Project No. 20-44(23)

Pilot Test of Climate Change Design Practices Guide for Hydrology and Hydraulics

FINAL CONTRACTOR'S REPORT

Compendium of proposed revisions to NCHRP 15-61 "Applying Climate Change Information to Hydrologic and Hydraulic Design of Transportation Infrastructure" based on pilot tests of the guidelines by eight state DOTs.

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EXECUTIVE SUMMARY

Extreme rainfall, sea level rise, and other hydrologic and coastal events are major climate-related hazards for transportation infrastructure. Engineers typically design infrastructure to withstand hazards up to a "design event," such as the 100-year discharge. These hazards are projected to increase across the country due to climate change, which needs to be factored into the design event calculation, especially when infrastructure has a long service life. Historically, however, there has not been good engineering guidance for incorporating information about future climate change into design calculations.

To address this challenge, in 2019, the National Cooperative Highway Research Program (NCHRP) released a set of provisional guidelines under project 15-61 called "Applying Climate Change Information to Hydrologic and Hydraulic Design of Transportation Infrastructure" (referred to as the Guide). The Guide was developed to help DOTs consider and address the potential effects of climate change in the hydrologic and hydraulic (H&H) design of roads, culverts, bridges, and other transportation assets.

To evaluate and improve the Guide, the NCHRP under project 20-44(23) contracted Dewberry Engineers and their subcontractor AEM Corporation (hereafter referred to as the Study Team) to work with State Departments of Transportation (DOTs) to pilot the Guide at existing and planned infrastructure project sites. As part of this effort, in 2021-2022, a total of two coastal and seven inland pilot projects were voluntarily undertaken by DOTs in Arizona, Colorado, Florida, Iowa, Maine, Maryland, North Carolina, and Oregon. The Study Team worked closely with the pilot projects to provide training on the Guide at pilot kickoff, administer regular surveys and technical assistance during implementation, and collect final feedback and proposed revisions during close-out.

This report catalogs and summarizes all of the proposed revisions to the Guide that were received over the course of the project. It is intended for persons interested in understanding how the Guide could be improved and those involved in developing a revised version. More than 200 comments from nearly three dozen pilot participants were distilled into 53 proposed revisions that are described in Appendix A. The Study Team categorized the proposed revisions into seven major categories.

- Guide Organization: Eight revisions recommend changes to the Guide organization to make current or readily available content easier for DOTs to access and apply.
- 10-Step Procedure for Precipitation Quantile Estimation: Fourteen revisions recommend changes to the 10-step procedure for precipitation quantile estimation.
- CMIP Tool: Nine revisions recommend improvements to the Federal Highway Administration (FHWA) Coupled Model Intercomparison Project (CMIP) Climate Data Processing Tool 2.1 and related tools.
- Methods – General: Eight revisions recommend changes to the methods in the Guide that apply to the entire workflow, including both inland hydrology and coastal applications.
- Methods – Inland Hydrology: Five revisions recommend changes to the methods in Part II of the Guide, which is focused on inland hydrology.
- Methods – Coastal Applications: Seven revisions recommend changes to the methods in Part III of the Guide, which is focused on coastal applications.
- Other: Three revisions recommend adding programmatic guidance to help DOTs implement the Guide and integrate it into existing processes and procedures.

This report concludes with the Study Team's recommendations for improving the Guide. The Study Team's bird's-eye view of pilot project implementation spurred reflections including the need for more visual aids, the role of the climate change indicator, the proliferation of regional change factor datasets, the ultimate influence of the Guide on final infrastructure design, the need to update the Guide as climate science evolves, and the importance of having a programmatic or system-wide perspective.

Chapter 1

Introduction

High-water events are a major hazard for bridges and other transportation infrastructure in the managed floodplain. Transportation engineers typically design infrastructure to withstand flooding up to a “design event,” such as the 100-year flood, which is calculated using historical data on a regional basis. At the same time, inland and coastal flooding incidences are likely to increase across the country due to climate change, which needs to be factored into the design flood calculation, especially when infrastructure has a long service life. Historically, however, there has not been good engineering guidance for incorporating information about future climate change into design calculations.

To address this challenge, in 2019, the National Cooperative Highway Research Program (NCHRP) released a set of provisional guidelines under project 15-61 called “Applying Climate Change Information to Hydrologic and Hydraulic Design of Transportation Infrastructure” (referred to as the Guide). The Guide was developed to help DOTs and other stakeholders consider and address the potential effects of climate change in the hydrologic and hydraulic (H&H) design of roads, culverts, bridges, and other transportation assets.

To evaluate and improve the design practices guide, the NCHRP under NCHRP 20-44(23) contracted Dewberry Engineers, Inc. and their subcontracts, AEM Corporation (hereafter referred to as the Study Team). The Study Team coordinated a select group of state DOTs to apply the Guide to existing and planned infrastructure projects (the pilot projects). In 2021 a total of nine coastal and inland pilot projects were initiated and completed by DOTs in Arizona, Colorado, Florida, Iowa, Maine, Maryland, North Carolina, and Oregon. The Study Team worked closely with the pilot projects to understand how they were using the Guide and how they would like them to be improved in future iterations.

1.1 Report Objective

The participating DOTs had many ideas to improve the Guide for future users during the pilot projects. These ideas have been assembled and summarized in this document, “Proposed Revisions to NCHRP 15-61,” also referred to as the Guide Revisions Report. This document serves as a foundational resource for future revisions to the Guide. It provides a complete list of all the changes and improvements proposed by the pilot DOTs and their implementing partners (e.g., consultants) while also highlighting the most emphatic and frequent recommendations. In addition, this document identifies potential solutions to implement the proposed revisions in future iterations. The pilot participants suggested most of the solutions, although the Study Team provided additional input in some cases. The solutions range from concept-level suggestions to specific inline textual edits.

1.2 Target Audience

This Guide Revisions Report is for persons interested in understanding how the Guide could be improved and those involved in developing a revised version of the Guide or developing a new set of guidelines with a similar purpose.

1.3 Companion Case Studies and Lessons Learned Reference

As part of NCHRP 20-44(23), a companion document has been produced to help state DOTs implement the current version of the Guide in their state. The companion document is called the "Piloting the Provisional Design Practices Guide for Applying Climate Change Information to Hydrologic and Coastal Design of Transportation Infrastructure: Case Studies and Lessons Learned," or simply the Case Studies and Lessons Learned Reference. The Case Studies and Lessons Learned Reference describes each pilot study as illustrative case studies that other DOTs can use as a template for their own projects. The case studies summarize the project motivation, the important data sources, the methods, and the results. It also delivers key lessons learned across all the case studies to help DOTs make the most of the Guide. Finally, the Case Studies and Lessons Learned Reference provides insight for project planners, including the level of effort and expertise typically required.

1.4 Contents Overview

The next chapter (Chapter 2) provides a brief overview of the Guide. Chapter 3 describes the nine projects that piloted the Guide in 2021 and describes the different sources of information for revisions. A more detailed description of each project can be found in the Case Studies and Lessons Learned Reference. Chapter 4 lists and describes each revision. Chapter 5 summarizes the pilot project feedback's overall trends and major themes. Finally, Appendix A provides a detailed description of each of the 53 pieces of individual feedback collected over the study.

Chapter 2

Guide Overview

In 2016 the NCHRP launched project 15-61 called “Applying Climate Change Information to Hydrologic and Hydraulic Design of Transportation Infrastructure.” The research project's objective was “to develop a design guide of national scope to provide hydraulic engineers with the tools needed to amend practice to account for climate change.”[1] Principal Investigator Roger Kilgore led a team of researchers to complete the first provisional version of the Guide in 2019 called “Design Practices Guide for Applying Climate Change Information to Hydrologic and Coastal Design of Transportation Infrastructure.” The 154-page guidebook was released with a more detailed 384 page supplemental Final Report.

While the primary purpose of this report is to describe a set of recommended revisions to the Guide, it is important to have knowledge of the original Guide to put the recommended revisions in context. To this end, this chapter provides a brief overview of the original Guide. The reader can review the full text of the Guide at https://onlinepubs.trb.org/Onlinepubs/nchrp/docs/NCHRP1561DesignPracticesGuide_rev.pdf.

The Guide is split into three parts. Part I provides an overview of the scope and use of the Guide. It introduces decision frameworks for considering climate change in hydrologic and coastal engineering applications. The frameworks recognize that not all projects and studies require the same attention.

Part II addresses inland hydrology, including the analysis of precipitation, runoff (discharge), infiltration, evaporation, soil moisture, groundwater, temperature, and other factors affecting runoff in a watershed. The chapters in Part II provide guidance on selecting and using information from Global Climate Models (GCMs) and overviews basic tools for incorporating climate change into hydrologic analysis and design. Part II also describes specific methods to analyze trends in historical discharges in gauged watersheds; estimate projected precipitation for use in rainfall/runoff models in ungauged watersheds; and estimate future discharge using regression techniques, index approaches, and continuous simulation models under projected precipitation and temperature.

Part III addresses coastal applications with a focus on sea level rise and storm-related coastal hazards. The chapters provide general guidance for selecting sea level rise for analysis and design, as well as guidance on combining coastal hazards, primarily water levels and waves, with climate change information.

1From https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4046

Chapter 3

Pilot Projects Overview

In 2021, with Study Team support, eight state DOTs conducted nine pilot projects using the Guide to incorporate climate change information into the hydrologic and hydraulic design of transportation infrastructure. The Study Team supported the identification and development of the pilot projects and worked closely with the pilots to provide technical support and solicit feedback on the Guide. This chapter describes this process of pilot project identification, implementation, and feedback solicitation to provide the reader with context to understand the origin of the proposed revisions. Refer to the Case Studies and Lessons Learned Reference for a more detailed summary of the pilot projects, including the main findings.

3.1 Pilot Project Identification

In 2020, the Study Team initiated a national search for state DOTs interested in implementing a pilot project. The Study Team posted information about the project, made contact with approximately one dozen DOTs and gave each an overview of the project's goals. In March 2021, the Study Team arranged virtual meetings with DOTs that expressed interest in participating. The Study Team gave each DOT an overview of NCHRP Project 20-44(23) and asked questions to understand their proposed pilot applications better.

To help assess the diversity of the candidate projects, the Study Team produced a matrix table that illustrated which components of the Guide would most likely be the subject of the pilot for each DOTs proposed project. In this context, the term “component” refers to a section or chapter of the Guide with instructions on how to perform a specific analysis.

After reviewing the Guide, Dewberry identified 17 components in the Guide that could be tested, ranging from the selection of climate scenarios (section 3.1) to the projection of coastal design specifications using hydrodynamical modeling (section 12.4). NCHRP Project 20-44(23) aimed to test as many of these components as possible.

Pilot Project Descriptions

This section briefly describes each of the pilot projects. The descriptions are based on information gleaned from the various data sources, which are described in the next section.

Table 1 shows the summary matrix with the Study Team’s best estimate of which components would be tested by the proposed DOT projects, based on our one-on-one discussions with each DOT. The matrix shows that the eight proposed projects by the seven DOTs would collectively test all 17 components. Most of the components (at least 12 out of 17) would be tested by two or more DOTs.

3.2 Pilot Project Descriptions

This section briefly describes each of the pilot projects. The descriptions are based on information gleaned from the various data sources, which are described in the next section.

Table 1. Summary matrix showing the alignment between the Guide components and projects proposed by each state DOT for testing, based on the best available information at the start of the pilots.

	Components of the Guide	Ref Ch.[1]	AZ	CO	FL	IA	MD	ME	NC	OR
Climate	Select climate scenarios	3.1	●	●	●	●	●	●	●	●
	Select climate projections	3.2	●	●	●	●	●	●	●	●
	Select climate models	3.2	●	●	●	●	●	●	●	●
	Calculate climate change index	4.4	◐	◐	◐	◐	◐	◐	●	○
Inland H&H	Select level of inland analysis	4.1	●	●	●	●	●	●	●	●
	Estimate design discharge based on historic trends	5	◐	●	○	◐	◐	○	◐	○
	Estimate design discharge based on rainfall-runoff model	6	○	●	○	●	○	●	●	○
	Estimate design discharge with USGS regression equations	7	●	●	○	○	○	●	○	●
	Estimate discharge based on index approach	8	●	●	○	○	●	●	○	○
	Estimate continuous discharge time series under projected climate conditions	9	○	◐	○	○	○	○	●	○
Coastal Applications	Select level of coastal analysis	10	○	○	●	○	○	○	●	●
	Estimate SLR under climate change using site-specific studies	11.2	○	○	●	○	○	○	●	●
	Estimate SLR under climate change using gridded SLR data	11.2	○	○	●	○	○	○	●	○
	Estimate SLR under climate change using United States Geological Survey (USGS) calculator	11.2	○	○	●	○	○	○	●	●
	Estimate SLR under climate change using National Oceanic and Atmospheric Administration (NOAA) tide station data	11.2	○	○	●	○	○	○	●	●

Table continues on next page.

Table 1 (cont.). Summary matrix showing the alignment between the Guide components and projects proposed by each state DOT for testing, based on the best available information at the start of the pilots.

	Components of the Guide	Ref Ch.[1]	AZ	CO	FL	IA	MD	ME	NC	OR
Coastal Application (cont.)	Project coastal specifications using design equations	12.1-12.3	○	○	●	○	○	○	●	
	Project coastal specifications using hydrodynamical modeling	12.4	○	○	●	○	○	○	●	

●: Component is likely to be tested; ◐: potentially tested; ○: unlikely to be tested

[1] Ref Ch. Is the reference chapter in the Guide

3.2.1 Arizona DOT

The Arizona DOT (ADOT) pilot team used the Guide to support development of a natural hazard resilience assessment for the State Route (SR) 80 St. David Bridge replacement project in St. David, AZ. The St. David Bridge is a scour critical, three-span continuous steel plate girder bridge on State Route 80, milepost 298.79. The facility crosses the San Pedro River at the confluence with Dragoon Wash. The contributing watershed is over 2,000 square miles with headwaters in Mexico.

The objective of pilot team was to understand how changes in climate could impact the safety and reliability of the bridge. In particular, the study looked at whether resiliency enhancement were needed (1) to address severe erosion at the site due to the convergence of two river systems at the project site and (2) to address concerns the bridge could overtop during a 50-year storm event.

In addition to piloting methods in the Guide, this project worked with the J. Sterling Jones Hydraulics Laboratory at the FHWA's Turner-Fairbank Highway Research Center to develop and pilot other innovative approaches to resiliency assessment including probabilistic modeling of climate and extreme weather loading, LiDAR-based scour and overbank mapping; and computational flow dynamics (CFD) simulation of pressure flow conditions.

3.2.2 Colorado DOT

The Colorado DOT (CDOT) pilot team used the Guide to investigate the potential effect of climate change on scour at two bridge projects. Bridge F-50-R is a 445 ft bridge that spans the Colorado River on Highway 13. There is an embankment failure upstream that threatens the abutment, and river shifts have caused adverse flow angles to attack the piers. Bridge P-22-D is a 110 ft bridge that spans the Chacuaco Creek on U.S. Highway 160. The average daily traffic over the two bridges is 17,000 and 190, respectively. Both bridges are on the CDOT critical scour list due to potential for severe scour. The pilot aimed to answer the following questions:

- What are the projected effects of climate change on the local hydrology?
- What are the projected effects on the system's hydraulics (discharge, velocity, shear stresses)?
- How do the projected hydrologic and hydraulics changes affect local bridge scour?
- What additional scour countermeasures (if any) are needed to mitigate the projected effects of climate change?

