).

⁴Federal Highway Administration, *FHWA Order 5520: Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events*, (Washington, D.C.: Dec. 15, 2014).

roles is to serve as a liaison between state departments of transportation and the federal government, and AASHTO has a committee focused on resilience. One of TRB's stated roles is to help improve transportation through research and information sharing, and TRB has a standing committee on extreme weather and climate change adaptation.

To understand how FHWA's programs, tools, and policies were used by recipients of federal funding for roads, we collected information on seven projects from four states—Arizona, Delaware, Maryland, and Washington State—that we identified as having used FHWA resilience resources and climate projection information to plan or implement physical resilience enhancements on federally funded roads.⁵ Such enhancements could include raising bridges to account for projected sea level rise or restoring wetlands to mitigate flooding. The seven projects we included in our review used climate projection information in project-level assessments and design decisions.⁶

To identify the seven projects we included in our review, we first reviewed project descriptions for all of the resilience research pilot projects funded by FHWA. Next, we obtained referrals from knowledgeable parties for additional projects that might meet our search criteria. The parties we contacted for recommendations included FHWA, AASHTO, TRB, and the Association of Metropolitan Planning Organizations, National Association of Regional Councils, National Association of City Transportation Officials, and American Road and Transportation Builders Association. We contacted these particular parties because we and other knowledgeable parties expected them, based on their roles, to be knowledgeable about the activities of departments of transportation and transportation-planning organizations throughout the United States. The views from these parties are not generalizable to those we did not include and speak with.

Using this methodology, we identified 27 planning organizations and state DOTs throughout the United States that were likely to have begun or

⁵We completed site visits in person with one state (Arizona), and gathered information on project sites from the remaining states by phone and email (Delaware, Maryland, and Washington State) due to COVID-19 pandemic travel restrictions.

⁶A fifth state—Minnesota—had a project that largely met our criteria. We did not include this project in our review because while project implementers for this project used climate projection information to understand the vulnerabilities of the project area, they used historic hydrologic data rather than climate projection information when designing the project.

completed physical resilience enhancements on federally funded roads using federal funding, FHWA's resilience resources, and climate projection information. We contacted these 27 organizations to confirm whether they had any projects that met all of our search criteria. We included in our review the seven projects from four states we found that met our search criteria. Findings from our reviews of these projects are not generalizable to those we did not select and review. Dollar figures presented in this report that relate to these projects have not been adjusted for inflation.

Describing the Strengths and Limitations of Options

To identify options to enhance the climate resilience of federally funded roads and describe the strengths and limitations of these options, we reviewed relevant literature and interviewed knowledgeable stakeholders.

Review relevant literature. First, we used multiple search strategies to search for and review potentially relevant literature to find examples of options that could be used to enhance the climate resilience of federally funded roads.

- To identify reports and legislation that proposed or described potential options, we conducted a literature search for reports on transportation infrastructure resilience or funding that proposed or described options to enhance the climate resilience of federally funded roads, such as by integrating climate resilience into federal funding for roads. We also searched for proposed and enacted legislation that included examples of incentives or requirements to consider resilience for federally funded projects. To conduct the literature search, we searched databases (e.g., ProQuest, EconLit, and WestEdge) using relevant key words (e.g., roads, policy options, funding, incentives, and authorization); a snowball approach using citations in reports we already identified; and preliminary background research. We supplemented the literature search with referrals from the knowledgeable parties we contacted to identify road projects (e.g., AASHTO and TRB) and from transportation and climate change analysts with whom we coordinated at the Congressional Research Service (CRS). Preliminary searches for background included CRS' report database, the Congressional Budget Office's website, GAO's product page, the U.S. Department of Transportation's (DOT) Inspector General website, Congress.gov, and more general internet searches using relevant key words.
- The literature search identified 85 potentially relevant sources—55 reports and 30 pieces of legislation. Of these, 25 sources were identified by literature database searches out of a total of 93 search

results—we excluded the remaining 68 results because we determined they were out of scope (e.g., focused on climate change impacts or financing), not directly relevant to climate resilience or roads, or duplicate results.⁷

- A more detailed review of these potentially relevant sources determined that 53 of the 85 sources had relevant examples of options—30 reports and 23 pieces of legislation. Of the 53 relevant sources we identified, 35 had resilience or climate specific examples and the remaining sources had examples that could be applied to this context.

Identify options. Second, we distilled examples from relevant literature into a preliminary list of options. For our purposes, we focused on options that could affect how and whether states took action to enhance the climate resilience of federally funded roads, such as by further integrating climate resilience into federal funding for roads through FHWA-administered programs. To identify options from literature, we analyzed the content of the 53 relevant sources in greater detail, recorded and categorized information about the examples of options, and then distilled the examples into a preliminary list of eight high-level options grouped by location in existing FHWA funding and program structures (e.g., formula funding or policy and guidance). We subsequently added two additional options related to FHWA’s technical assistance and policy roles based on suggestions provided by knowledgeable stakeholders during interviews.

Identify knowledgeable stakeholders. Next, we used the results of the literature search to identify stakeholders with knowledge of both climate resilience and federal funding for roads. We continued to ask each knowledgeable stakeholder we interviewed to recommend other knowledgeable stakeholders who might meet our criteria. When selecting knowledgeable stakeholders, we primarily considered type of expertise, relevance of published work, and referrals from other stakeholders as criteria.

- Specifically, we selected stakeholders who: (1) had authored or contributed to a report identified by our literature search that contained resilience or climate-change specific examples of options to

⁷There were three potentially relevant reports that we did not review in detail because they were only available as hard copies and we determined were unlikely to be highly relevant based on their abstracts so we elected not to pursue them due to COVID-19 related limitations.

integrate climate resilience into federal funding for roads, or (2) were referred by more than one other knowledgeable stakeholder we interviewed and (a) had written, presented, or testified specifically about options to integrate climate resilience into federal funding for roads or (b) would otherwise have the knowledge or expertise to comment on the strengths and limitations of such options. This selection included state DOT officials from the four states we identified as having used FHWA resources to plan or implement a physical resilience enhancement on a federally funded road.

- We selected a total of 30 individual and organizational stakeholders, including 25 based on authorship or contribution to a relevant report, four based on our state site selection process, and one based on referrals from other stakeholders, who we then determined had relevant written work, presentations, and testimonies. There were also several instances of stakeholders referring us to other stakeholders whom we had already identified based on our literature search.

Interview knowledgeable stakeholders. We then asked the knowledgeable stakeholders we selected to participate in interviews in which we asked them for their perspectives on the strengths and limitations of each option, any other options that should be considered, and other knowledgeable stakeholders we should interview for this purpose. When interviewing the stakeholders, we asked them to consider the options at a high-level and to describe their strengths and limitations as they relate to limiting the federal government's fiscal exposure to climate change risks.