3.2.3 Florida DOT

The Florida Department of Transportation (FDOT) used the Guide to a understand the potential impacts of climate change on a coastal replacement bridge project. The SR-30/US-98 bridge over St. Joe Inlet, Gulf County, FL, was being constructed at the time of the pilot to replace a 3-span tidally influenced bridge.

FDOT arranged for two pilot teams to use the Guide to evaluate the bridge project at the same time, referred to here as pilot team A and pilot team B. This provided a unique opportunity to test the consistency of Guide implementation in the hands of different design teams. Both pilot teams produced reports which are included in the Appendices for reference. The main question the pilot teams were trying to answer was how will project SLR affect clearance and wave loading at the project site.

3.2.4 Iowa DOT

Iowa DOT used the Guide to evaluate the impact of projected increases in precipitation on two bridge projects on IA 3 near the City of Dumont. The first bridge at Hartgrave Creek is included in planned roadway reconstruction. The roadway will form a Line of Protection (LOP) that is designed to protect nearby communities with a 500-year level of service (LOS). The second bridge at West Fork River was recently completed and sits next to a dike that was designed to protect nearby communities with a 50-year LOS. A major goal of the pilot project was to estimate the level of service for the two structures under projected climate change.

3.2.5 Maine DOT

The Maine Department of Transportation used the Guide to help consider climate change in the design of culverts for the Brewer-Eddington connector project, which will join I-395 and Route 9 in central Maine. The goal of the pilot was to understand (1) how much will the design precipitation event change under projected climate change and (2) to what extent are the current culvert designs adequate for the projected precipitation.

3.2.6 Maryland DOT

The Maryland Department of Transportation (MDOT) pilot team used the Guide to evaluate the effect of climate change on an active design project at Great Mills, MD in St. Mary’s County on the Chesapeake Bay. This urban reconstruction project will upgrade a quarter-mile stretch of MD Route 5 with road widening, drainage improvements, stormwater management, and stream stabilization. When the pilot began, the design phase for the project was past 65 percent complete. Due to the advanced stage of work, the pilot did not consider potential design changes. Rather, the pilot aimed to understand whether MDOT should anticipate an increase in roadway flooding or drainage complaints over time if the project was designed using current criteria and standards.

3.2.7 North Carolina DOT (Coastal)

The North Carolina Department of Transportation (NCDOT) coastal pilot team used the Guide to evaluate the potential effects of sea level rise (SLR) on flooding at a continuous concrete coastal bridge on North Carolina 24 (NC-24). The 2,277 ft bridge crosses the White Oak River to connect Swansboro to Cedar Point, Onslow County. The site is near an inlet to the Atlantic Ocean, approximately 3 miles to the south. As such, the bridge is vulnerable to coastal hazards, including flooding and storm surges. The pilot team aimed to answer several questions including:

- What is the likelihood of flooding over the bridge lifetime and how does it depend on SLR?

- What is the likelihood of nuisance flooding each year and how does it depend on SLR?

3.2.8 North Carolina DOT (Inland)

The NCDOT inland pilot team used the Guide to evaluate the potential effects of climate change on a planned I-95 highway widening and elevating project in the vicinity of Lumberton Regional Airport in Robeson County. The project includes widening I-95 to 8 lanes and upgrading three interchanges with new bridges and ramps. The pilot project is described in detail in a final project report. The pilot aimed to answer the following questions about the project:

- How much is extreme rainfall at the project site projected to increase by 2100?
- How will projected increases in extreme rainfall affect flood elevations along the corridor, and how will the proposed system perform?

3.2.9 Oregon DOT

The Oregon Department of Transportation (ODOT) pilot team used the Guide to understand the potential impact of climate change on the Millport Slough Bridge on the Oregon Coast Highway (US 101). The 382 ft, 4 span bridge was recently reconstructed in 2011. The structure is adjacent to the coast and straddles a narrow channel, approximately 6 miles south of Kernville, OR. The pilot aimed to answer several questions including the following:

- How will climate change affect bridge scour and flood exposure?
- How sensitive are the results to the methods (e.g., GCM selection)?
- How consistent are the results to other data sources (e.g., USGS, historical record)?
- How could the design be changed to mitigate potential future issues?

3.3 Pilot Project Feedback Sources

The Study Team worked with DOTs to solicit feedback and proposed revisions to the Guide and collected DOT feedback from six primary sources: level of effort surveys, post-pilot interviews, final workshop presentations, final workshop discussion, final project reports, and help desk support. Each source is described below.

3.3.1 Level of Effort Surveys

The Study Team developed an online survey instrument for participating state DOTs to collect various types of information, including the Level of Effort (LOE) required to implement the guidelines. The survey instrument was developed using Dewberry’s paid subscription to the SurveyMonkey online platform. The survey questions were iteratively tested and improved by several members of the Study Team. The survey questions included the following:

- Which state DOT do you represent?
- What period are you reporting on?
- What were your main activities during this period?
- How many hours were spent on each activity?
- What are your impressions of the guidelines so far?
- Do you have any recommendations to improve the guidelines?

The survey asked at least one representative from each state DOT to complete the survey at approximately monthly intervals.

3.3.2 Post-Pilot Interviews

The Study Team conducted post-pilot interviews with DOTs who completed their pilot project. The interview objective was to review and confirm all of the information that the DOT provided in their LOE surveys. Additionally, the interviews helped fill in any information gaps related to costs and benefits, record final impressions about the Guide, and identify and collect available pilot project materials (e.g., reports, presentations). The interviews were conducted using a standardized questionnaire after the DOTs finished their pilots.

3.3.3 Final Pilot Reports

Some pilot projects produced and provided final technical project reports with a detailed explanation of methods and results and, in some cases, feedback on the Guide. The production of a final project pilot was considered opti and was not completed by all pilot participants.

3.3.4 Final DOT Workshop Presentations and Discussions

On November 17-18, 2021, the Study Team convened a workshop to solicit input from state DOTs who had piloted the Guide to incorporate climate change into their transportation infrastructure designs. The workshop solicited feedback from DOTs that had completed or nearly completed pilot projects to implement the Guide. The workshop's objectives aligned with the aim of NCHRP 20-44(23), which is "to determine the effectiveness and ease of implementation of the Design Practices Guide produced in NCHRP Project 15-61". The workshop discussions focused on the following topics related to the Guide:

- Gaps, challenges, and successes with the Guide.
- Identification and prioritization of Guide improvements.
- Perceived benefits of Guide implementation.
- DOT plans to institutionalize guidelines.

On the first day of the final DOT workshop, each pilot project delivered a presentation that summarized the objectives, approach, and results. The presenters also provided feedback on the Guide and how they thought it could be improved.

The second day of the workshop was dedicated to interactive group discussions. The discussions aimed to (1) identify any gaps in the guidance that were not already discussed during Day-1 and (2) develop potential solutions to these gaps, including potential revisions to the Guide.

3.3.5 Help Desk Support

The Study Team included dedicated technical staff who answered questions related to the implementation of the Guide. These exchanges were archived as sources of technical feedback.

Chapter 4

Proposed Revisions – Summary

The pilot projects and feedback solicitation process generated over 200 pieces of feedback that could be potentially addressed with revisions to the Guide. Feedback was sorted and grouped into 53 proposed revisions. This chapter provides a high-level overview of the revisions, including significant categories and themes. Appendix A describes each proposed revision, including the source and a list of potential revisions to address the feedback.

4.1 Overall Impressions

The pilot project participants provided substantial feedback on the Guide, as discussed below. It is, however, important to note that participants' overall impression of the Guide was very positive. In the LOE surveys, nearly all participants agreed or strongly agreed with the following statements:

- Guide meets my team’s expectations;
- Guide covers the relevant topics;
- Guide is well organized;
- Guide provides clear and actionable guidance;
- Guide instructions are easy to follow;
- Guide represents the state of practice; and
- Guide is a helpful resource.

4.2 Summary of Proposed Revisions

The Study Team reviewed and consolidated the pilot project feedback from the sources described in Section 3.3 to generate 53 unique proposed revisions listed in Table 2. The Study Team categorized each revision into one of seven different themes. The seven themes are described below.

1. Guide Organization: Eight (8) revisions recommend changes to the Guide organization to make current or readily available content easier for DOTs to access and apply. Several revisions aim to consolidate the information needed to perform a level 1 or level 2 analysis, which is currently dispersed throughout the Guide. Other revisions include adding guidance tailored to different country regions, adding more example calculations, and adding more user-friendly graphics, tables, and text boxes.
2. 10-Step Procedure for Precipitation Quantile Estimation: Fourteen (14) revisions recommend changes related to the 10-step procedure for precipitation quantile estimation. The 10-step procedure was used by nearly all of the inland hydrology pilot projects to estimate the projected increase in future precipitation. The procedure is summarized in Chapter 6 of the Guide (see Figure 6.1, pg 47) and incorporates a lot of material from Chapter 3. The proposed revisions include adding guidance for climate scenario selection; adding regional guidance for GCM selection; and clarifying whether correction factors are needed for the change factor calculation. These revisions might be addressed with

a combination of edits to the description of the 10-step procedure in Chapter 6 and the description of the underlying climate science in Chapter 3.

3. CMIP Tool: Nine (9) revisions recommend changes to the Federal Highway Administration (FHWA) Coupled Model Intercomparison Project (CMIP) Climate Data Processing Tool 2.1. Pilot participants recognized that the CMIP Tool is not technically part of the Guide. However, the tool proved to be critical because most inland hydrology pilot participants relied on the CMIP Tool to perform the 10-step procedure. Their revisions are premised on the idea that the CMIP Tool will continue to be an essential aid in implementing the 10-Step Procedure. However, even if the CMIP Tool is supplanted by another tool, the proposed revisions capture performance expectations that could be applied to its replacement. The proposed revisions include improving the CMIP Tool documentation, adding new features, and providing more detailed output files.
4. Methods – General: Eight (8) revisions recommend changes to the methods in the Guide that apply to the entire workflow, including the inland hydrology and coastal applications. In particular, pilot participants asked for more guidance and examples on how confidence limits can be incorporated into project design and how to calculate and interpret uncertainty in the downscaled GCMs. Other proposed revisions include adding guidance to address the effect of changing temperature, making it easier for different engineers to produce consistent results, and providing more pragmatic advice for high-risk coastal communities.
5. Methods – Inland Hydrology: Five (5) revisions recommend changes to the methods in Part II of the Guide, which is focused on inland hydrology. Several revisions would help users understand the pros and cons of the different approaches presented to choose the most appropriate one(s) for their project. Other proposed revisions would clarify some of the technical explanations and add references to helpful third-party tools. Note that revisions related to the 10-Step Procedure were pulled from this section and put into a separate theme.
6. Methods – Coastal Applications: Six (6) revisions recommend changes to the methods in Part III of the Guide focused on coastal applications. Revisions include adding guidance for probabilistic methods, which are increasingly important for coastal applications; offering an alternative equation to account for the non-linear effect of SLR on coastal surge heights; and elaborating on how to select a reference tidal gauge.
7. Other: Three (3) revisions recommend adding guidance to help DOTs implement the Guide and integrate it into existing processes and procedures. While these revisions may go beyond the Guide's original scope, they could help facilitate DOT uptake and adoption. The revisions would add guidance on connecting with communities, engaging climate scientists, and weighing the costs and benefits of Guide implementation.

The Study Team used their judgement to assign a complexity rating to each revision as follows:

- Higher complexity: Fourteen (14) revisions involve the development of substantial new content and methodologies that could require significant effort;
- Medium complexity: Twenty-seven (28) revisions involve the synthesis and repackaging of available content and methodologies that could require moderate effort; and
- Lower complexity: Twelve (12) revisions involve adding readily available content into the existing Guide structure that is likely to require minimal effort.

The Study Team also calculated a popularity rating as follows:

- Higher popularity: Nine (9) revisions were classified as "higher" popularity because they were suggested by four or more different pilot DOTs;

- Medium popularity: Twelve (12) revisions were classified as “medium” popularity because they were suggested by two or three different pilot DOTs; and
- Lower popularity: Thirty-two (32) revisions were classified as “lower” popularity because they originated from only one pilot DOT.

Table 2. List of revisions to the Guide proposed by DOTs throughout the pilot projects.

Theme	ID	Revision	Complexity	Popularity
Guide Organization	1	Add region-specific guidance for the southwest and other parts of the U.S.	Higher	Lower
	2	Create separate procedures manual.	Higher	Medium
	3	Make the Guide online, a living document with a shareable repository.	Higher	Medium
	4	Provide separate appendices with detailed workflow for each level of analysis.	Higher	Higher
	5	Add more detailed and specific guidance for Level 2 analysis.	Medium	Lower
	6	Make the Guide more user-friendly with hyperlinks, additional graphics, and lookup tables.	Medium	Lower
	7	Provide more example calculations.	Medium	Higher
	8	Expand use of pop-up boxes.	Lower	Lower
10-Step Procedure for Precipitation Quantile Estimation	9	Simplify the steps required to estimate future rainfall at a project site.	Higher	Higher
	10	Add guidance for estimating future rainfall in coastal regions with limited tool coverage.	Medium	Lower
	11	Clarify guidance on the use of correction factors for the change factor calculation.	Medium	Medium
	12	Improve guidance on RCP scenario selection.	Medium	Lower
	13	Propose more efficient ways to calculate the change factor for large contributing areas.	Medium	Higher
	14	Provide better guidance on how to identify the best GCM scenarios.	Medium	Higher
	15	Provide more background information on climate science.	Medium	Lower
	16	Provide more guidance on selecting GCMs for regions that experience atmospheric rivers.	Medium	Lower
	17	Update the example calculation for the 10-Step Procedure with a more typical climate scenario.	Medium	Lower
	18	Add an explanation on how the CCI relates to the 10-Step Procedure for projecting precipitation quantiles.	Lower	Medium
	19	Add tips to catch and avoid anomalies in the GCM data.	Lower	Lower
	20	Clearly identify the 14 recommended Group 1 GCM models.	Lower	Lower

Table continues on next page.

Table 2 (cont.). List of revisions to the Guide proposed by DOTs throughout the pilot projects.

Theme	ID	Revision	Complexity	Popularity
10-Step Procedure (cont.)	21	Explain why downscaled GCM data might be sensitive to the emissions scenario during the baseline period.	Lower	Lower
	22	Provide more options for obtaining downscaled GCM data.	Lower	Lower
CMIP Tool	23	Improve the response time of tools that support the 10-Step Procedure, especially the DCHP website.	Higher	Lower
	24	Improve access to documentation for the CMIP Tool output spreadsheets.	Medium	Lower
	25	Help users use available web tools to extract raw GCM data if needed.	Medium	Lower
	26	Provide additional guidance for using the CMIP Tool near the coastline.	Medium	Lower
	27	Provide more complete and/or more easily downloaded documentation for the FHWA CMIP5 Tool.	Medium	Higher
	28	Update CMIP Tool to output a shapefile with the location of processed grid cells.	Medium	Medium
	29	Add FHWA 2009 reference in the CMIP Tool user's guide to the bibliography.	Lower	Lower
	30	Revise Table 3.3 to make sure GCMs names corresponds with FHWA CMIP Tool data.	Lower	Lower
	31	Make it easier to determine the type of statistical distribution used to calculate the CMIP Tool's precipitation quantiles.	Lower	Higher
Methods - General	32	Make it easier to implement the Guide consistently.	Higher	Lower
	33	Make the levels of analysis classification more practical for real-world applications.	Higher	Lower
	34	Provide more guidance for the consideration of temperature changes.	Higher	Lower
	35	Provide more guidance on handling uncertainty and sensitivity analysis.	Higher	Higher
	36	Provide more pragmatic guidance for high-risk coastal communities.	Higher	Medium
	37	Recommend more simple design rules to account for climate change.	Higher	Lower
	38	Add example calculations of the climate change indicator.	Medium	Lower
	39	Add guidance on considering the effect of climate change on FEMA flood maps that were used in the design.	Medium	Lower

Table continues on next page.

Table 2 (cont.). List of revisions to the Guide proposed by DOTs throughout the pilot projects.

Theme	ID	Revision	Complexity	Popularity
Methods – Inland Hydrology	40	Discuss relative strengths and weaknesses of the rainfall/runoff model and regression equation approaches.	Medium	Lower
	41	Explain how to calculate the Pearson Type III frequency factor for historic gauge analysis.	Medium	Lower
	42	Provide clarity on how to combine projections based on historic gages with other types of projections.	Medium	Medium
	43	Add formula to approximate areal reduction factors in large watersheds.	Lower	Medium
	44	Add references to StreamStats for the regression equation analysis.	Lower	Higher
Methods – Coastal Applications	45	Include probabilistic risk-based methodologies for coastal SLR analysis.	Higher	Medium
	46	Elaborate on GMSLR (MSL) datum adjustment.	Medium	Medium
	47	Expand guidance for SLR analysis for cases with multiple nearby tides gauges.	Medium	Lower
	48	Expand guidance on how to account for storm intensification in hydrodynamic models.	Medium	Lower
	49	Provide an alternative equation for future coastal flood elevation.	Medium	Medium
	50	Keep the coastal applications section general and non-prescriptive.	Lower	Medium
Other	51	Add guidance on connecting with communities.	Higher	Lower
	52	Add guidance on how to engage with climate scientists.	Medium	Medium
	53	Discuss ways for DOTs to determine the cost/benefit of Guide implementation.	Medium	Lower

Chapter 5

Study Team Discussion

This chapter concludes the report with the Study Team's thoughts and recommendations for improving the Guide. The Study Team recognizes that DOTs and their implementing partners are the Guide's primary end-user and that their feedback is of paramount importance. At the same time, the Study Team had a unique "birds-eye-view" of pilot project implementation across eight DOTs, which spurred several recommendations related to general patterns and trends. Other recommendations emanated from the deep familiarity that the Study Team developed with the Guide over the course of pilot implementation and the Study Team's experience with implementing similar projects at the intersection of transportation design and climate science.

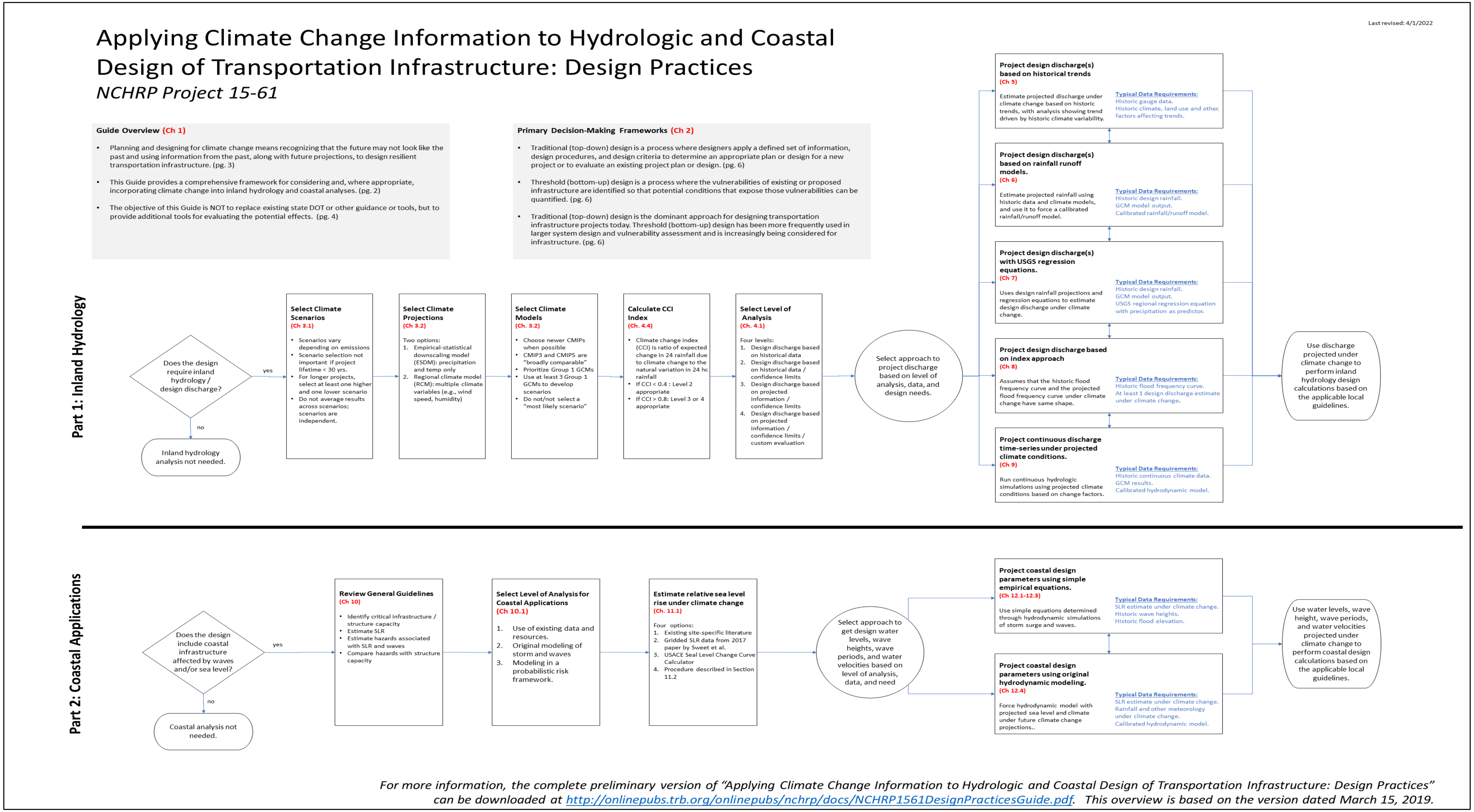
5.1 Adding Visual Aids

The pilot participants recommended adding flowcharts and other visualizations to make the Guide easier to follow (e.g., see Revision ID 6). It is notable, for example, that while there are flowcharts for certain components of the Guide, there is no single flowchart or visual aid that explains the structure of the Guide itself.

Over the course of the project, to help present the contents of the Guide to DOTs, the Study Team developed a flow chart that explains how the three parts and 12 chapters relate (see Figure 1). The flowchart helps illustrate which chapters are relevant for all projects (Chapters 1-2), which chapters should be relevant for inland hydrology projects (Chapters 3-9), and which chapters are relevant for coastal applications (Chapters 10-11). The flowchart also helps illustrate which chapters should be applied sequentially (e.g., Chapter 3-4) and which chapters should be applied in parallel on an as-needed basis (e.g., Chapters 5-9). The flow chart seemed to help DOTs and their partners understand the overall structure and contents of the Guide. The flowchart could be further enhanced by reducing the text and making the flowchart less dense and easier to read. In response to Revision IDs 4 and 5, similar flowcharts could be created to chart the implementation of different levels of analysis.

5.2 Revisiting the Climate Change Indicator

The Guide presents the climate change indicator (CCI) as a "tool to inform a decision on whether a higher level of analysis is appropriate for a given project" (see Guide pg. 30). It says the CCI "provides a measure of the projected change in the 24-hour precipitation for a given AEP from historical conditions, relative to the uncertainty within the estimates of historical precipitation. That is, the CCI provides a measure of whether projected future changes in precipitation are large, compared to the historical variability in precipitation" (see Guide pg. 30). As a broad recommendation, the Guide suggests performing a Level 2 analysis if the CCI is less than 0.4, and a Level 3 or 4 analysis if the CCI is greater than 0.8 (see Guide pg. 41).



Last revised: 4/1/2022

Applying Climate Change Information to Hydrologic and Coastal Design of Transportation Infrastructure: Design Practices

NCHRP Project 15-61

Guide Overview (Ch 1)

- Planning and designing for climate change means recognizing that the future may not look like the past and using information from the past, along with future projections, to design resilient transportation infrastructure. (pg. 3)
- This Guide provides a comprehensive framework for considering and, where appropriate, incorporating climate change into inland hydrology and coastal analyses. (pg. 2)
- The objective of this Guide is NOT to replace existing state DOT or other guidance or tools, but to provide additional tools for evaluating the potential effects. (pg. 4)

Primary Decision-Making Frameworks (Ch 2)

- Traditional (top-down) design is a process where designers apply a defined set of information, design procedures, and design criteria to determine an appropriate plan or design for a new project or to evaluate an existing project plan or design. (pg. 6)
- Threshold (bottom-up) design is a process where the vulnerabilities of existing or proposed infrastructure are identified so that potential conditions that expose those vulnerabilities can be quantified. (pg. 6)
- Traditional (top-down) design is the dominant approach for designing transportation infrastructure projects today. Threshold (bottom-up) design has been more frequently used in larger system design and vulnerability assessment and is increasingly being considered for infrastructure. (pg. 6)

Part 1: Inland Hydrology

Does the design require inland hydrology / design discharge?

yes

no

Inland hydrology analysis not needed.

Select Climate Scenarios
(Ch 3.1)

- Scenarios vary depending on emissions
- Scenario selection not important if project lifetime < 30 yrs.
- For longer projects, select at least one higher and one lower scenario
- Do not average results across scenarios; scenarios are independent.

Select Climate Projections
(Ch 3.2)

Two options:
1. Empirical-statistical downscaling model (ESDM): precipitation and temp only
2. Regional climate model (RCM): multiple climate variables (e.g., wind speed, humidity)

Select Climate Models
(Ch. 3.2)

- Choose newer CMIPs when possible
- CMIP3 and CMIP5 are "broadly comparable"
- Prioritize Group 1 GCMs
- Use at least 3 Group 1 GCMs to develop scenarios
- Do not/not select a "most likely scenario"

Calculate CCI Index
(Ch. 4.4)

- Climate change index (CCI) is ratio of expected change in 24 rainfall due to climate change to the natural variation in 24 hr. rainfall
- If CCI < 0.4 : Level 2 appropriate
- If CCI > 0.8: Level 3 or 4 appropriate

Select Level of Analysis
(Ch. 4.1)

Four levels:
1. Design discharge based on historical data
2. Design discharge based on historical data / confidence limits
3. Design discharge based on projected information / confidence limits
4. Design discharge based on projected information / confidence limits / custom evaluation

Select approach to project discharge based on level of analysis, data, and design needs.

Project design discharge(s) based on historical trends
(Ch 5)

Estimate projected discharge under climate change based on historic trends, with analysis showing trend driven by historic climate variability.

Typical Data Requirements:
Historic gauge data.
Historic climate, land use and other. factors affecting trends.

Project design discharge(s) based on rainfall runoff models.
(Ch 6)

Estimate projected rainfall using historic data and climate models, and use it to force a calibrated rainfall/runoff model.

Typical Data Requirements:
Historic design rainfall.
GCM model output.
Calibrated rainfall/runoff model.

Project design discharge(s) with USGS regression equations.
(Ch 7)

Uses design rainfall projections and regression equations to estimate design discharge under climate change.

Typical Data Requirements:
Historic design rainfall.
GCM model output.
USGS regional regression equation with precipitation as predictor.

Project design discharge based on index approach
(Ch 8)

Assumes that the historic flood frequency curve and the projected flood frequency curve under climate change have same shape.

Typical Data Requirements:
Historic flood frequency curve.
At least 1 design discharge estimate under climate change.

Project continuous discharge time-series under projected climate conditions.
(Ch 9)

Run continuous hydrologic simulations using projected climate conditions based on change factors.

Typical Data Requirements:
Historic continuous climate data.
GCM results.
Calibrated hydrodynamic model.

Use discharge projected under climate change to perform inland hydrology design calculations based on the applicable local guidelines.

Part 2: Coastal Applications

Does the design include coastal infrastructure affected by waves and/or sea level?

yes

no

Coastal analysis not needed.

Review General Guidelines
(Ch 10)

- Identify critical infrastructure / structure capacity
- Estimate SLR
- Estimate hazards associated with SLR and waves
- Compare hazards with structure capacity

Select Level of Analysis for Coastal Applications
(Ch 10.1)

1. Use of existing data and resources.
2. Original modeling of storm and waves
3. Modeling in a probabilistic risk framework.

Estimate relative sea level rise under climate change
(Ch. 11.1)

Four options:
1. Existing site-specific literature
2. Gridded SLR data from 2017 paper by Sweet et al.
3. USACE Seal Level Change Curve Calculator
4. Procedure described in Section 11.2

Select approach to get design water levels, wave heights, wave periods, and water velocities based on level of analysis, data, and need

Project coastal design parameters using simple empirical equations.
(Ch 12.1-12.3)

Use simple equations determined through hydrodynamic simulations of storm surge and waves.

Typical Data Requirements:
SLR estimate under climate change.
Historic wave heights.
Historic flood elevation.

Project coastal design parameters using original hydrodynamic modeling.
(Ch 12.4)

Force hydrodynamic model with projected sea level and climate under future climate change projections..

Typical Data Requirements:
SLR estimate under climate change.
Rainfall and other meteorology under climate change.
Calibrated hydrodynamic model.

Use water levels, wave height, wave periods, and water velocities projected under climate change to perform coastal design calculations based on the applicable local guidelines.

For more information, the complete preliminary version of "Applying Climate Change Information to Hydrologic and Coastal Design of Transportation Infrastructure: Design Practices" can be downloaded at http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP1561DesignPracticesGuide.pdf. This overview is based on the version dated March 15, 2019.

Figure 1. Illustrative flowchart summarizing the three main parts of the Guide.

Despite its potential application, very few of the inland hydrology pilot projects reported calculating the CCI at their project site and/or using it to help identify the most appropriate level of analysis. This may be because the DOTs were implementing a small number of projects so the CCI was not needed to help with screening and prioritization. Nevertheless, the Study Team has reflected on the presentation of the CCI in the Guide and identified several potential problems that could be addressed to make it more accessible and useful.