- Of the 30 individual and organizational stakeholders we selected, two declined to participate and seven did not respond to multiple inquiries. As appropriate and at the request of stakeholders, we conducted joint interviews with stakeholders who were co-authors or affiliated with the same organization. We treated the perspectives gathered at these joint interviews as one interview for the purposes of tallying stakeholder perspectives. We completed 21 semi-structured interviews with knowledgeable stakeholders. These stakeholders included representatives from AASHTO, FHWA officials, officials from several state DOTs, former DOT officials, and stakeholders from academic institutions, research organizations, think tanks, and consultancies. The FHWA officials we interviewed said they would not comment on the strengths and limitations of these options. Also, one stakeholder who agreed to participate was unprepared to comment on the options' strengths and limitations at the time of our scheduled interview and declined to provide information in writing at a later time.

Therefore, in the end, we gathered information on the strengths and limitations of options to enhance the climate resilience of federally funded roads during 19 semi-structured interviews that included a total of 34 knowledgeable stakeholders as participants.

- Because we selected a nongeneralizable sample of knowledgeable stakeholders to interview, findings from our analysis of their views cannot be generalized to all stakeholders who might have relevant knowledge and expertise. Rather, these interviews provided us with insights from a selected group of knowledgeable stakeholders on the strengths and limitations of options to enhance the climate resilience of federally funded roads. In addition, the specific areas of expertise varied among the stakeholders we interviewed, so not all of the stakeholders commented on all of the interview questions we asked.

Describe options' strengths and limitations. To describe the options' strengths and limitations, we synthesized perspectives from 19 semi-structured interviews with knowledgeable stakeholders. Specifically, we analyzed the information we gathered during each of these knowledgeable stakeholder interviews to identify relevant insights on the option's strengths and limitations, and grouped individual insights into overall themes. In reporting the results of our content analysis, we also provided additional context to stakeholder perspectives from the relevant literature we reviewed and our prior work. We do not report the entire range of stakeholder responses in this report but instead report relevant overall themes and illustrative examples from specific stakeholder perspectives. We also included FHWA statements on the extent to which it could implement these options under its existing authority. Throughout this report, we defined modifiers to characterize knowledgeable stakeholder views as follows:

- “*some*” stakeholders represents 1 to 3 stakeholders,
- “*several*” stakeholders represents 4 to 9 stakeholders, and
- “*many*” stakeholders represents 10 or more stakeholders.

Although our methodology was based on a comprehensive literature search and supplemented with information from interviews with knowledgeable stakeholders, it was not intended to result in an exhaustive list of options but rather an informed menu of potential options with insights on their strengths and limitations. We believe the scope and methodology we used is sufficient for the purpose of providing relevant and useful information to decision makers on the range of options to

enhance the climate resilience of federally funded roads and to inform their choices about an appropriate mix of options, if any, to pursue with insights on the strengths and limitations of these options.

Identifying Opportunities Using the *Disaster Resilience Framework*

To illustrate how each of the options we identified in this report could enhance the climate resilience of federally funded roads, we compared the available options with FHWA's current climate resilience efforts and the principles and subprinciples in GAO's *Disaster Resilience Framework*.⁸ These principles and subprinciples were developed in conjunction with a series of questions to help analyze federal efforts to promote resilience. For each option, FHWA effort, and principle or subprinciple included in our analysis, an analyst made a determination about how the option could enhance the climate resilience of federally funded roads. A second analyst then reviewed the first analyst's work to ensure that the conclusions drawn were sound. See appendix III for additional information about how we conducted this analysis.

We conducted this performance audit from July 2019 to September 2021 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

⁸GAO, *Disaster Resilience Framework: Principles for Analyzing Federal Efforts to Facilitate and Promote Resilience to Natural Disasters*, [GAO-20-100SP](#) (Washington, D.C.: Oct. 2019).

Appendix II: Resilience Project Information

As shown below, we identified seven projects in four states—Arizona, Delaware, Maryland, and Washington State—that used FHWA resilience resources and climate projection information to plan or implement physical resilience enhancements on federally funded roads. See appendix I for information about how we found these seven projects.

Arizona

St. David Bridge, State Route 80

Location: St. David, Arizona

Federal funding: Approx. \$7.5 million from the federal-aid highway program's Surface Transportation Block Grant Program

Why Arizona Department of Transportation (ADOT) is making resilience enhancements: (1) to address severe erosion (shown below, top) due to the convergence of two rivers at the project site, which removes soil around the bridge and may reduce the life cycle of the bridge (shown below, bottom); and (2) to address concerns that the bridge could be overtopped during a 50-year storm event.



Planned Resilience Enhancements:

ADOT plans to reduce the number of bridge spans subject to erosion and deepen the bridge's vertical supports.

Source: GAO analysis of information from U.S. Geological Survey (USGS) and ADOT. Photos: USGS (top) and ADOT (bottom). | GAO-21-436

Arizona's roads and bridges are vulnerable to flooding, extreme heat, wildfires, freeze-thaw cycles, and other weather-related risks, according to Arizona's Department of Transportation (ADOT).¹ For example, extreme heat can deform pavements, and precipitation events can create maintenance issues for drainage structures underneath roads. Climate models used by ADOT project that Arizona will receive less precipitation in the future, but precipitation events will be more extreme when they occur. Consequently, ADOT's Resilience Program, housed within ADOT's Environmental Planning unit, plans for routine weather, extreme weather, and projected climate changes, according to ADOT officials we interviewed.

At the three sites we visited in Arizona—the St. David Bridge, the Gila River Bridge on State Route (SR) 79, and the Gila River Bridge on Interstate 10—ADOT is using federal-aid highway program funds to incorporate climate resilience enhancements into project designs. For example, at the St. David Bridge, ADOT plans to reduce the number of bridge spans subject to erosion. ADOT also plans to deepen the bridge's vertical supports to fortify it against anticipated precipitation events. All three projects involve replacing the bridges, which have reached the ends of their service lives. In addition, all three have been programmed through state transportation-planning processes to receive federal funding through the federal-aid highway program. As of May 2021, construction was scheduled to begin in 2021 at all three sites.

ADOT was able to integrate resilience enhancements into the designs for these projects by supplementing FHWA resilience tools with site-specific data, according to ADOT officials we interviewed. Specifically, ADOT used FHWA's Coupled Model Intercomparison Project (CMIP) Climate Data Processing Tool to download project-level climate projection information, such as frequencies of very hot days and future precipitation trends, for the 30,000-square mile areas in which the assets are located.

¹Arizona Department of Transportation, *Extreme Weather Vulnerability Assessment: Final Report* (Jan. 2015).