- The Guide does not have any sample calculations of the CCI (e.g., see Revision ID 7).
- The Guide explains the CCI using nomenclature that is inconsistent with other sections (e.g., see Revision ID 18).
- The Guide cannot pinpoint any tool to help facilitate and automate the CCI calculation. The Study Team is not aware of any tools that calculate the CCI. The CMIP Tool calculates some variables needed to calculate the CCI, but not the CCI itself.
- The Guide doesn't discuss how to consider uncertainty in the CCI calculation (e.g., see Revision ID 35), which could affect its usefulness. Based on tests run by the Study Team, the CCI calculation frequently results in ambiguous guidance on which level of analysis to use when uncertainty is considered. This is because the upper and lower confidence limits for the ratio of the model future to model baseline 24-hour precipitation for a given quantile RFB_q (see Equation 6.2 in the Guide pg 50) tend to produce upper and lower confidence limits for the CCI that range from less than 0.4 (which would suggest the need for Level 2 analysis) to greater than 0.8 (which would indicate the need for Level 3 or 4 analysis).
- The Guide recommends obtaining precipitation confidence limits from NOAA Atlas-14, which has potential quality concerns. The Guide recommends calculating the CCI with the 90% confidence limit precipitation values from NOAA Atlas-14 (see Guide, pg. 31). However, Atlas-14 Volume 2 (Ohio Region) is reported to have overly narrow confidence bounds compared to other Volumes that used better statistical methods (C. Trypaluk, NOAA staff, email communication dated 12/8/2020). The Study Team performed CCI calculations that suggest this could significantly overestimate the CCI in the Ohio region compared to other eastern regions (see Figure 2).

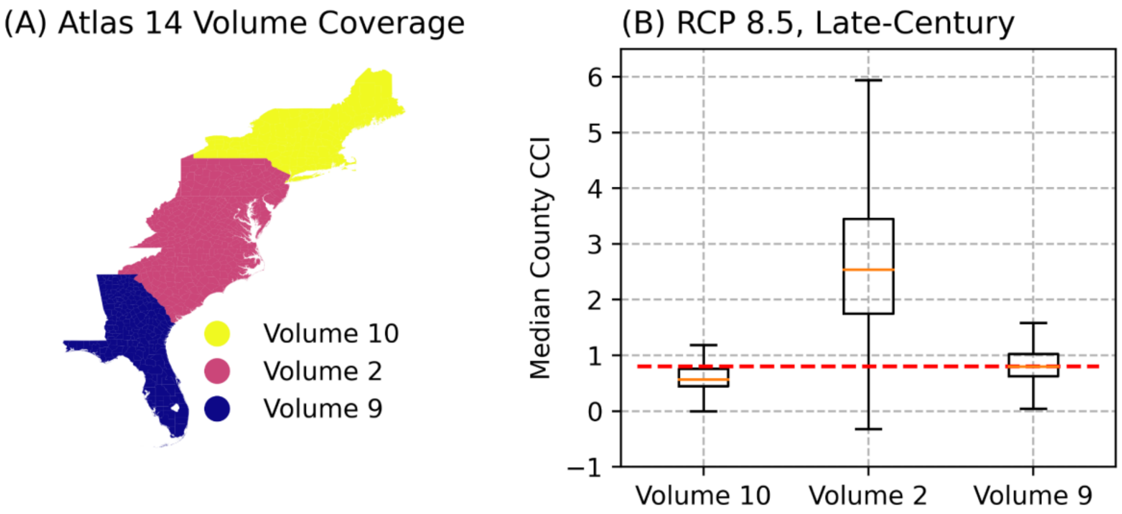


Figure 2. Comparison of county-averaged estimates of the CCI for areas covered by the Volume 10, 2, and 9 regions of the Atlas-14 dataset.

- The Guide doesn't discuss how the CCI may shift over time in ways that have nothing to do with climate change, which DOTs might want to factor into their decision-making framework. For example, the term for the upper 90% confidence limit for the T-year 24-hour precipitation event labeled $P_{24,T,O,U}$ in the denominator of the CCI equation is sensitive to the quality of historic rainfall observations in the vicinity of a particular site.[2] With the periodic updating of Atlas-14, this term value could shift as new historical data is added to the archive or existing historical data is reconsidered and removed. This term could also shift as the statistical techniques used to calculate the confidence interval are refined (as discussed in the previous bullet).

5.3 Revisiting Level 2 Analysis

The Study Team notes that none of the inland hydrology pilot participants use Level 2 analysis in their current agency workflow. None seemed very enthusiastic about applying Level 2 analysis in the pilots. The Guide defines a Level 2 analysis as one where "the design team quantitatively estimates a range of discharges (confidence limits) based on historical data to evaluate plan/design performance" (see Guide pg. 8). Although the approach was previously described and recommended in HEC-17 (Kilgore et al., 2017), none of the pilot participants reported using confidence limits in their H&H design practices at the start of the pilots. Furthermore, the pilot projects all focused on Level 3 analyses using projected rainfall. Some pilot participants questioned whether the levels of analysis were a practical framework (see Revision ID 33), while also asking for more clarity on Level 2 analysis (see Revision ID 5).

The Study Team recommends reviewing Level 2 analysis and whether it is a practical and useful way to account for climate change in inland transportation infrastructure design. While pilot projects may have focused on Level 3 analyses because projecting future rainfall is a newer concept and major focus of the Guide, this may also point to a systemic issue with the widescale adoption of Level 2 approaches . In particular, some stakeholders might question the logic of using Level 2 analysis to address climate change, because it suggests that accounting for uncertainty in existing climate conditions can be used as a substitute for accounting for the effect of future climate conditions. These stakeholders might feel that the projected effect of climate change could be significant even if it is small compared to the variability in the historic rainfall record.

5.4 Discussing Impact on Infrastructure Design

After implementing the Guide, fewer than half of the pilot projects recommended design changes to the transportation infrastructure under study. The Case Studies and Lessons Learned Reference summarizes the recommendations that were made as a result of each pilot project. Out of the nine projects, only three resulted in the articulation of specific potential design changes. Most of the others concluded that the existing design is sufficiently resilient to future climate change and/or that potential future threats can be addressed through adaptive design and other risk mitigation strategies (e.g., early warning systems, road closures).

The Guide might add additional discussion to help DOTs decide when and how to implement design changes to address climate change. Across pilot studies, the Study Team noted that DOTs seemed more likely to consider future design changes under one or more of the following conditions.

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[2] See for example the explanation of the confidence limit calculation in Section 4.7 the NOAA Atlas-14 Volume 2 documentation. The confidence limit is derived from Monte Carlo simulations "with the same data length as the actual data" (pg. 44).

- Structure is in design and has not been built. The pilot studies that looked at structures still in design had more freedom to develop and recommend design changes. The pilot studies that retrospectively analyzed existing infrastructure had fewer options.
- Structure is at risk due to projected climate change. Some pilot studies found that projected changes in precipitation would introduce new threats such as scour, surcharge, and overtopping. Other pilot studies showed the projected changes would pose no significant new threat.
- Projected risk can be significantly reduced or eliminated with design changes. At some pilot sites, projected risks due to climate change could be mitigated with feasible counter measure redesign such as culvert upsizing or scour countermeasure reinforcement. At other sites, however, the effect of climate change could only be mitigated by addressing more systemic issues that transcend the design of any individual structure. For example, the projected risk due to SLR facing many bridges in coastal areas cannot be addressed by changing the bridge design because rising waters are projected to inundate not only the bridges but also the approach roads and communities that they serve (see Revision ID 36).

5.5 Using Third-Party Change Factor Datasets

A growing number of DOTs have access to local and/or national datasets that provide “off-the-shelf” projected IDF curves and change factors that could significantly simplify the implementation of the Guide. These datasets could be used to perform change factor analysis (see Section 9.1 in the Guide, pg. 90) and estimate the ratio of the future to baseline precipitation quantile $RFB_{q,n,m}$ for discharge estimates based on future precipitation (see Equation 6.1 in the Guide, pg. 49). They include:

- The Mid-Atlantic Regional Integrated Sciences and Assessments (MARISA) project maintains a web map with the projected IDF curves for the entire Chesapeake Bay Watershed and Virginia;[3]
- The U.S. Environmental Protection Agency (EPA) has updated and released change factors for the continental U.S. in the Climate Resilience Evaluation and Analysis Tool (CREAT) Climate Scenarios Projection Map;[4]
- The Northeast Regional Climate Center maintains a web map with projected IDF curves for New York State[5] and more recently released projected IDF curves in tabular format for New Jersey.[6]
- The U.S. Federal Highway Transportation Administration (FHWA) has been supporting research into how the NOAA Atlas 14 methodology could someday be updated to include future precipitation frequency estimates.[7]

The Guide could be significantly streamlined if and when it can be assumed the users can access the change factors from external datasets. Many pilot participants spent a significant amount of time and effort calculating the projected IDF curve as part of the 10-Step Procedure in the Guide (see Figure 6.1 in the guide, pg. 47). In addition, the process requires a lot of engineering judgment, and pilot participants

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[3] MARISA dataset last accessed at https://midatlantic-idf.rcc-acis.org/ on April 4, 2022.

[4] CREAT web map last accessed on 4/4/2022 at https://epa.maps.arcgis.com/apps/MapSeries/index.html?appid=3805293158d54846a29f750d63c6890e

[5] Future Precipitations for a Changing Climate web map last accessed on 4/4/2022 at https://ny-idf-projections.nrcc.cornell.edu/

[6] Projected Changes in Extreme Rainfall in New Jersey base on an Ensemble of Downscaled Climate Model Projections last accessed on 4/4/2022 at https://www.nj.gov/dep/dsr/publications/projected-changes-rainfall-model.pdf.

[7] Analysis of Impact of Nonstationary Climate on NOAA Atlas 14 Estimates Assessment Report last accessed on 7/8/2022 at https://hdsc.nws.noaa.gov/hdsc/files25/NA14_Assessment_report_202201v1.pdf.

noted there could be significant variation in how the analysis is done between teams. At the same time, there are challenges to relying on external datasets, including:

- External datasets may not include the frequency, duration, time period, emissions scenario, or GCM ensemble of interest for a particular project;
- External datasets might be more prone to being misapplied, especially if users don't understand how they were generated; and
- External datasets with gridded results still need to be analyzed to calculate area-weighted average change factors over the watershed of interest.

5.6 Updating Guide with Latest Climate Science

The Guide makes several recommendations that are likely to become outdated in the next few years due to the relatively fast evolution of climate change science. As a result, it is important to have a process in place to regularly update the Guide. In several important ways, the Guide is already becoming out of date. For example, in the absence of better information, the Guide recommends using the RCP4.5 and RCP8.5 climate scenarios (see Guide pg. 20), which were introduced in the 2013 Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). However, the RCP scenarios have been replaced in the most recent 2021 IPCC Sixth Assessment Report with Shared Socioeconomic Pathways (SSPs). The Guide also recommends, in the absence of better information, using GCM data from the fifth phase of the Coupled Model Intercomparison Project (CMIP5) (see Guide pg. 20). However, the CMIP5 dataset is being supplanted with the more advanced CMIP6 dataset, which has been released over the past two years. Although it will likely take several more years for the SSP scenarios and CMIP6 data to become mainstream, the current version of the Guide will need regular updates to account for these and other advances.

5.7 Adopting a Programmatic Approach

The pilot projects were designed to test the application of the Guide to a small number of individual transportation assets (e.g., a single bridge or road). While it is important for DOTs to develop this capacity, it is also important for agencies to develop a more programmatic or system-level approach to incorporating climate change into design. What kinds of policies, procedures, and technical tools would make it easier for engineers to consider climate change in their designs? In the words of one of the NCHRP panel members, "designing for climate change should not be a science project every time".

With the exception of a relatively short discussion of bottom-up decision making frameworks (see Guide Section 2.2), the Guide seems to provide relatively little concrete guidance for establishing a more holistic or programmatic approach. Pilot participants seemed to recognize this issue in the comments that prompted the recommendation to provide more pragmatic guidance for high-risk coastal communities (Revision ID 36), where a systems approach can be especially important. Future work could consider adding recommendations for implementing programmatic guidance into the Guide, as well as case studies to showcase successful approaches at state DOTs.

5.8 Prioritizing Revisions

It would be useful to be able to prioritize the 53 revisions listed in Table 2. Which are most important to address first? Which can wait or be dismissed? After consideration, the Study Team concluded it is not practical to develop a single master priority list because (1) it wasn’t feasible to ask the pilot participants to rank all 53 revisions against one another and (2) there are too many factors that influence priority (e.g., potential impact, complexity, urgency) to produce a single ranking that would make sense to all stakeholders.

The Study Team tried to offer at least some insight into prioritization by providing a rank score of the most “popular” revisions (shown in Table 2 and described in Section 4.2). Under this scoring rubric, the revisions that were recommended by four or more different pilot teams were designated as having “higher popularity”. All else equal, it makes sense to give these revisions extra attention due to their widespread appeal. The nine revisions with the “higher popularity” score are listed below.

- Provide separate appendices with detailed workflow for each level of analysis (Revision ID 4).
- Provide more example calculations (Revision ID 7)
- Simplify the steps required to estimate future rainfall at a project site (Revision ID 9).
- Propose more efficient ways to calculate the change factor for large contributing areas (Revision ID 13)
- Provide better guidance on how to identify the best GCM scenarios (Revision ID 14)
- Provide more complete and/or more easily downloaded documentation for the FHWA CMIP5 Tool (Revision ID 27)
- Make it easier to determine the type of statistical distribution used to calculate the CMIP Tool's precipitation quantiles (Revision ID 31).
- Provide more guidance on handling uncertainty and sensitivity analysis (Revision ID35).
- Add references to StreamStats for the regression equation analysis (Revision ID 44).

In addition, the Study Team offers our subjective opinion of some of the most important topics to address in future revisions, listed below.

- Add guidance for each level of analysis (see Revision ID 4).
- Streamline the change factor calculation with “off-the-shelf” values from online tools or other authoritative datasets (see Section 5.5).
- Add guidance to develop a more system-wide and programmatic approach to considering climate change in transportation infrastructure design (see Revision ID 36 and Section 5.7).
- Develop approach to update guidance with the latest climate science (see Section 5.6).

Chapter 6

Acronyms

AASHTO	American Association of State Highway Transportation Officials
BCA	Benefit-Cost Analysis
BCR	Benefit-Cost Ratio
CCI	Climate Change Indicator
CMIP	Coupled Model Intercomparison Project
CREAT	Climate Resilience Evaluation and Analysis Tool
DOT	Department of Transportation
EPA	US Environmental Protection Agency
FHWA	Federal Highway Administration
GCM	Global Climate Models
HEC-RAS	Hydrologic Engineering Center's River Analysis System
IDF	Intensity-Duration-Frequency curves
IPCC	Intergovernmental Panel on Climate Change
LOE	Level of Effort
NCHRP	National Cooperative Highway Research Program
NOAA	National Oceanic and Atmospheric Administration
RCP	Representative Concentration Pathway
SLR	Sea level rise
TRB	Transportation Research Board
USGS	United States Geological Survey

Appendix A

Proposed Revisions – Detailed Tables

This appendix contains a detailed table of information for each revision listed in the main report (see Table 2). The detailed tables have the following information fields:

- Revision ID: Unique number assigned to each proposed revision.
- Title: Sentence summarizing the proposed revision.
- Feedback Summary: Synthesis of information provided about the revision by the pilot participants in all the sources of feedback listed in Section 3.3. This field also includes background information from the Guide and other sources to help the reader understand the full context of the proposed revision.
- Original Comments: Quotations from the feedback provided by the pilot participants related to the proposed revisions. The quotations are a mix of direct quotes from primary sources (e.g., DOT LOE surveys, DOT final reports) and indirect quotes from secondary sources (e.g., the Study Team's meeting notes from a DOT post-pilot interview). Each quotation has brackets at the end that contain the state abbreviations of the pilot that provided the quotation or the letters "WS" to indicate the quote originated from the Final DOT Workshop.
- Study Team Commentary: Commentary from the Study Team attempts to synthesize, interpret, and enrich the DOT feedback. The Study Team commentary does not necessarily reflect the views of the pilot participants. The study team commentary includes the complexity and popularity scores, which were described in Section 4.2.
- Proposed Revisions: List of recommended revisions. The revisions were generally explicitly or implicitly proposed in the feedback sources by the pilot participants.