Gila River Bridge, State Route 79

Location: Florence, Arizona

Federal funding: Approximately \$19 million from the federal-aid highway program's Surface Transportation Block Grant Program

Why Arizona Department of Transportation (ADOT) is making resilience enhancements: The mile-wide, 4,000-foot floodplain surrounding the bridge (shown below) creates concerns that the bridge will be overtopped and closed to traffic during a 100-year storm. The bridge serves an area with significant planned growth and is an important route for emergency services into Florence.

Planned resilience enhancements: ADOT plans to: (1) redesign at least one of the two berms at the site, one of which is shown below, to better manage water flows at the site; (2) use different piers to reduce the effects of scour—the erosion of a streambed or bank material due to flowing water—on the bridge; and (3) drill deeper enclosures for the bridge piers to reduce stress on the structure.



Source: GAO analysis of information from ADOT. Photo: GAO. | GAO-21-436

Next, ADOT used federal funds to supplement these data with site-specific data needed to make engineering decisions.

ADOT's efforts to obtain site-specific data involved:

- Using FHWA funding to hire researchers at the University of North Carolina and Arizona State University to validate the CMIP data ADOT downloaded and map these data to specific project sites.
- Establishing an intergovernmental agreement with the U.S. Geological Survey (USGS) that allows USGS to use FAHP funds to collect site-specific hydrologic data, according to ADOT and USGS officials. At the sites we visited, USGS has deployed instruments such as submersible water sensors to collect continuous, real-time data that engineers are using in project designs. These data include average stream flows and stream depths during storm events. ADOT's Resilience Program has used these data to better understand downscaled climate projection information from FHWA's CMIP tool.
- Using federal-aid highway program funds to hire a consulting firm to analyze how the structural subcomponents (e.g., bridge spans) of the St. David Bridge could deteriorate under various long-term climate scenarios, including extreme heat scenarios.

Taking the following steps also helped ADOT's Resilience Program integrate climate resilience enhancements into project designs, according to ADOT officials we interviewed:

- Developing a standard process—called the Climate Engineering Assessment for Transportation Assets—for incorporating extreme weather and climate change into engineering analyses. Steps in this process include, among others, developing probabilistic models for climate stressors before tracking and monitoring resilience investments.²
- Assessing climate hazards and prioritizing highest risk assets before making the business case to ADOT management for either making resilience enhancements or accepting risks when the cost of addressing them cannot be justified. Preparing “climate narrative”

²See <https://azdot.gov/> for additional information about Arizona's Climate Engineering Assessment for Transportation Assets process.

Gila River Bridge, Interstate 10

Location: Arizona, Arizona

Federal funding: Almost \$78 million is expected from the federal government, including the federal-aid highway program's National Highway Performance Program.

Why Arizona Department of Transportation (ADOT) is making resilience enhancements: This bridge serves a key commercial corridor between Arizona's two largest metropolitan areas. The bridge has been overtopped and closed to traffic during past flooding.

Planned resilience enhancements: ADOT is conducting hydrologic and hydraulic modeling to understand: (1) how well the berms near the bridge (shown below) are working; (2) the likelihood that the bridge will be overtopped during a 100-year storm; and (3) any benefits associated with drilling deeper vertical supports and hardening the approaches to the bridge. As of May 2021, ADOT's State Engineer's Office and the Resilience Program were analyzing the costs and benefits of raising the bridge 2-4 feet and adding 2 bridge spans.



Source: GAO analysis of information from ADOT. Photo: GAO. | GAO-21-436

documents that summarize key climate hazards at specific sites has helped make the business case for different courses of action.

- Persistently asking ADOT management to add climate variables to engineering analyses as part of a wider program-level effort to elevate science-driven decision-making and formalize the costs and benefits of incorporating weather and natural hazard risks into project designs.
- Citing FHWA regulation has helped ADOT's Resilience Program justify its climate resilience work to ADOT management.

Delaware

Delaware's roads and bridges also face a variety of risks to climate changes, according to the Delaware Department of Natural Resources and Environmental Control (DNREC).³ Because of its low-lying topography and location within three major watersheds, flooding is a frequent occurrence in many parts of the state. Changes in precipitation may increase the vulnerability of state roads and bridges to flooding and erosion. In addition, Delaware beach communities—which are critical to

³Delaware Department of Natural Resources and Environmental Control, *Delaware Climate Change Impact Assessment* (February 2014).

the state’s tourism industry—may see their primary access and evacuation routes increasingly cut off due to sea level rise, according to DNREC. Delaware State Route (SR) 1 is an example of a major access route to state beaches and tourist facilities that is vulnerable to flooding and sea level rise.

The project site we reviewed on SR 1 in the Town of Dewey Beach is particularly vulnerable to flooding and sea level rise. Located between the Atlantic Ocean and Rehoboth Bay, the site is subject to wind and rain in the spring and hurricanes in the fall. During precipitation events, the bay often cannot discharge water because ocean tides also are elevated. This causes SR1 to flood and close to traffic at the project site a few times every year, according to the Delaware Department of Transportation (DelDOT). See figure 7 for a photograph of flooding along Delaware State Route 1 near Seashore State Park.

Figure 7: Flooding (Left) and Resilience Enhancements Made (Right) on Delaware State Route 1



Source: Delaware Department of Transportation (2017). | GAO-21-436

DelDOT engineers hoped to address flooding at the project site by improving site conditions. Because they thought that green infrastructure techniques could reduce flooding and outperform the existing clogged drainage system, they applied for and received FHWA resilience research pilot funding—worth about \$100,000—to document vulnerabilities and a rationale for implementing green infrastructure techniques. DelDOT officials hired consultants to help them reconcile available data sets and incorporate climate change information into specific site assessments. During the analysis, officials determined that the project site is one of the most vulnerable locations in the project area. In addition, analyses of projected sea level rise during different storm scenarios found that the entire project area would be submerged 50 years from now.

Based on these findings, DeIDOT officials decided to raise the road where 30 outfall pipes to the bay were clogged and below the current high tide elevation. Doing so would allow for drainage during most storm events, according to DeIDOT officials. The new road elevation did not address sea level rise estimates; so as a proof of concept project, DeIDOT chose to use about \$150,000 in state funds to implement a combination of gray and green infrastructure improvements on one isolated drainage pipe outfall from SR 1 designed to address 90 percent of the current flooding events. Green enhancements included building a sand dune levee and tidal marsh—and stabilizing the beach with bags filled with oyster shells. Gray enhancements included repairing a rock wall and replacing existing drainage with a larger drainage structure called a box culvert. See figure 7 for a rendering of the resilience enhancements implemented at the project site in Dewey Beach. As a result of these improvements, DeIDOT officials now expect the project site to be able to withstand the 5-year storm.

In addition to using FHWA resilience research pilot funding, DeIDOT officials used other FHWA resources to design and implement the project. FHWA's *Vulnerability and Adaptation Assessment Framework* helped DeIDOT officials identify which resources and data they would need to design a resilience project in a coastal location. For example, it became evident after reviewing the framework that DeIDOT would need to hire coastal engineers. DeIDOT also participated in FHWA peer exchanges and webinars that were helpful for identifying lessons learned and other perspectives on resilience improvements, according to a DeIDOT official we interviewed.

Maryland

Reconstruction, MD 261

Location: North Beach, Maryland

Federal funding: \$1.9 million from the Surface Transportation Block Grant.

Why the Maryland Department of Transportation State Highway Administration (MDOT SHA) Is Making Resilience Enhancements Here: Located between the Chesapeake Bay and an inland wetland, this stretch of MD 261 is the most direct and efficient route for emergency services into neighboring communities. However, the road closes to traffic two to four times yearly due to flooding.

Planned resilience enhancements: MDOT SHA raised the roadway by approximately 2 feet to accommodate for anticipated sea level rise. MDOT SHA also removed drainage pipes beneath the road and replaced them with a 32-foot span bridge to improve water flows between the wetland and the bay.



Source: GAO analysis of information from MDOT SHA.
Photo: MDOT SHA. | GAO-21-436

Roads and bridges along Maryland’s approximately 7,700 miles of shoreline are vulnerable to sea level rise, changes in precipitation patterns, and extreme weather events, according to the Maryland Department of Transportation State Highway Administration’s (MDOT SHA) *Climate Change Adaptation Plan with Detailed Vulnerability Assessment*.⁴ For example, according to this assessment, many counties in the state are expected to experience about 2 feet of sea level rise by 2050, given Maryland’s exposure to the Atlantic Ocean, Chesapeake Bay, and numerous tidal and non-tidal rivers. The assessment also reports that rising sea levels may undermine bridge foundations and damage pavements, and intensified precipitation may cause drainage pipes underneath roads to weaken or collapse if not well maintained.

Among the two sites we reviewed in Maryland—U.S. Route 113 in Snow Hill and MD 261 in North Beach—MDOT SHA used climate projection information, FAHP funds, and MDOT SHA and FHWA resilience tools, such as FHWA’s Vulnerability Assessment Scoring Tool, to incorporate climate resilience enhancements into project designs. Specifically, MDOT SHA raised portions of U.S Route 113 and MD 261 by approximately 2 feet to protect against the roadways being overtopped by rising sea levels.

MDOT SHA was able to integrate resilience enhancements into these project designs for several reasons, according to the MDOT SHA representatives we interviewed. Namely, project designers:

- **Had ready access to useable climate projection information.** With assistance from Salisbury University and resilience research pilot funding from FHWA, MDOT SHA prepared a state-wide assessment report of how climate changes could affect the state’s roads.⁵ In 2014, MDOT SHA published this report with tables reflecting projected changes in sea level rise for many Maryland counties. Project implementers for MD 261 used the sea level change projections in this report—along with other available data, such as a topographic survey of roadway elevations and a U.S. Army Corps of Engineers analysis of the project site—when deciding to raise the roadway by approximately 2 feet.

⁴Maryland Department of Transportation State Highway Administration, *Climate Change Adaptation Plan with Detailed Vulnerability Assessment: Final Report* (Oct. 11, 2014).

⁵Maryland Department of Transportation State Highway Administration, *Climate Change Adaptation Plan with Detailed Vulnerability Assessment: Final Report*.

Reconstruction, U.S. Route 113

Location: Snow Hill, Maryland

Federal funding: Approximately \$64 million from the National Highway Performance Program.

Why the Maryland Department of Transportation State Highway Administration (MDOT SHA) made resilience enhancements here: MDOT SHA replaced a 2-lane highway with a divided 4-lane highway and new bridge to improve safety, as this roadway experienced more fatal accidents than comparable roads. However, the project area is expected to experience 2 feet of sea level rise, and hydraulic analyses indicated that the new bridge would be overtopped under these conditions. This is a designated emergency route, so ensuring that sea level rise would not compromise it was paramount.

Resilience enhancements made: MDOT SHA raised the new bridge and its approaches by approximately 2 feet.



Source: GAO analysis of information from MDOT SHA. Photo: MDOT SHA. | GAO-21-436

- **Recognized the need for improvements.** At the MD 261 project site, conditions on the ground demonstrated the need for resilience improvements, according to the MDOT SHA representatives we interviewed. The project site closes to traffic two to four times yearly due to flooding, and the shoreline adjacent to the roadway is eroding. Project implementers were concerned about road closures along this route because this stretch of MD 261 serves as a connection for emergency services to southern Anne Arundel County. In addition, local residents had already invested in flood protection nearby and expressed support for additional climate resilience improvements at the project site.
- **Benefited from FHWA’s resilience resources.** For example, project implementers for U.S. Route 113 benefitted from FHWA guidance on how to project future sea levels for road projects. This guidance says that road engineers can use a U.S. Army Corps of Engineers formula for calculating future sea levels at their project sites. Based on their calculations, project implementers found that the new bridge planned for the site—as well as the approaches to the bridge—would need to be raised by about 2 feet.

Washington State

Washington State is expected to experience a range of projected climate changes. For example, the Climate Impacts Group at the University of Washington found that increases in extreme high precipitation rates in western Washington and reductions in Cascades Mountains snowpack are consistently projected.⁶ The Climate Impacts Group also found that projections of sea level rise for 2100 in Washington State vary due to

⁶Climate Impacts Group, University of Washington, *The Washington Climate Change Impacts Assessment* (Mar. 2009).

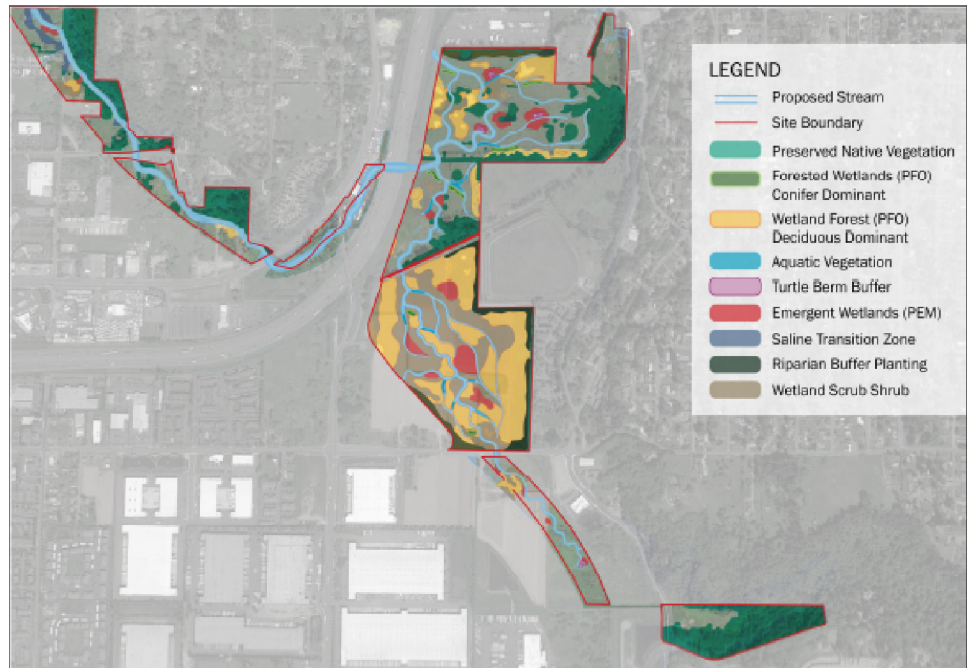
various factors, such as location and land movement. The Washington State Department of Transportation (WSDOT) has reported that the increasing likelihood of extreme heat events may stress transportation infrastructure.⁷