Attribute	**Description**
Revision ID	1
Title	Add region-specific guidance for the southwest and other parts of the U.S.
Feedback Summary	A pilot participant asked for guidance tailored to the unique environment of the US Southwest.
Original Comments	*Need a dedicated reference for the entire southwestern US. [WS]*
Study Team Commentary	The Study Team agrees that it could be useful to have sections that discuss regional considerations such as major climate-related hazards and GCM selection. The Guide does not address regional differences in any substantial way. Complexity: Higher Popularity: Lower
Proposed Revisions Summary	Add sections with regional considerations related to hazards, GCM selection, and model selection.

Attribute	**Description**
Revision ID	2
Title	Create a separate procedures manual.
Feedback Summary	Pilot participants thought that it would be useful to create a companion/separate procedures manual addressing specific characteristics and challenges that each region may face when analyzing climate change and hydrologic-related hazards.
Original Comments	*Consider not modifying the existing guidance document but creating separate procedures manuals. [CO]* *Guidelines should have a companion document or appendix with case study-like examples. Without that, the user might hit a wall after reading the guidelines and not know how to respond. The companion could be split into 7-9 geographic regions, which deal with specific challenges facing different parts of the country (e.g., atmospheric rivers in the west, snowmelt in the west, extreme heat in the south, coastal storms in the southeast) [AZ]* *Create a new procedure manual with step-by-step documentation. [WS]*

Study Team Commentary	The Study Team is developing a companion document with best practices and lessons learned from the pilots. Complexity: Higher Popularity: Medium
Proposed Revisions Summary	Add a reference in the Guide with best practices and lessons learned from the pilots and/or with more step-by-step procedures and/or with regional guidance.

Attribute	**Description**
Revision ID	3
Title	Make the Guide an online, living document with a shareable repository.
Feedback Summary	Many pilot participants suggested making the guidebook a living document where updates and examples from different agencies applying these methodologies could be added as needed so other agencies could benefit from these examples. The guidebook could be housed in a centralized repository, such as GitHub, to facilitate knowledge sharing.
Original Comments	*Consider making the guidance a living, online document for easier updating. [WS]* *Suggest turning the guidance into an online, living document that can be more easily and more frequently updated. [CO]* *Develop a repository like GitHub for knowledge management and share lessons learned across DOTs. [WS]* *Consider establishing a repository like GitHub so that states can share knowledge. [CO]*
Study Team Commentary	Publishing the guidance online as a living document would facilitate immediate dissemination of updates. In addition, navigation would be simplified through hyperlinks, site map, etc. Outside resources, such as the CMIP5 Climate Data Processing Tool and sites hosting data could be linked to the guidance. There is some precedence for this. One of the deliverables of NCHRP Project 20-24(95) is The Agency Capability Building Web Portal, an online guidebook. Funding would need to be secured for both the site development and ongoing maintenance. Complexity: Higher Popularity: Medium
Proposed Revisions Summary	Consider hosting the revised guidance at an online repository.

Attribute	**Description**
Revision ID	4
Title	Provide separate appendices with detailed workflow for each level of analysis.
Feedback Summary	Many of the pilot participants agreed that it would be beneficial to have separate chapters or appendices for each one of the analysis levels, especially levels 1 to 3 for inland hydrology. In addition, the appendices should include detailed examples to help users to better understand the process as well as provide an estimated LOE for each level.
Original Comments	*Providing separate appendices that individually detail each of the four levels of analysis. [OR]* *Add appendices that walkthrough guidelines for level 1 analysis, level 2 analysis, etc. This would help because the level 1 user has to wade through a lot of irrelevant material. This would add redundancy, but that's ok. [OR]* *A concise document outlining and recommending a specific procedure would be helpful . . . however, this is most likely beyond the scope of the NCHRP project. [IA]* *Steps needed to conduct different types of analyses and methods were provided according to the availability of data and steps needed to complete climate change effects on rainfall were explained with examples. For studies investigating the range of variability due to climate change models (up to Level 3), the guidance was adequate. [IA]* *Providing separate appendices that individually detail each of the four levels of analysis would help users rather than getting lost in the details. [OR]* *Provide separate appendices for each level of analysis. [WS]* *Add guidance on rainfall distributions obtained from GCMs. [WS]* *Separate appendices for each level of analysis with examples would be helpful for the first-time user. [WS]* *Guidance is a bit long. There are tradeoffs, but it could be simpler so that less experienced front-line engineers could use it. That said, the guidance is good and does not need significant edit. [AZ]* *Add information on the LOE for different levels of analysis. [WS]* *The guide has too many alternative pathways. Not straightforward. [OR]* *A more prescriptive approach would be useful for at least Level 1 analysis. [OR]*
Study Team Commentary	The "How to Use this Guide" section says that the guide is designed to be "read in its entirety for maximum benefit, but it is also designed for quick reference by topic" (see Guide, pg. 4). The feedback from the pilot projects suggests that DOTs

	did not want to have to read through the entire guidebook to understand the process for a specific level of analysis, and that the DOTs wanted a quicker reference on how to do a specific level of analysis. The Study Team was not able to find in the Guide any figure or table dedicated to how to do a specific level of analysis, even though it has many figures and tables on how to do components of the analysis (e.g., Figure 6.1). There are also no start-to-finish examples of a particular level of analysis calculation. The Study Team notes that the structure of Chapters 5 thru 9 could contribute to confusion about how to "pick-and-choose" the best tools and methods for a particular level of analysis. At first glance, these chapters seem to describe different analytic options such that the user should pick the best one for their application. Upon closer inspection, the story is more complicated. The techniques in Chapter 5 using historic data could be done in conjunction with methods in the other chapters. The techniques in Chapter 6 are prerequisites for some of the approaches in Chapters 7 to 9. Additional flow charts and figures would help users understand how the Chapters relate to one another and to each level of analysis. Complexity: Higher Popularity: Higher
Proposed Revisions Summary	Provide separate appendices with detailed workflow for each level of analysis.

Attribute	**Description**
Revision ID	5
Title	Add more detailed and specific guidance for Level 2 analysis.
Feedback Summary	One pilot participant commented that the Guidelines should have provided more information about how to conduct Level 2 analysis. Level 2 analysis is described in the Guidelines as "Design discharge based on historical data/confidence limits" (see pg. 8).
Original Comments	*"Including additional information on the Level 2 analysis could be helpful" [MD]* *"Expand Level 2 Analysis Description." [MD]*
Study Team Commentary	The Level 2 analysis explanation is shorter than the explanation for the other three levels of riverine analysis in Section 4.1 of the guidelines. That said, the text does note that the explanation of the Level 1 analysis also applies to Level 2 analysis. The text also refers the reader to HEC-17 for more information, which can be accessed at https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hif16018.pdf. It would be useful to provide a few more sentences about the information in HEC-

	17, and which parts of the document would be most relevant (e.g., Section 7.4.2 Level 2 – Historical Discharger / Confidence Limits). Complexity: Medium Popularity: Lower
Proposed Revisions	Add more detailed and specific guidance for Level 2 analysis.

Attribute	**Description**
Revision ID	6
Title	Make the Guide more user-friendly with hyperlinks, additional graphics, and lookup tables.
Feedback Summary	Pilot participants recommended enhancing with more graphics, better examples, and easier navigation.
Original Comments	*Need more graphics. [WS]* *Enhance guidance with lookup tables. [WS]* *Add hyperlinks, short descriptions, and screenshots. [WS]* *Ensure guidelines refer to related guidelines (guidelines that overlap) to avoid redundancy. [WS]* *Add hyperlinks, short descriptions, and screenshots. [WS]*
Study Team Commentary	The Study Team agrees that the usability of the Guide would be improved with better organization and more examples. Complexity: Medium Popularity: Lower
Proposed Revisions Summary	Make hyperlinks between table of contents and chapters, sections, figures, and tables. Add lookup tables, additional graphics, and worked examples. Add links to related/overlapping sections.

Attribute	**Description**
Revision ID	7

Title	Provide more example calculations.
Feedback Summary	Pilot participants praised the detailed examples and suggested adding more throughout the Guidelines. In addition to more examples like the ones already included, participants asked for more examples of typical analyses from start to finish for different levels of analysis.
Original Comments	*Adding detailed examples for each of the different levels of analysis [OR]* *Give more practical guidance / references / examples on how to do rainfall/runoff modeling. [OR]* *Add examples of level 1, level 2, …, etc analysis from start to finish. [OR]* *The walk-through examples were very helpful [CO]* *Adding detailed examples for each of the different levels of analysis [OR]* *More examples may be helpful [NC]* *Need more example problems. [WS]* *Exhaustive, worked out examples would be helpful. [WS]* *Sections need to be strengthened with more example problems. [WS]*
Study Team Commentary	The Study Team believes there is a particular need for (1) an example of the Climate Change Indicator calculation and (2) an example of historic gage trend analysis that finds a significant trend in discharge over time that can be attributed to climate change. Complexity: Medium Popularity: Higher
Proposed Revisions Summary	Provide more example calculations throughout the Guide.

Attribute	**Description**
Revision ID	8
Title	Expand use of pop-up boxes.
Feedback Summary	Pilot participants found the “Bottom Line” boxes in the guidelines helpful and asked for more of this kind of summary.
Original Comments	*“The blue bottom-line boxes are very helpful and offer a nice short summary for the sections.” [MD]*

	"Add pop-up boxes to highlight salient points." [MD] *"Pop-out boxes could be useful in highlighting key pieces of information." [MD]*
Study Team Commentary	Pilot participants described parts of the guidelines as confusing in their feedback (e.g., Revision ID 11). The addition of more "Bottom Line" boxes could help make them easier to use. Complexity: Lower Popularity: Lower
Proposed Revisions Summary	Keep and, if possible, enhance the use of highlight boxes throughout the guidance.

Attribute	Description
Revision ID	9
Title	Simplify the steps required to estimate future rainfall at a project site.
Feedback Summary	Multiple DOTs thought that the 10-step method described in the guidelines to calculate future precipitation quantiles is too difficult and/or time-intensive. The 10-step method is summarized in the guidelines Section 6.1.1 and Figure 6.1. Respondents thought the most difficult parts of the 10-step method were related to downloading and analyzing the GCM outputs. Several respondents had difficulty using the FHWA tool. Other respondents remarked that the process seemed to require an advanced understanding of statistics, computer programming, and climate science. Note that more specific feedback on the FHWA CMIP 5 Tool is described in separate revisions. Many respondents commented that it would be more efficient to produce future precipitation quintiles for large regions instead of on a project-by-project basis. At least two DOTs have developed or are developing a clearinghouse with future precipitation quintiles for an entire state or region. For example, one DOT pointed to a relatively new website with intensity-duration-frequency curve data for the entire Chesapeake Bay Watershed and Virginia (link).
Original Comments	*"Establishing climate adjusted IDF curves - projecting a region to study, developing future rainfall, doing change factors mean, max, mid, and the thinking about generating future depth of rainfall prediction is all very time consuming and skill intensive." [AZ]* *"Had difficulty obtaining CMIP5 data with FHWA tool." [IA]* *"It is clear that it would be advantageous, as the Guidelines suggest, for the downscaled CMIP5 data to be processed regionally or otherwise in a way that the*

	end user might extract data in a method similar to using Atlas 14, as opposed to doing so on a project-by-project basis." [NC] *"In most cases the projected climate change rainfalls did not significantly impact project performance. As designed the pilot site was able to reasonably accommodate the projected increases in rainfall. Within this period the projected rainfalls using the NCHRP method were compared to projected rainfalls that were determined as part of a MARISA research project. While their methodology was slightly different the results were similar. A potential advantage of their research is the development of a web viewer that provides predetermined ratios to calculate projected rainfalls. Regardless of how MDOT SHA incorporates climate change into our design guidelines the MARISA research highlights an interesting way to provide the data to designers while reducing the work required on a project-by-project basis. If interested their web viewer is available here: https://midatlantic-idf.rcc-acis.org/." [MD]* *"It's likely that if these guidelines are implemented on a project-by-project basis that this step of gathering projected rainfalls may take longer than the actual drainage design if designers must work through the process from start to end for every project." [MD]* *"Level of effort for future projection is high, implementing on a project-by-project basis." [MD]* *"Statewide coverage of Projected Rainfall Ratios, similar to Atlas 14, may make sense."[NC]* *Counterpoints:* *"Obtaining and processing the data to arrive at future precipitation ratios is fairly quick (in man hours) once the infrastructure has been set up (spreadsheets to summarize data, etc.)." [IA]*
Study Team Summary	The pilot participants seemed to recognize that the 10-step method in the guidelines and the FHWA CMIP 5 Tool made it much easier to calculate a future precipitation quantile than it would have otherwise been. At the same time, they commented that it needs to be even easier. The participants also seemed to recognize that the FHWA CMIP 5 Tool is not part of the guidelines, although it was remarked that the 10-Step Procedure would have been practically impossible to implement without it. The Study Team notes that a potential benefit of developing regional future precipitation quantiles maps is that it ensures that projects use a consistent set of change factors across a region. A problem with the site-by-site approach is that neighboring projects could arrive at different change factors due to normal variation in engineering judgement. This did not emerge as an issue in any of the pilots but could become an issue as the number of implementation sites increases. Complexity: Higher

	Popularity: Higher
Proposed Revisions Summary	Some pilots recommended developing regional precipitation quantile maps like the MARISA maps in the Chesapeake Bay Watershed so that fewer project-by-project calculations would be necessary.

Attribute	**Description**
Revision ID	10
Title	Add guidance for estimating future rainfall in coastal regions with limited tool coverage.
Feedback Summary	The pilot participants were heavily dependent on the CMIP Climate Data Processing Tool 2.1 to calculate the change factor for future precipitation events. The tool requires users to identify and extract data from an area of interest. However, the tool is unable to extract data from some coastal areas due to limitations in the mapping extent. As a result, it is more difficult (if not impossible) to use the tool to estimate change factors for some coastal infrastructure. The pilot participants suggest adding more guidance on how to overcome the tool limitations to calculate change factors in these problematic coastal areas.
Original Comments	*Adding guidance for using the tool for locations that have a coastal impact. This is not straightforward and many bridges at/along the coast will have this issue. [OR]* *Adding guidance for using the tool for locations that have a coastal impact. [OR]*
Study Team Commentary	Complexity: Medium Popularity: Lower
Proposed Revisions Summary	Add more guidance on how to overcome the tool limitations to calculate change factors in these problematic coastal areas.