The project site we reviewed near the Port of Tacoma is vulnerable to riverine flooding and sea level rise. WSDOT is in the process of investing about \$750 million in the project to connect State Route (SR) 167 to Interstate 5 (I-5). Building an interchange there is expected to improve the movement of goods to and from the Port of Tacoma, which is critical for trade between the Midwest and Asian and Alaskan markets. However, relatively flat topography makes the project area vulnerable to flooding during moderate storms, including 2-year and 5-year storms, according to WSDOT officials. When the nearby Hylebos Creek floods, water encroaches on I-5 in the future interchange area with SR 167, causing lane closures and congestion.

Due to these vulnerabilities—as well as the economic value and high cost of the project—project implementers planned from the onset to include green infrastructure design elements into project designs to protect the state’s investment against future flooding. According to WSDOT officials we interviewed, they wanted to be very confident that I-5 would remain safe and fully functional throughout its design life. The project they designed involves relocating and widening stream channels, expanding floodplain connectivity with streamflow, removing several small creek bridges and culverts that are no longer needed, and enhancing wetlands and native riparian vegetation in floodplain areas adjacent to this future interchange area for I-5 and SR 167. The project required acquisition of numerous residential, commercial, and agricultural properties from willing sellers, involving approximately 150 acres of land. The stream banks and floodplains will be planted with a variety of native vegetation to capture and hold floodwater, reduce erosion, and provide habitat for fish and wildlife. Figure 8 shows design plans for the project.

⁷Washington State Department of Transportation, *Climate Impacts Vulnerability Assessment Report* (Nov. 2011).

Figure 8: Design Plan for Restoring Streams, Wetlands, and Floodplains in the Future Interchange Area for Interstate 5 and Washington State Route 167



Source: Washington State Department of Transportation. | GAO-21-436

When designing the project, project implementers used FHWA’s Coupled Model Intercomparison Project (CMIP) Climate Data Processing Tool to confirm that the project’s extensive wetland restoration, stream restoration, and floodplain storage elements would accommodate projected future flooding. Specifically, they used CMIP to obtain downscaled climate data on variables such as storm frequencies and depths. They supplemented CMIP data with existing tidal data to better understand future conditions on the ground, and added sea-level-rise estimates to those data to better estimate floodwater elevations. They assumed about 2 feet of sea-level rise by the year 2100, based on probabilistic estimates relative to the project area developed by Washington Sea Grant.⁸ They also reviewed existing precipitation records and emerging products from academic institutions, such as revised

⁸I.M. Miller, H. Morgan, G. Mauger, T. Newton, R. Weldon, D. Schmidt, M. Welch, E. Grossman, Projected Sea Level Rise for Washington State – A 2018 Assessment, a collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, University of Oregon, University of Washington, and US Geological Survey. Prepared for the Washington Coastal Resilience Project. July 2019.

statewide rainfall analyses from Washington State University. During a resilience research pilot project funded by FHWA to evaluate assessment tools for infrastructure resilience and associated adaptation strategies, WSDOT officials determined that including extensive stream and wetland restoration and floodplain storage elements in project designs is an effective strategy for improving the climate resilience of the infrastructure.⁹ Specifically, they expect the project to improve floodwater conveyance, reduce peak flood levels, and prevent flooding on I-5. WSDOT officials also told us that they expect to save millions of dollars in storm water infrastructure construction and long-term maintenance costs after the project is complete.

⁹Herrera Environmental Consultants, Inc., *Discussion Paper: Applicability of the SR 167 Completion Project Riparian Restoration Program as an Adaptation Strategy for Climate Resilience (Draft)* (Mar. 9, 2017).

Appendix III: Using the *Disaster Resilience Framework* to Analyze Options to Further Enhance Climate Resilience

GAO's *Disaster Resilience Framework* 9 through 12 illustrate how we used GAO's 2019 *Disaster Resilience Framework* to analyze the extent to which each of the options identified in this report could further enhance the climate resilience of federally funded roads.¹ As shown in these figures, we compared the options available for further enhancing the climate resilience of federally funded roads with FHWA's current climate resilience efforts using the principles and subprinciples in GAO's *Disaster Resilience Framework*. As stated in the *Framework*, some principles and concepts are likely to be more relevant in the analysis of certain federal efforts than others. It is appropriate to apply portions of the *Framework* to improve the resilience of federal programs depending upon the specific circumstances. Users of the *Framework* should exercise their professional judgment when determining how best to make the principles and concepts meet their needs. This appendix documents the professional judgment GAO applied to the analysis of options to further enhance the climate resilience of federally funded roads.

For each option, an analyst made a determination about which FHWA efforts and *Disaster Resilience Framework* principles, subprinciples, and analysis questions were relevant. The analyst then made an assessment of and documented the extent to which each option could further enhance the climate resilience of federally funded roads, based on a qualitative assessment of the gap between the option and FHWA's current climate resilient efforts. A second analyst reviewed the first analyst's work to ensure that the conclusions drawn were sound. If the second analyst did not concur with the conclusions drawn, the second analyst documented the rationale. The team also documented in its work papers how any differences of opinion were resolved before presenting its final analyses in figures 9 through 12.

¹GAO, *Disaster Resilience Framework: Principles for Analyzing Federal Efforts to Facilitate and Promote Resilience to Natural Disasters*, [GAO-20-100SP](#) (Washington, D.C.: Oct. 2019).

Appendix III: Using the Disaster Resilience Framework to Analyze Options to Further Enhance Climate Resilience

Figure 9: Using GAO’s *Disaster Resilience Framework* to Show How the Options We Identified That Relate to Information Could Enhance the Climate Resilience of Federally Funded Roads

| | | | |
|--|--|--|--|
| <p>Principle Information Accessing information that is authoritative and understandable can help decision makers to identify current and future risk and the impact of risk-reduction strategies.</p> <p>Provide reliable and authoritative information about current and future risk To what extent could federal efforts: • Enhance the validity and reliability of the disaster risk information produced? • Generate and share additional information that would help decision makers understand their disaster risk?</p> <p>Reduce the complexity of and translate risk information for nontechnical audiences? • Help leverage and synthesize disaster risk information from other partners across agencies, governments, and sectors? • Promote consensus around the reliability of the sources and methods that produce disaster risk information? Improve the ability to assess alternatives to address risk To what extent could federal efforts: • Help decision makers identify and select among disaster risk-reduction alternatives? • Provide technical assistance to help build capacity of nontechnical partners? • Contribute to an understanding of approaches for estimating returns on investment? • Help decision makers identify and combine available funding sources and innovative methods for meeting disaster risk-reduction needs? Strengthen the ability to assess status and report progress To what extent could federal efforts: • Advance methodologies or processes to measure the current state of nationwide resilience? • Promote monitoring of progress toward resilience on a programmatic basis?</p> | <p>Information subprinciple: provide reliable and authoritative information about current and future risk</p> | | |
| <p>Option to improve the climate resilience of federally funded roads</p> | <p>Federal Highway Administration’s (FHWA) climate resilience effort(s)</p> | <p>Question for Consideration: To what extent could the additional option reduce the complexity of and translate risk information for nontechnical audiences?</p> | |
| <p>Option 3: Provide climate information.</p> | <p>Providing technical assistance and funding resilience research</p> | <p>To some extent. FHWA has provided technical assistance and funded resilience research to reduce the complexity of risk information. Providing authoritative climate information on topics that stakeholders said could help them make resilience decisions, such as how to select among climate change scenarios, could further reduce the complexity of risk information. However, this issue is larger than FHWA, as GAO previously recommended that the federal government provide authoritative climate information at a government-wide scale.^a</p> | |
| <p>Option 2: Update design standards.</p> | <p>Providing technical assistance</p> | <p>To some extent. FHWA has developed some design guidance to reduce the complexity of risk information. Working with standards-setting organizations to update design standards to account for climate change and resilience best practices could further reduce the complexity of risk information. However, GAO has reported that this is a government-wide problem.^b</p> | |

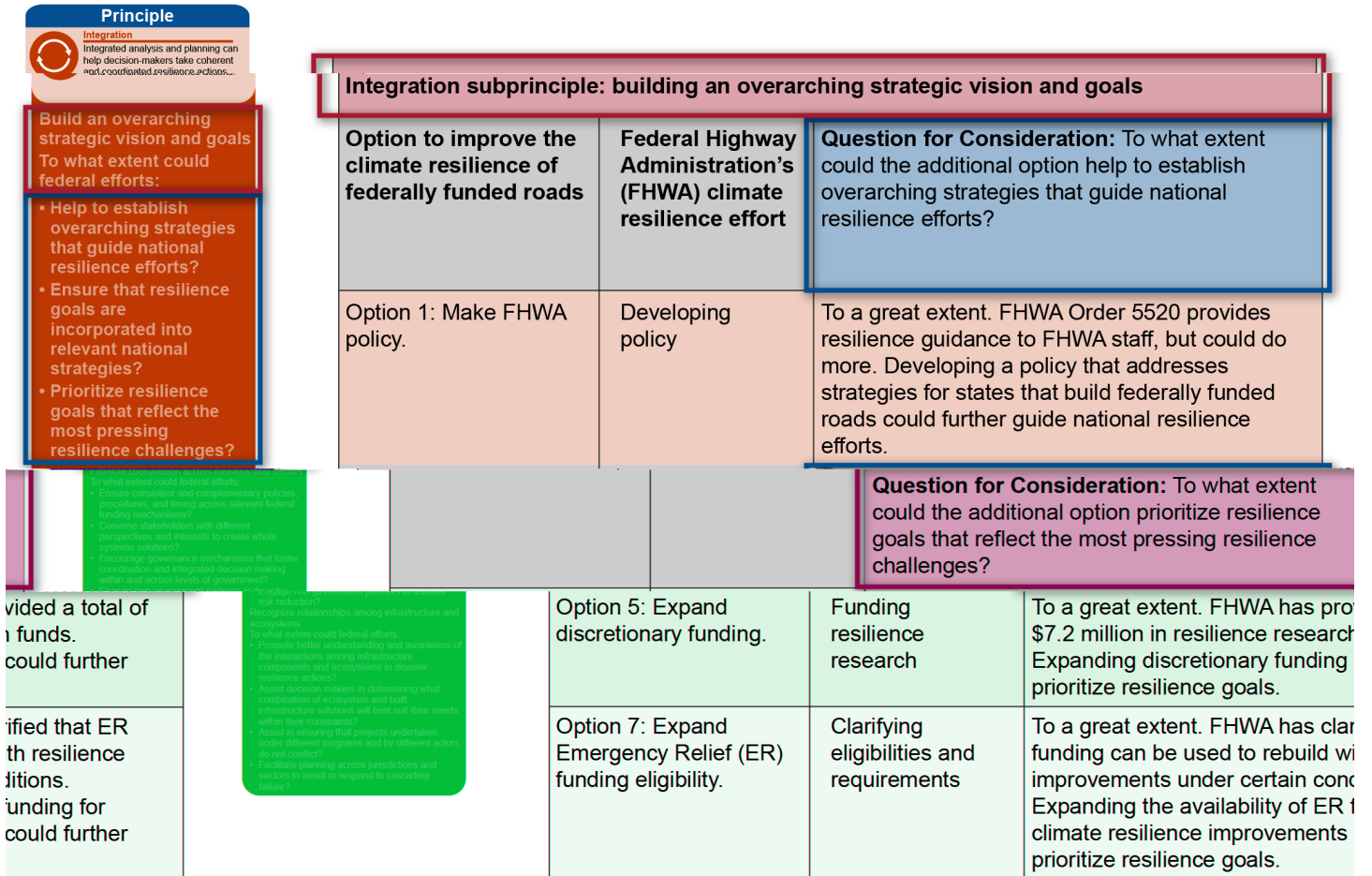
Sources: GAO’s *Disaster Resilience Framework* (GAO-20-100SP) and GAO analysis of FHWA documents, relevant literature, and interviews with knowledgeable stakeholders. | GAO-21-436

^aGAO, *Climate Information: A National System Could Help Federal, State, Local, and Private Sector Decision Makers Use Climate Information*, [GAO-16-37](#) (Washington, D.C.: Nov. 23, 2015).

^bGAO, *Climate Change: Improved Federal Coordination Could Facilitate Use of Forward-Looking Climate Information in Design Standards, Building Codes, and Certifications*, [GAO-17-3](#) (Washington, D.C.: Nov. 30, 2016).