Attribute	**Description**
Revision ID	11
Title	Clarify guidance on the use of correction factors for the change factor calculation.
Feedback Summary	The Guide recommends a 10-step procedure for projecting the 24-hour precipitation quantiles (see Guide Figure 6.1). Step 5 instructs the engineer to download GCM precipitation data, extract the annual maximum series (AMS), and

	make two adjustments: (1) an adjustment from constrained daily values to unconstrained 24-hour values and (2) an adjustment from spatially averaged values to point values. In steps 6-8 the engineer uses the adjusted AMS data to calculate a change factor for each GCM/scenario combination. Many pilot participants used the FHWA CMIP Climate Data Processing Tool to complete steps 5-8 and calculate the required change factors. The Tool helps the user extract the GCM data and produces a spreadsheet with the final change factor values. Pilot participants asked for clarification on whether the Tool is programmed to make the recommended adjustments and, if so, what corrections are applied. Pilot participants also wondered whether the adjustments were really necessary, given that the ultimate goal is to calculate the change factor, which is the ratio of the adjusted projected future rainfall to the adjusted historic rainfall. If the adjustments act as a constant multiplier to both the future and historic rainfall, then they would "cancel" and not change the ratio.
Original Comments	*A clearer discussion on the areal and 24-hour unconstrained correction would be helpful, it doesn't appear this is necessary (since ratios) and it's not clear whether the tool does this, or if it has to be manual, negates some of the utility of the tool. [NC]* *Guidelines and CMIP Tool should explain how to handle correction factors (e.g., AEF). A pilot study suggested they do not need to be considered because they don't affect results. The modeling team did a sensitivity analysis to confirm this. [NC]* *How are the ratios and confidence intervals calculated in the CMIP tool? [OR]* *The 24-hour unconstrained and areal reduction corrections – are these necessary? Not able to make these corrections if using the CMIP Tool output directly (can examine AMS manually and do this) [NC]*
Study Team Commentary	Pilot participants might be unaware that this issue is discussed in the Tool documentation, which states that the Tool does not apply the adjustments, reasoning that "since the quintile ratios [i.e., change factors] are the relevant output, these adjustments are not needed for the ratios."[8] This reasoning seems to assume that the adjustments act as a constant multiplier to both the historic and future quintile projections, so they "cancel out" and have no effect on their ratio. If the adjustments are not necessary to calculate the change factors, it should be possible to remove the adjustment step from the Guide procedures. Complexity: Medium Popularity: Medium

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[8] See footnote 4 on page 38 in https://www.fhwa.dot.gov/engineering/hydraulics/pubs/CMIP_Tool_User_Guide_Version_2_1_508_version_03092021.pdf. Accessed on March 11, 2022.

Proposed Revisions Summary	Update the Guide to explain if and when the adjustments must be made to the raw AMS values and when the adjustments can be skipped because they "cancel out" and don't affect the final outcome.

Attribute	Description
Revision ID	12
Title	Improve guidance on RCP scenario selection.
Feedback Summary	Pilot participants asked for better guidance on how to select the most appropriate "Representative Concentration Pathway (RCP)" scenario.
Original Comments	*Need guidance on scenario (RCP) selection). [WS]* *Provide more information on the RCPs. [WS]*
Study Team Commentary	The Guide recommends using one higher and one lower RCP when the design lifetime is greater than 30 years (see Guide pg. 16). When using the recommended LOCA downscaled GCMs, this corresponds to RCP4.5 and RCP8.5. Neither the Guide nor the Guide Final Report gives context to help the user understand the terms "higher" and "lower". If might be useful, for example, to know what future emissions pathways could produce a RCP8.5 or an RCP4.5. Would the Guide characterize either one as "business as usual"? The Guide should be updated to provide guidance on climate scenario selection for the newest generation of CMIP6 projections, which are based on Shared Socio-economic Pathway (SSP) scenarios instead of RCP scenarios. Complexity: Medium Popularity: Lower
Proposed Revisions Summary	Add guidance on how to select the most appropriate RCP.

Attribute	Description
Revision ID	13
Title	Propose more efficient ways to calculate the change factor for large contributing areas.

Feedback Summary	Several pilot participants recommended more efficient ways to select grid cells in the CMIP Tool for the change factor calculation. The Guide says that the change factor calculation should use data from all of the GCM grid cells that cover a watershed of interest. The pilot participants noted that the calculations can be onerous in large watersheds that span up to 75 or more grid cells. The pilots did tests to show that using the watershed centroid grid for calculations was much easier and gave similar results to using every individual grid cell.
Original Comments	*Guidelines could describe/recommend shortcuts for calculations, as the use of subwatershed centroids instead of all grid cells. [NC]* *Using the four 1/16th downscaled CMIP5 grid cells that contain the centroids of the four subareas of the watershed produced very similar values compared to using all 75 downscaled grid cells that intersect the watershed to determine area-weighted values. This may not always be the case but is a consideration when modeling large watersheds, as the time to process the data can vary significantly between the two approaches, depending on the level of experience and programming capabilities of the user. Perhaps more importantly, multiple download requests had to be made to obtain the 75 downscaled grid cells that intersect the watershed using the area-weighted method, along with surrounding cells that were included because of selections being limited to rectangular. [NC]* *Guidance on LOCA location selection for analysis (bridge site vs watershed vs ?) [OR]* *Centroids – consider using centroid CMIP5 grid cells of areas of the watershed instead of area-weighting all intersecting grid cells (if it makes sense, and still check neighboring cells) [NC Inland]* *The modeling team would like to be able to provide the Downscaled CMIP5 data website to allow specifying a polygon to select the desired GCM cells, instead of using the rectangular option that is currently provided. The rectangular option requires grabbing many more GCM cells than are actually needed (e.g. that intersect a study area)..[NC Inland]* *Clarify/highlight guidance on what GCM cells to analyze in a big watershed. [OR]* *Need guidance on how to handle big watersheds that span multiple GCM grid cells. How can you take advantage of all of the downscaled climate data without aggregating it to a single number? How do you preserve spatial variability? [WS]*
Study Team Commentary	The pilot participants reported that they calculated representative climate parameters in large watersheds by taking the area-weighted average of each grid cell value, where the area is the overlap between the watershed and the grid cell. Thus, grid cells that are completely within the watershed of interest would be assigned a weight of 1.0, grid cells that are a quarter within the watershed of interest would be assigned a weight of 0.25, and so forth. While this approach seems intuitive, the Guide seems to recommend using a simpler, unweighted average of all the overlapping grid cells (see Guide pg. 51, Step 4, which makes no

	mention of area-weighting). Given the pilot participants' inclination to do area-weighting, the Guide could be clearer about whether this is recommended and/or potentially useful. Complexity: Medium Popularity: Higher
Proposed Revisions Summary	With respect to GCM grid cell section for the change factor calculation in the Guide (Chapter 6), consider revising the Guide and/or the CMIP Users Guide with advice on if/when to use the GCM grid cells at the watershed centroid and if/when to use all the grid cells that cover the watershed. Consider adding a feature to the U.S. Bureau of Reclamation's Downscaled CMIP5 Climate and Hydrology Projections that allows the user to draw a polygon shapefile that the interface would use to provide data for intersecting GCM cells.

Attribute	**Description**
Revision ID	14
Title	Provide better guidance on how to identify the best GCM scenarios.
Feedback Summary	Pilot projects requested more information about how to identify the most appropriate GCM scenarios for their particular pilot site. Many of the Study Teams followed the Guidelines' suggestion to use the 14 identified Group 1 models (see Guidelines pg. 20). Other Study Teams followed the Guidelines' suggestion to "use as many GCMs as logistics permit" (see Guidelines pg. 19) and used all 32 GCMs available in the CMIP5 tool. Regardless of how they selected GCMs, participants seemed concerned that their choice of GCMs was subjective and could change the outcome of the analysis in unexpected ways. In addition, some pilot participants felt their project was in a region dominated by regional-scale weather phenomena (e.g., atmospheric rivers), in which case the guidance recommends that "GCM selection should be based on expert opinion from a climate scientist." Pilot participants asked for more direction because they did not have support from climate scientists.
Original Comments	*Choosing the appropriate grids in the CMIP tool considering both coastal and inland impacts on the location of interest. Automatic selection of large ocean parcels was problematic. - Trying to compare the results of using all 32 GCMs vs the 12 GCMs that the guide highlights. - Considering different projected periods based on each climate scenario [OR]* *The modeling team used all ~32 GCMs available in the CMIP tool. Did not use 14 GCMs recommended in the guidelines because guidelines emphasized the need to examine model ensembles. [NC]*

	In addition, to deciding on the level of analysis a decision would be needed on which emission scenario would be used. As shown by the rainfall data presented in this report, the different scenarios can result in significantly different rainfalls. The guidelines provide one actionable piece of direction regarding which scenario to use: for projects with a short service lifetime, scenario selection is not critical as there is no major difference between the scenarios in the near future. However, when designing a project for the mid or late-century, the scenarios will differ by a much greater amount and the guidelines recommend considering both a higher and lower emissions scenario. The guidelines also note some exceptions, one is that when designing for highly critical infrastructure the designers may wish to default using the worst-case scenario to ensure that the infrastructure remains passable during storm events. [MD] *Kilgore suggests choosing a certain set of models (DPG p. 18 – 21), CMIP Tool suggests "All" (p. 11). Probably not a big deal, but worth noting [ME]* *Give better guidance to help states identify the best set of GCMs (and not just use the defaults blindly.) [OR]* *How do states pick the set of GCMs that are best for them? [OR]* *Climate Change Scenario Decision Point - additional data or resources [MD]* *Consider limiting CMIP5 models according to Guidelines, be aware of the variability that could be seen from various selections [NC]* *Guidance for CMIP Model selection, especially for specific regions. [WS]* *Need guidance for states on GCM selection. [WS]* *Reconcile the Guidance with the CMIP Tool. Compile a list of state and regional GCMs. [WS]*
Study Team Commentary	The Study Team found several examples of seemingly impractical and/or inconsistent information in the guidelines that might contribute to the pilot participants' lingering questions about GCM selection. • On one hand, the Guide warns against "trying to identify the 'best models'" (pg. 20). On the other hand, the Guide essentially identifies the best models by "prioritizing the use of Group 1 GCMs" (pg. 19). • The Guide suggests that "regionally-appropriate GCMs" might be preferred in a list of geographies that seems to span most of the continental United States (pg. 20). The current guidance on where and when to use regionally-appropriate GCMs seems very broad and difficult to operationalize. • The Guide recommends working with a climate scientist if and when regionally-appropriate GCMs are required. Based on our pilot project experience, most DOT staff do not access to climate scientist support. • The Guide says that GCM selection should not be based on comparisons with observations or historical events (pg. 20), even though this is a

	common approach[9] that has been used across the country including in the State of California[10] and two of three FHWA pilot project examples described in the Final Report (see Final Report pg. 44). Further, the Guide seems to contradict itself in the Final Report, which says that models can be removed from consideration due to "extremely poor model performance" (Final Report pg. 43). The Guide says that any model selection should be based instead on "an analysis of climate dynamics" (pg. 20), but it's not clear how that would be done without comparing to historic data. Finally, the Guide says that using a subset of models based on historic data is "more likely to generate false confidence in future performance… than provide useful information" (pg. 21), but no citation could be found for this assertion in either the Guide or the Final Report. In addition, the Study Team is concerned with the recommendation in the Guide to select as few as three Group 1 GCMs with different climate sensitivities to compute screening indicators such as the CCI (see pg. 19). Our sense is that the indicated screen is likely to be very sensitive to GCM selection. For example, at a given pilot site, one set of three GCMs might recommend the use of historic confidence intervals (i.e., CCI < 0.4) while another set of three GCMs might recommend the consideration of future climate change (i.e., CCI > 0.8). Complexity: Medium Popularity: Higher
Proposed Revisions Summary	Provide more specific guidance on how to select GCMs for a particular site. Reconcile any potential inconsistent or impractical guidance on how to select GCMs.

Attribute	**Description**
Revision ID	15
Title	Provide more background information on climate science.
Feedback Summary	A pilot participant thought climate science should be expanded and incorporate more information.
Original Comments	*The climate science section of the guidance should be beefed up. [FL]*

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[9] See for example Raju, Komaragiri Srinivasa, and Dasika Nagesh Kumar. "Review of approaches for selection and ensembling of GCMs." Journal of Water and Climate Change 11.3 (2020): 577-599.

[10] See https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/All-Programs/Climate-Change-Program/Climate-Program-Activities/Files/Reports/Perspectives-Guidance-Climate-Change-Analysis.pdf

Study Team Commentary	The guidance as currently written does not provide much explanation of basic climates science concepts, such as GCMs or RCP scenarios. Considering that users of the guide will like to vary in levels of knowledge about these subjects, adding some discussion of basic climate science could be beneficial.
Proposed Revisions Summary	Add a primer to the guide to familiarize the reader with basic climate science concepts and terminology.

Attribute	**Description**
Revision ID	16
Title	Provide more guidance on how to select GCMs for regions that experience atmospheric rivers.
Feedback Summary	A pilot participant in the northwest asked for more information on how to select GCMs in western regions that experience atmospheric rivers. In this region, atmospheric rivers are a major driver of extreme precipitation. The current guidelines suggest that GCM selection in these regions be done in consultation with a climate scientist and peer-reviewed literature (see Guide pg. 20), which are not readily accessible to DOT staff.
Original Comments	*Process well streamlined for establishing upper-lower discharge boundaries. [OR]* *Adding guidance for selecting the appropriate climate models that could be most suitable for different regions (such as those impacted with atmospheric rivers). [OR]* *Add more information about how to account for west coast atmospheric rivers in GCM selection (and other special cases) [OR]* *Adding guidance for selecting the appropriate climate models that are most suitable for different regions (such as those impacted with atmospheric rivers. Guide has only a couple sentences) [OR]* *Select/calibrate climate models that are appropriate for the specific conditions at the project location (hindcast to known long-term data records to gain confidence. [OR]*
Study Team Commentary	The Guide notes that atmospheric rivers are one of several regional-scale weather phenomena that might be considered in GCM selection. While it wouldn't be possible to discuss all potential considerations, it seems feasible to discuss atmospheric rivers and a few of the other most important phenomena. Complexity: Medium Popularity: Lower

Proposed Revisions Summary	Update the Guide with more information about GCM selection in regions where flooding is driven by atmospheric rivers.