Appendix III: Using the Disaster Resilience Framework to Analyze Options to Further Enhance Climate Resilience

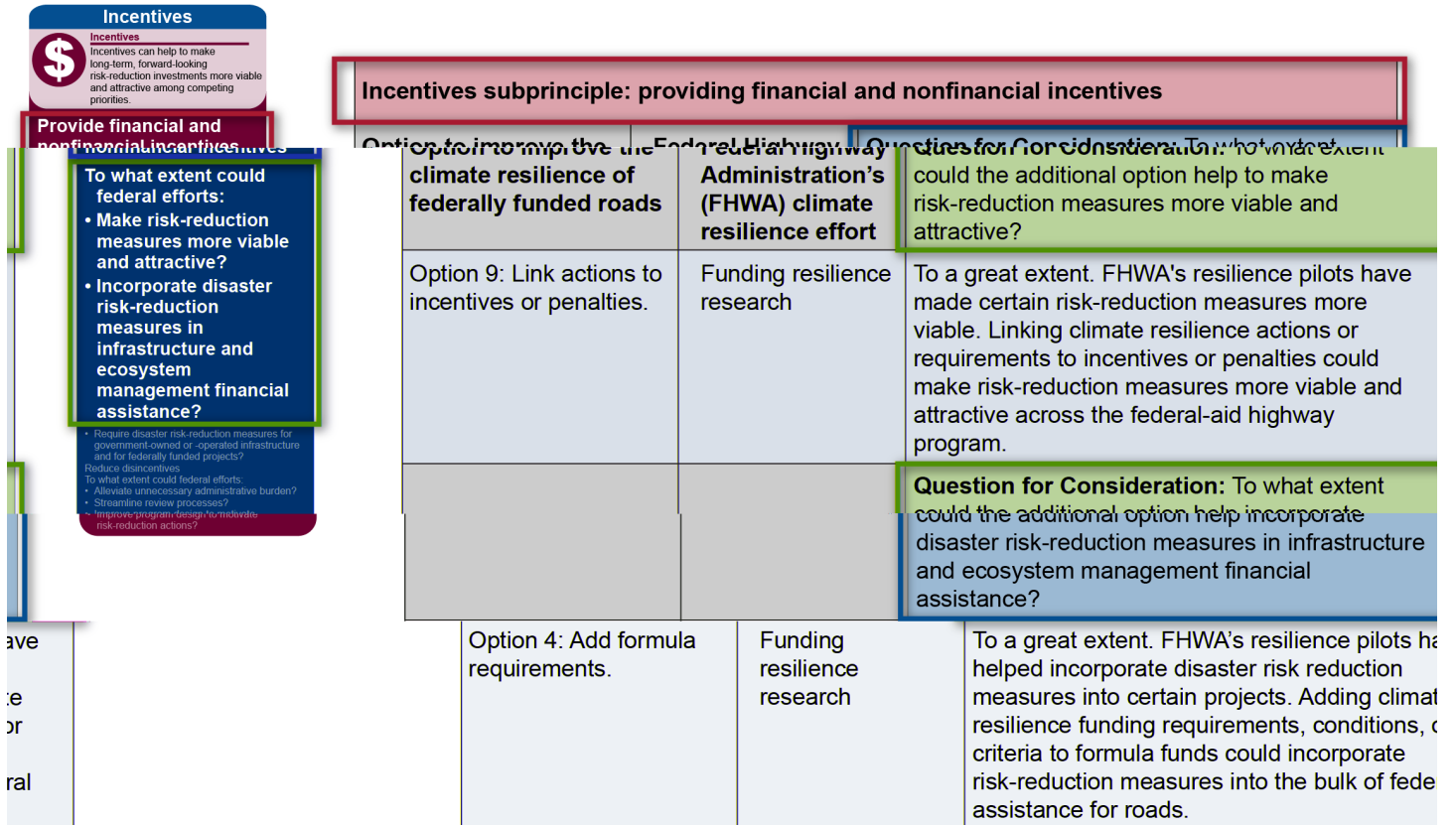
Figure 10: Using GAO’s Disaster Resilience Framework to Show How the Options We Identified That Relate to Integration Could Enhance the Climate Resilience of Federally Funded Roads



s. | GAO-21-436

Sources: GAO’s Disaster Resilience Framework (GAO-20-100SP) and GAO analysis of FHWA documents, relevant literature, and interviews with knowledgeable stakeholder

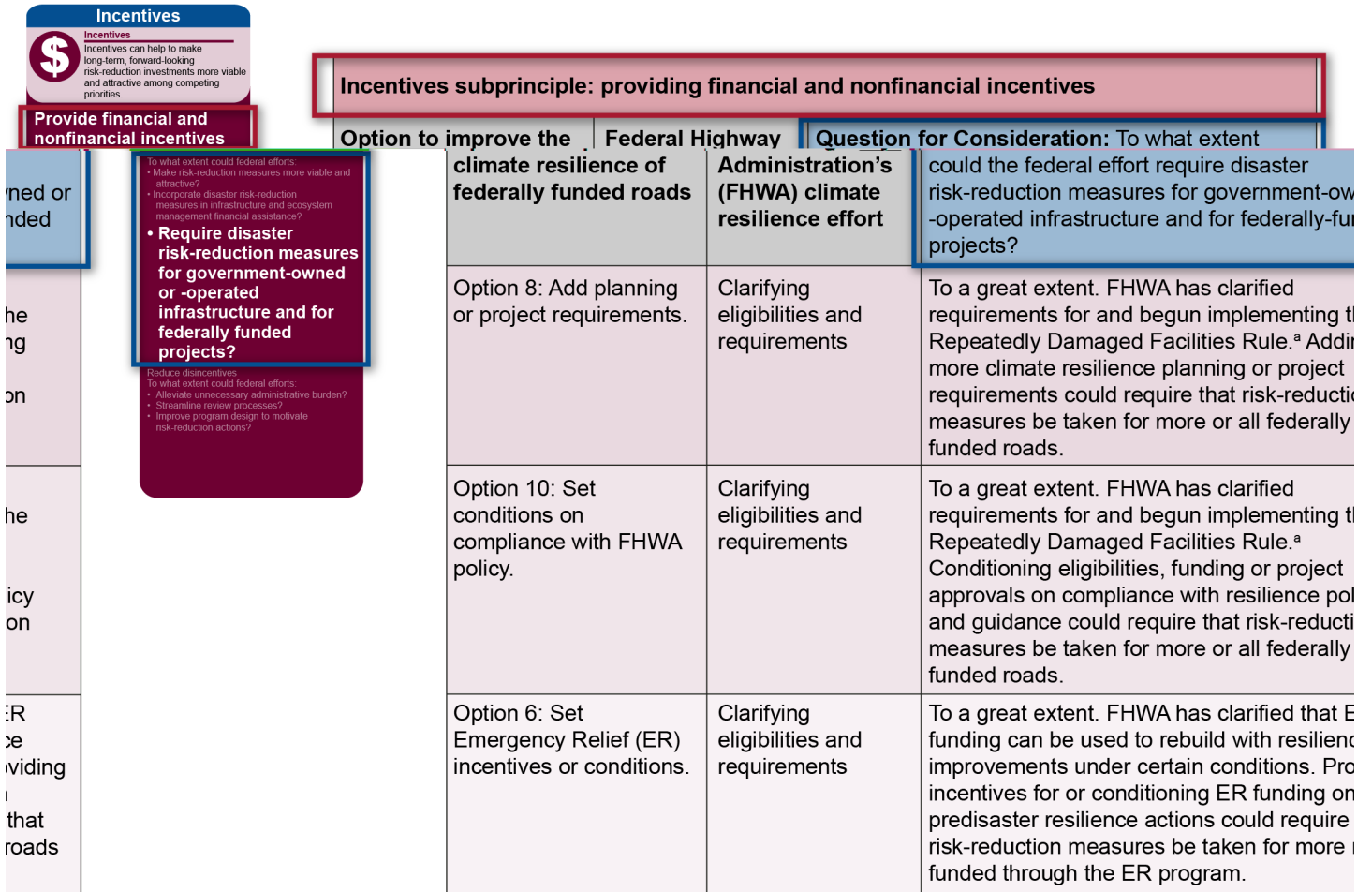
Figure 11: Using GAO's *Disaster Resilience Framework* to Show How the Options We Identified That Relate to Incentives Could Enhance the Climate Resilience of Federally Funded Roads



Sources: GAO's *Disaster Resilience Framework* (GAO-20-100SP) and GAO analysis of FHWA documents, relevant literature, and interviews with knowledgeable stakeholders. | GAO-21-436

Appendix III: Using the Disaster Resilience Framework to Analyze Options to Further Enhance Climate Resilience

Figure 12: Using GAO’s Disaster Resilience Framework to Show How the Options We Identified That Relate to Incentives Could Enhance the Climate Resilience of Federally Funded Roads



36 Sources: GAO’s Disaster Resilience Framework (GAO-20-100SP) and GAO analysis of FHWA documents, relevant literature, and interviews with knowledgeable stakeholders. | GAO-21-4

^aThe Repeatedly Damaged Facilities rule, which requires states to conduct statewide evaluations to determine if there are reasonable alternatives to roads that have required repair and reconstruction on two or more occasions due to emergency events, such as natural disasters. The rule specifies that the evaluation include identification and consideration of any alternative that will mitigate, or partially or fully resolve, the root cause of the recurring damage and consider the risk of recurring damage and cost of future repair under current and future environmental conditions. See 23 C.F.R. §§ 667.1, 667.3.

Appendix IV: Comments from the U.S. Department of Transportation



U.S. Department of
Transportation

Office of the Secretary
of Transportation

Assistant Secretary
for Administration

1200 New Jersey Ave., SE
Washington, DC 20590

September 10, 2021

J. Alfredo Gomez
Director, Natural Resources and Environment
Government Accountability Office (GAO)
441 G Street NW
Washington, DC 20548

Dear Mr. Gomez:

Protecting our Nation's highway infrastructure is a priority for the Department of Transportation (the Department or DOT) and its Federal Highway Administration (FHWA). The Department is committed to increasing its effectiveness in ensuring that infrastructure is resilient enough to withstand climate change and extreme weather events that could otherwise disrupt the transportation network and require major reconstruction. Within the Department, FHWA provides technical assistance to conduct vulnerability assessments of assets and incorporate resilience into transportation planning and engineering design processes. FHWA supports the implementation of requirements related to integrating resilience into transportation system planning and asset management planning by funding recipients for those purposes. *See* 23 U.S.C. §§ 134 and 135; and 23 CFR 515.7. FHWA also conducts research to develop tools, methods, and procedures to help our partners better incorporate resilience into their decision-making.

The Department and FHWA have several programmatic activities underway to assist State Departments of Transportation (State DOTs) and other stakeholders in integrating climate resilience in their programs and projects, such as:

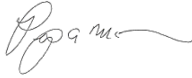
- Including resilience and climate change as part of the criteria for the most recent rounds of the Rebuilding American Infrastructure with Sustainability and Equity (RAISE) and Infrastructure for Rebuilding America (INFRA) grant programs.
- Completing the results of 11 pilot projects on Resilience and Durability to Extreme Weather.
- Hosting a new National Highway Institute Course on incorporating climate resilience into highway projects in the fall of 2021.
- Releasing the third edition of Hydraulic Engineering Circular Number 25 (HEC-25), "Highways in the Coastal Environment." The HEC-25 provides the transportation community with the science and application of climate resilience within coastal areas.
- Co-funding research conducted by the National Oceanic and Atmospheric Administration (NOAA) and United States Geological Survey (USGS) into the non-stationarity of precipitation and streamflow to incorporate this fundamental basis for climate change projections into FHWA's resilience efforts.
- Requiring the State DOTs to periodically evaluate roads and bridges repeatedly requiring repair and reconstruction because of emergency events and encouraging State DOTs to consider resilient alternatives to increase infrastructure resilience as part of emergency relief repairs and save future program costs. *See* 23 CFR Part 667.

**Appendix IV: Comments from the U.S.
Department of Transportation**

Upon review of the GAO draft report, DOT concurs with GAO's recommendation to consider how FHWA plans to implement options to enhance the climate resilience of federally funded roads when prioritizing actions on climate change in policy-making, as called for in Executive Order 14008. DOT will provide a detailed response to the recommendations within 180 days of the final report's issuance.

We appreciate the opportunity to respond the GAO draft report. Please contact Madeline Chulumovich, Director of Audit Relations and Program Improvement, at 202-366-6512 with any questions or if GAO would like additional information.

Sincerely,



Philip A. McNamara
Assistant Secretary for Administration

Appendix V: Staff Acknowledgements and GAO Contacts

GAO Contacts

J. Alfredo Gómez as (202) 512-3841 or gomezj@gao.gov

Staff Acknowledgments

In addition to the individual named above, Joe Thompson (Assistant Director); Mary Koenen (Analyst-in-Charge); Elise Vaughan Winfrey; and Andrew Edkins made key contributions to this report. Other staff who made important contributions were Kevin Bray, Steve Cohen, Tara Congdon, Philip Farah, Cindy Gilbert, Kathryn Godfrey, Ivan Hernandez, Susan Irving, Elizabeth Repko, Sara Sullivan, and Matt Voit.

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