Attribute	Description
Revision ID	17
Title	Update the example calculation for the 10-step procedure with a more typical climate scenario.
Feedback Summary	One pilot participant thought it was odd and potentially confusing for an illustrative example in the Guide to use the RCP6.0 (see Section 6.1.2 on pg. 51), because the Guide suggests that the RCP4.5 and RCP8.5 scenarios are more important to consider at a minimum in the absence of better information. According to the Guide, "at a minimum, one higher and one lower scenario should be considered in the analysis and design" (Guide, pg. 16). The Guide identifies the "higher" scenario as RCP8.5, and the "lower" scenario as RCP4.5 (Guide, Table 3.1).
Original Comments	*The Guidelines example uses RCP6.5 but that isn't available (a little odd). [NC]*
Study Team Commentary	The Study Team recognizes that some projects would want to use the RCP6.0 and that the ability of the example to illustrate the 10-step method does not hinge on the choice of RCP. At the same time, the example would be even more educational if it reinforced as many of the recommendations in the Guide as possible. In that sense, it would make sense to illustrate a more typical situation with an RCP4.5 or RCP8.5 scenario. Along the same lines, it seems odd and potentially confusing that the same example uses 12 GCMs from the BCCA dataset because the Guide clearly states that "engineers are discouraged from using BCCA" (Guide, pg. 17). It would make more sense for the example to illustrate the use of a recommended set of GCMs (e.g., the 14 Group 1 GCMs with LOCA downscaling shown in Figure 3.3). Complexity: Medium Popularity: Lower
Proposed Revisions Summary	Update the illustrative example in Section 6.1.2 to use a more typical climate scenario like RCP4.5 or RCP8.5. If that is not feasible, at least highlight the fact that RCP4.5 and RCP8.5 would have been a more typical choice but for the specifics of the example project site. Update the illustrative example in Section 6.1.2 to substitute the 12 GCMs from the BCCA dataset with a recommended set of GCMs such as the 14 Group 1

	GCMs with LOCA downscaling described in the Guide, Section 3.3. If that is not feasible, at least highlight the fact that the 14 Group 1 GCMs would have been a more typical choice if better information was not available.

Attribute	**Description**
Revision ID	18
Title	Add an explanation on how the CCI relates to the 10-Step Procedure for projecting precipitation quantiles.
Feedback Summary	Related to the Climate Change Indicator (CCI), the introduction to Chapter 6 should reference the CCI and explain how CCI effects the decision to go through the 10-step procedure. In addition, the guidance should show the connection between the CCI and CMIP Tool.
Original Comments	*Related to the use of CCI – the intro to Chapter 6 should reference CCI and explain how CCI effects the decision to go through the 10-step procedure. Somewhat repetitious, but worth repeating at least briefly. [ME]* *Guidance should show connection between CCI and CMIP Tool. [WS]*
Study Team Commentary	There is a short reference to the CCI in Section 6.1 of the Guide that reads, “This method is appropriate… for applying the CCI (see Chapter 4)” (Guide pg. 44). This reference could be expanded to describe exactly how the 10-step method can be used to calculate the CCI. Note that Section 4.4 mentions that “the CCI should be calculated based on guidance in Section 6.1 for estimating project T-year 24-hour precipitation using an ensemble of high-resolution climate datasets” (Guide, pg. 41). To make the link between Section 4 and Section 6 more clear and explicit, the CCI equation could be rewritten to include the exact parameter that is calculated in the 10-step procedure. The CCI is defined in Chapter 4 as: $CCI = \frac{P_{24,T,P} - P_{24,T,O}}{P_{24,T,O,U} - P_{24,T,O}}$ Guide Eq. 4.1 Where $P_{24,T,P}$ is the projected T-year 24-hour precipitation. Based on the guidance in Section 6, this term can be rewritten as: $P_{24,T,P} = P_{24,T,O} * RFB_q$ Where RFB_q is the ratio of the model future to model baseline precipitation for quintile q (see Guide, pg. 50). By substitution, we can rewrite the climate change indicator equation as:

	$CCI = \frac{P_{24,T,O}*RFB_q - P_{24,T,O}}{P_{24,T,O,U} - P_{24,T,O}} = \frac{P_{24,T,O}*(RFB_q - 1)}{P_{24,T,O,U} - P_{24,T,O}}$ A nice feature of equation 30-B is that it expresses the CCI in terms of RFB_q, and step 9 of the 10-step method in Section 6 contains detailed instructions on how RFB_q is calculated. Incidentally, step 1 of the method described how to calculate the other terms on the left-hand side using Atlas-14. The Study Team notes that the connection between the CCI, the 10-step method, and other parts of the guide would be clearer if the Guide used more consistent nomenclature. For example, the Section 4 equations use the T subscript on precipitation terms to denote the event frequency as the T-year event (e.g., the 100-year event) while the section 6 equations use the q subscript to denote event frequency based on an annual exceedance probability (e.g., the 0.1 AEP event). To avoid confusion, the Guide should use just one approach to denote frequency. The use of subscript capitalization across equations also seems inconsistent. Finally, in Chapter 9 the guide introduces the concept of Change Factors (see Guide, pg. 90), which seems to be another name for RFB_q. Complexity: Lower Popularity: Medium
Proposed Revisions Summary	Expand the explanation of the how the 10-Step Procedure can be used to calculate the CCI. Make the subscripts and other nomenclature used in the equations more consistent across Guide sections.

Attribute	**Description**
Revision ID	19
Title	Recommend adding tips to catch and avoid anomalies in the GCM data.
Feedback Summary	One pilot participant recommended adding advice to catch and avoid anomalies in the GCM data. First, download and examine data for multiple time periods. Even if the user is only interested in one time window (say, 2070-2099), it is useful to examine data at other time windows (e.g., 2040-2069) to make sure the trendlines are consistent. Second, plot and example the annual maximum series (AMS) data in the CMIP Tool output to explain and avoid anomalies.
Original Comments	*Use multiple future time periods; plot and examine the AMS (provided by the CMIP Tool) to explain and avoid anomalies. [NC]*
Study Team Commentary	The Guide could also include instructions on how to detect anomalies in the AMS and how to address them.

	Complexity: Lower Popularity: Lower
Proposed Revisions Summary	Recommend that users use multiple future time periods and examine the annual maximum series data for anomalies.

Attribute	**Description**
Revision ID	20
Title	Clearly identify the 14 recommended Group 1 GCM models.
Feedback Summary	One pilot participant commented that the Guide should be edited to make it easier to identify the 14 recommended Group 1 GCMs. In the current guidelines, the reader must complete two steps to determine the full list. First, the reader must search Table 3.3 for the 12 GCMs that have asterisks. Second, the reader must return to the text to find the names of the other 2 GCMs. The pilot participant felt that this information was very important and should be easier to extract.
Original Comments	*"Some parts of the guidelines could benefit from additional explanation or clarification; one area of note is Table 3.3 and the recommended 14 Group 1 models for the LOCA dataset. In the first read through, it was unclear what the 14 models were, additional clarification could be beneficial." [MD]*
Study Team Commentary	The Study Team agrees that the 14 recommended GCMs should be highlighted and easier to identify. Many of the pilots used this information in their analysis. The comment could be addressed by listing the GCMs in a separate table and highlighting the contents of the table in a blue "Bottom Line" box. Complexity: Lower Popularity: Lower
Proposed Revisions Summary	Edit the Guide so users can more easily identify the 14 recommended Group 1 GCM models.

Attribute	**Description**
Revision ID	21
Title	Explain why downscaled GCM data might be sensitive to the emissions scenario during the baseline period.

Feedback Summary	One pilot participant noticed that a GCM model reported different climate values for the baseline period for the RCP4.5 and RCP8.5 scenarios. The pilot participant thought that the conditions and model outputs during the baseline period should be identical and insensitive to the choice of climate emissions scenario
Original Comments	*So then I checked the baseline results in the outputs. I expected them to be exactly the same, after all, same baseline, same models, etc. Differences were not big, but surprised that they were at all different. I assume that over the baseline period, the same models are using the same inputs regardless of future RCP.[ME]*
Study Team Commentary	The Study Team cannot explain why the pilot participant would see different GCM model data during the baseline period for different emissions scenarios. There was no clear explanation in the Guide or the Final Report about whether or not GCM results for the baseline period should be different for an RCP4.5 and RCP8.5 scenario. As a test, the Study Team downloaded data for an arbitrary GCM (bcm-csm1-1-m) from the Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections website and found that the RCP4.5 and RCP8.5 simulation outputs were identical from 1950 until 2005, and different after 2005. Thus, the Study Team was not able to reproduce the issue, although the pilot participant might have been looking at a different set of GCMs. Complexity: Lower Popularity: Lower
Proposed Revisions Summary	Make a clear statement in the report about whether the GCMs should show the same or different results during the baseline period. If some GCMs provide different results, explain why (e.g., because they are stochastic and not deterministic models).

Attribute	**Description**
Revision ID	22
Title	Provide more options for obtaining downscaled GCM data.
Feedback Summary	A pilot participant commented at the workshop that the Guide should explain that there are many sources of downscaled GCMs.
Original Comments	*Add clarification explaining that there are many sources of downscaled climate data that can be used for design. [WS]*
Study Team Commentary	The pilot participant might have overlooked the discussion of options for selecting high-resolution climate projections in the Guide (see pg. 17-18). The Guide lists

	many potential sources for downscaled GCMs while concluding that the LOCA datasets are the best choice for many users. Complexity: Lower Popularity: Lower
Proposed Revisions Summary	Review and update recommended sources of downscaled climate data as needed.

Attribute	**Description**
Revision ID	23
Title	Improve the response time of tools that support the 10-Step Procedure, especially the DCHP website.
Feedback Summary	At least one pilot participant wanted the CMIP5 data processing and download tools to run faster. To use the CMIP Climate Data Processing Tool 2.1, the user must request and wait for data from the tool's website (link) and from the U.S. Bureau of Reclamation's Downscaled CMIP5 Climate and Hydrology Projections (DCHP) website (link). There could be a delay associated with one or both websites.
Original Comments	*Improve the response times from the database.[CO]*
Study Team Commentary	When the Study Team tested the tools, the wait times were relatively long (>24 hours) to get a response from the DCHP website and relatively short to get a response from the CMIP Climate Data Processing Tool 2.1 (<1 hour). Long delays increase the time and effort for each engineering calculation. Complexity: Higher Popularity: Lower
Proposed Revisions Summary	Evaluate wait times and make improvements where possible. If longer delays from third-party sites cannot be reduced, tell users to anticipate longer wait times.

Attribute	**Description**
Revision ID	24

Title	Improve access to documentation for the CMIP Tool output spreadsheets.
Feedback Summary	A pilot participant requested a better explanation of the spreadsheets that the FHWA CMIP5 Climate Data Processing Tool produces.
Original Comments	*The simple reporting form containing the CGM calculation results is confusing and seems to contradict the rainfall details of the pr AEP.xls [OR]-* *Provide guidance on how to read and interpret the GCM data output files [OR]* *Improving the Simple reporting file containing the CGM calculation results. It doesn't explicitly give data needed for design (24 hr 2 year return) [OR]* *Need to look at pr AEP to know the "real" numbers. Need to know the distribution type. [OR]*
Study Team Commentary	Pilot participants might have been unaware that the Coupled Model Intercomparison Project (CMIP) Climate Data Processing Tool 2.1 Tool User's Guide document contains an overview of the CMIP Tool outputs. Note that, as of March 15, 2022, the CMIP5 Tool website does not have a link to the User's Guide. The User's Guide page is under construction (see link). The User's Guide can however be downloaded from https://www.fhwa.dot.gov/engineering/hydraulics/pubs/CMIP_Tool_User_Guide_Version_2_1_508_version_03092021.pdf (last accessed in July 2022) . In addition, the FHWA posted a training webinar on CMIP Tool operation at https://connectdot.connectsolutions.com/pvo0lkm8vfzh/ (last accessed in July 2022). Complexity: Medium Popularity: Lower
Proposed Revisions Summary	Update the CMIP Tool website to include a prominent, active link to the User's Guide.

Attribute	**Description**
Revision ID	25
Title	Help users use available web tools to extract raw GCM data if needed.
Feedback Summary	A few pilot participants wanted to analyze the raw temperature data from the CMIP Tool. They wanted to get estimates of the change in temperature under different climate change scenarios. The change in temperature was needed as a parameter to the local USGS regression equations. The CMIP Tool outputs include

	summary metrics related to temperature (e.g., the average annual mean temperature) but does not provide any raw daily temperature data.
Original Comments	*Temperature change needs to be computed in the CGMs as these are needed as input into rainfall-runoff regression equations. These can only be inferred from the GCM calculated results. [OR]* *Temperature change needs to be computed in the CGMs as these are needed as input into rainfall-runoff regression equations. These can only be inferred from the GCM calculated results. [OR]* *Give users access to the individual GCM data outputs for other key variables (temperature). [OR]* *Add option for the CMIP tool to provide all the raw data. [OR]* *How can I access individual model results for the CMIP output? [OR]*
Study Team Commentary	The first step in using the CMIP Tool is to request and download the downscaled GCM data in NetCDF format from the Downscaled CMIP5 Climate and Hydrology Projections (DCHP) website. These files are input into the CMIP Tool and used in calculations. In theory, the pilot participants could have extracted the raw data that they needed from the NetCDF file. In practice, however, many DOT and consultant staff do not know how to read and use NetCDF files. Alternatively, the pilot participants could have downloaded the dataset from the DCHP website in ASCII format. ASCII format can be opened in standard spreadsheet software (e.g., Excel), and might be easier for some DOTs to analyze. However, the files could be very large depending on the number of scenarios and grid cells. Currently the CMIP Tool outputs the results in Excel format – “calculation results – all.xls” and ”calculation results – simple.xls”. The “simple’ file presents the outputs for over 80 climate variables. These outputs are the average of outputs from the ensemble of selected GCMs. The “all” file provides the raw data for each selected grid square; however, the raw data is also an average of the outputs from the ensemble. The only way currently to get outputs for an individual model is to select only a single model when ordering data through the Bureau of Reclamations website. Complexity: Medium Popularity: Lower
Proposed Revisions Summary	Update the CMIP5 Tool Users Guide with instructions on how to open the DCHP outputs in Excel or other common spreadsheet software.

Attribute	Description
Revision ID	26

Title	Provide additional guidance for using the CMIP Tool near the coastline.
Feedback Summary	A pilot participant had trouble using the FHWA CMIP5 Climate Data Processing Tool at a project site along with west coast The downscaled GCM grid did not extent to the coastline which caused errors and/or incomplete data output.
Original Comments	*Guidance for using the LOCA tool at sites near coast[OR]* *I have a question about step 1.3 in the CMIP tool. Given that the bridge location is over water, the grid I select is still over water which leads to an error in my output files. How can I make it smaller so that it doesn't include an area that is overwater?[OR]*
Study Team Commentary	The Study Team has limited information about the nature of the problem. More information may be needed to understand the exact issue and the potential solutions. It seems likely that other coastal projects could experience the same issue, and/or non-continental U.S. states and territories such as Hawaii, Alaska, and Puerto Rico. Complexity: Medium Popularity: Lower
Proposed Revisions Summary	Ensure that any workflow using downscaled GCM data works for the entire U.S. including the coastline and non-continental states and territories.

Attribute	**Description**
Revision ID	27
Title	Provide more complete and/or more easily downloaded documentation for the FHWA CMIP5 Tool.
Feedback Summary	Several participating pilots said that the FHWA CMIP5 Tool was invaluable and that they relied heavily on the documentation provided by the 22-43(20) Study Team. They recommended having more information about the tool in the guidelines.
Original Comments	*When requesting and processing data for the climate change projections I relied heavily on the training materials from the orientations. Looking back through the guidelines it does not appear that the FHWA CMIP5 tool to process the data is mentioned in the guidelines. If it is not mentioned it may be worthwhile since it is a valuable resource for this work and may not be widely known within DOTs. [ME]* *I was also trying to find the recorded FHWA CMIP webinar and I couldn't find it. I would appreciate it if you can send me the link. [OR]*

	Some issues with running climate models with scant feedback from software indicating faults in the execution.[OR] *Need detailed examples for using CMIP Tool outputs. [WS]* *Need to add guidance on use of the CMIP tool. [WS]* *Add an appendix to explain the CMIP tool. [WS]*
Study Team Commentary	The Study Team agrees that it would be helpful to add information to the Guide about the FHWA CMIP5 tool. The Guide already reference a number of other online tools such as the USGS National Climate Change Viewer (pg. 25), the USACE Sea Level Rise Calculator (pg. 111, 118), and the USACE ERDC Coastal Hazards System database (pg. 123). The FHWA should be encouraged to add more documentation about the FHWA CMIP5 Tool to the website. As of March 2022, the tool homepage does not have an obvious link to any documentation. The homepage says "User's Guide Under Construction", although a web search finds a link to a version dated March 2021. In addition, the FHWA has posted a recorded webinar that describes the tool at https://connectdot.connectsolutions.com/pvo0lkm8vfzh/ (last accessed in July 2022). Complexity: Medium Popularity: Higher
Proposed Revisions Summary	Add information about the FHWA CMIP5 Tool and how it could be used to perform the relevant steps in the Guidelines. Encourage the FHWA to add a link to the CMIP5 Climate Data Processing Tool User's Guide and any other training material to the tool website.

Attribute	**Description**
Revision ID	28
Title	Update CMIP Tool to output a shapefile with the location of processed grid cells.
Feedback Summary	Pilot participants thought it would be useful for the FHWA CMIP5 Climate Data Processing Tool to output shapefiles that provide the location of each analyzed grid cell. The shapefile could be used to understand the fractional overlap of a watershed with different grid cells, which in turn could be used to calculate area-weighted change factors.
Original Comments	*It would be helpful if the Tool provided a grid index of the processed grid cells (I developed this from the NetCDF files, but that's not clear. This matters for area-weighting several grid cells). [NC]*

	CMIP Tool could be improved with an option for shapefile output to support the weighted average for rainfall. [WS] *CMIP Point or Polygon shapefile output? [NC]*
Study Team Commentary	Complexity: Medium Popularity: Higher
Proposed Revisions Summary	Update CMIP Tool to output a shapefile with the location of processed grid cells.

Attribute	**Description**
Revision ID	29
Title	Add FHWA 2009 reference in the CMIP Tool user's guide to the bibliography.
Feedback Summary	A pilot participant noted that the CMIP Tool User's Guide contains a reference to FHWA 2009 on pg. 39, but the document does not appear in the bibliography.[11]
Original Comments	*CMIP Tool p. 39 refers to FHWA 2009, but this reference is not included in the "References" list on p. 45 [ME]*
Study Team Commentary	Complexity: Lower Popularity: Lower
Proposed Revisions Summary	Ask the FHWA to consider adding the FWHA 2009 reference to the bibliography of the CMIP Tool documentation.

Attribute	**Description**
Revision ID	30
Title	Revise Table 3.3 to make sure GCMs names corresponds with FHWA CMIP Tool data.
Feedback Summary	A pilot participant noticed discrepancies between the naming of GCMs in the guide versus the CMIP tool. It would be good to make them consistent.

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[11] See page 39 in https://www.fhwa.dot.gov/engineering/hydraulics/pubs/CMIP_Tool_User_Guide_Version_2_1_508_version_03092021.pdf. Accessed on March 15, 2022.

Original Comments	*The global climate model names in Table 3.3 do not correspond one-to-one with the available data from the CMIP Tool. It would be beneficial for them to correspond exactly. [CO]*
Study Team Commentary	The Study Team compared the 14 recommended GCM names in the Guide versus the GCM names in Step 2.5 of the Downscaled CMIP Climate and Hydrology Projections (DCHP) website. The two differences that were observed are as follows. First, the DCHP GCM names are all upper case, whereas the Guide has a mix of lower and upper case. Second, the DCHP GCM names seem to have replaced the "-" character with a "_" character. Complexity: Lower Popularity: Lower
Proposed Revisions Summary	Review the GCM names in the Guide and update as needed.

Attribute	Description
Revision ID	31
Title	Make it easier to determine the type of statistical distribution used to calculate the CMIP Tool's precipitation quantiles.
Feedback Summary	Several pilot participants asked for clarification on which statistical distribution was used to calculate the precipitation quantiles in the FHWA CMIP Tool.
Original Comments	*CMIP: Specify type of statistical distribution used (e.g. Extreme Value), corrections applied? [NC]* *Report the statistical fit of the GCM data for the variables (normal?) [OR]* *It would help if the CMIP tool could output results from multiple distributions. [WS]* *The data analysis that was done through the tool wasn't explicit about the distributions it used. It would be helpful to know that information. It would also be helpful if the results for multiple distributions (e.g. normal and GEV) would be provided. [CO]*
Study Team Commentary	Pilot participants might be unaware that this issue is discussed in the Tool documentation, which states that the Tool uses a Gumbel extreme value

	distribution with an option to compute the distribution assuming the actual sample size or an infinite sample size.[12] The comment raises a potential issue, which is that DOTs might – and arguably should – be interested in using a particular, optimal distribution for their study area. The current Tool only has two options for distributions (i.e., Gumbel with or without infinite sampling), and the Guide doesn't have instructions on how to choose a best distribution. It is common for the most appropriate distribution to vary from region to region. For example, the NOAA Atlas 14 Volume 2 Version 3.0 analysis considered multiple theoretical candidate distributions including Generalized Logistic, Generalized Extreme Value, Generalized Normal, Generalized Pareto, and Pearson Type III.[13] Complexity: Lower Popularity: Higher
Proposed Revisions Summary	Update the CMIP Tool web interface with information that is easy to find about the underlying statistical distribution used in calculations. Add more information to the Guide about how to select the most appropriate underlying statistical distribution.

Attribute	**Description**
Revision ID	32
Title	Make it easier to implement the Guide consistently.
Feedback Summary	Pilot participants expressed concern about the potential for the guidelines to be applied inconsistently across projects. The participants made a general call to update the guidelines to reduce potentially inconsistent implementation.
Original Comments	*Additionally, the MDOT SHA drainage manual would need to be modified to include guidance on how to properly incorporate the data into the design of a project to avoid the potential of the guidelines being inconsistently applied between projects. [MD]* *The guidelines provided some tools to provide additional information to help select a level of analysis. However, the guidelines or included tools do not provide a single direction to follow instead the final decision of what level of analysis to use was left to the design team. This opens the potential risk of designers inconsistently applying the guidelines across projects. If these guidelines are implemented*

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[12] See page 24 in https://www.fhwa.dot.gov/engineering/hydraulics/pubs/CMIP_Tool_User_Guide_Version_2_1_508_version_03092021.pdf. Accessed on March 11, 2022.

[13] https://www.weather.gov/media/owp/oh/hdsc/docs/Atlas14_Volume2.pdf, page 28

	additional guidance would likely be needed to provide clear direction on how to appropriately incorporate them into a project and decide on the required level of analysis. [MD]
Study Team Commentary	The Study Team agrees it is important that DOTs are able to consistently apply the guidelines to different projects with different engineering teams. In order to explore the consistency issue, one pilot project asked two different contractors to perform a coastal analysis at the same site, and the contractors reached very similar conclusions. Notwithstanding this encouraging result, more studies like that one are needed to determine the potential for inconsistent application and how to avoid it. Complexity: Higher Popularity: Lower
Proposed Revisions Summary	Update the guidelines with an eye towards reducing potentially inconsistent implementation.

Attribute	**Description**
Revision ID	33
Title	Make the levels of analysis classification more practical for real-world applications.
Feedback Summary	The level 1/2/3 breakdown may be more useful in theory than in practice. In practice, projects don't seem to fall into any of the categories neatly.
Original Comments	*The level 1/2/3 breakdown may be more useful in theory than in practice. In practice, projects don't seem to fall into any of the categories neatly. [AZ]*
Study Team Commentary	Complexity: Higher Popularity: Lower
Proposed Revisions Summary	Consider adding other practical ways to define the levels of analysis.

Attribute	**Description**
Revision ID	34

Title	Provide more guidance for the consideration of temperature changes.
Feedback Summary	It was highlighted that the guidance should provide more attention to the importance and possible impact of changes in temperature due to climate change and the possible negative effect on assets and surrounding conditions.
Original Comments	*Changes in temperature could impact design resilience. This is not given much attention in the guidelines. In particular, higher temperatures could reduce streambed vegetation and thereby increase scour. Higher temps could also cause long-term damage to pavement and bridge components. ADOT is doing R&D on this now to see if, for example, we need to change the pavement grade binders we use at different elevations. [AZ]*
Study Team Commentary	The guidance currently focuses entirely on the impacts of precipitation changes on riverine and coastal flooding. The outputs of the CMIP5 Climate Data Processing tool provide many climate temperature-related variables for evaluating impacts on infrastructure design. For example, for roadway design the 7-day consecutive average lowest temperature and the 7-day consecutive highest temperature could be leveraged to estimate changes to the required pavement grade. The number of days where the temperature fluctuates above and below freezing can be used as a proxy for freeze-thaw. Complexity: Higher Popularity: Lower
Proposed Revisions Summary	Add guidance that explains how to use the temperature-related outputs from the CMIP5 Data Processing Tool to assess the impacts of climate change on transportation assets.

Attribute	**Description**
Revision ID	35
Title	Provide more guidance on handling uncertainty and sensitivity analysis.
Feedback Summary	Pilot participants requested more information and examples in several sections of the Guidance on how to handle uncertainty. In particular, pilot participants asked for more guidance and examples on how confidence limits can be incorporated into project design, as well as how to calculate and interpret uncertainty in the downscaled GCMs. In addition, it seems there is a need for a section on how to conduct a sensitivity analysis of parameters.
Original Comments	*The guidelines note that most projects will be adequately addressed by level 1 or 2 analysis, it may be beneficial to include some recommendations on how historical*

	confidence limits can be incorporated into the project design, even if it is just a few short sentences. [MD] *More discussion on confidence limits would be helpful. [NC]* *Clarify what level of design uncertainty should be used, recognizing uncertainty is coming in from the models themselves (90% confidence how?) [OR]* *Quantifying uncertainty – more example computations and discussion. [NC]* *Need guidance on computing uncertainty. [WS]* *Add discussion on GCM uncertainties with numerical examples. [WS]* *Add discussion on design uncertainties.[WS]* *Need guidance on which GCMs are producing outliers. Engineers need to know the range of variability. [WS]* *Finding the projected percentage of increase in discharge in the future - Getting very similar results in the cases of using all 32 climate models versus the 14 highlighted ones [OR]* *I did 4.5 first, then 8.5. Baseline 1950 – 2005; then project from 2020 – 2099. For now I am just looking at the results from the "simple" worksheet generated by the CMIP tool. Very little (essentially insignificant) difference between the (projected/baseline) ratios. I would have expected some difference, maybe not a lot but something. I was under the impression that there is a big difference between the 4.5 and 8.5 emissions scenarios. [ME]* *Modeling team noted that ratio was lower in the RCP 8.5 compared to the RCP 4.5, which was surprising. Guidelines should set explain that this may be expected due to the natural variability in the climate system. [NC]* *Mention that more aggressive RCP can still result in lower projected rainfall – another demonstration of variability in climate modeling. [NC]* *Need a section dedicated to sensitivity analysis. [WS]* *Should consider addressing sensitivity analysis and uncertainty. [FL]*
Study Team Commentary	The Study Team notes that pilot participants called for more discussion of uncertainty and confidence intervals, in spite of the fact that these topics are addressed throughout the guidelines. For example, the guidelines discuss uncertainty in Level 2 analysis on pg. 25, uncertainty in the 10-step method to calculate future precipitation quantiles on pages 44-50, and uncertainty with the regression equations and their standard error of estimate on pg. 81. One potential issue is that pilot participants were sometimes surprised or confused by the large variability in GCM data. At one project site, the change factor for the RCP 4.5 event was determined to be slightly higher than the change factor for the RCP 8.5 event. The pilot participant assumed that something went wrong with the calculation and contacted the Study Team. We explained that this can happen due to natural variability in the GCM data. At several other project sites, pilot

	participants asked what to do when the confidence interval for the calculated change factor spans values greater than one (i.e., precipitation will increase) and less than one (i.e., precipitation will decrease). While this behavior is expected and was exemplified in the Guidelines (see Guidelines Table 6.8 and Table 6.9), it raised questions about whether the results should be considered "statistically significant" and whether it should be used to inform design practice. Another potential issue is that pilot participants seem hesitant to use precipitation-based confidence limits derived from historic data, even though this is a key component of the Guidelines' approach. The Guidelines state that "engineers should consider confidence limits based on historic data in the design practice more often than is done today" (pg. 58), and the Climate Change Indicator approach is premised on the idea that DOTs could adopt confidence limits based on historic data when historic variability is greater than projected increases. However, none of the DOTs in the pilot project reported using or planning to use historic precipitation confidence intervals in their design standards. Some stakeholders may find it counterintuitive to introduce new design practices using historic rainfall variability in order to account for future climate change. Complexity: Higher Popularity: Higher
Proposed Revisions	Add more specific guidance, discussion, and examples that describe how to address uncertainty into the analysis described in the Guidelines.

Attribute	**Description**
Revision ID	36
Title	Provide more pragmatic guidance for high-risk coastal communities.
Feedback Summary	Several pilot participants thought that the Guide should provide more practical design guidance for bridges in coastal communities that are likely to flood under expected SLR. They were concerned that a rigid application of the Guide would conclude that the deck should be raised high enough to clear the projected SLR, without considering the fact that the bridge will be useless if and when the surrounding roads become submerged under normal tides. In the words of pilot participants, it is important to "balance worst-case scenarios with responsible engineering design" and to not always assume that infrastructure should be designed to be "fully functioning" under projected climate change.
Original Comments	*Group discussed the need to balance worst-case scenarios with responsible engineering design: Not always practical to address worst-case scenarios for various reasons. Analysis should not always assume fully functioning*

	infrastructure (e.g., due to siltation) At their best, guidelines can and should help demonstrate a responsible consideration of climate change. [FL] *Options for areas likely to be inundated under low SLR scenarios. [FL]* *Employ engineering judgment regarding incorporating SLR into design with regard to the surrounding community. [FL]* *There is a strong preference to get away from rigid scenarios because they are not practical: for example, raising a bridge to guard against SLR while the surrounding city is left underwater. [WS]*
Study Team Commentary	The Study Team agrees that the Guide seems to emphasize the need for infrastructure to be fully functioning over its lifetime in the face of projected climate change. For example, the introduction to the guide says the goal of designing for climate change is to "design resilient transportation infrastructure" (Guide, pg. 3), where resilient is defined as "maintaining or rapidly recovering functionality in response to changing conditions" (Guide, pg. 2). As the pilot participants point out, maintaining functionality is not a practical goal for some coastal infrastructure projects. The Guide could address this issue more directly and discuss alternative resiliency frameworks for designing infrastructure in high-risk areas (e.g., adaptive design, managed withdrawal). The Study Team also agrees that the Guide seems to emphasize the analysis of individual asset performance under climate change over the performance of the entire transportation system. As the participants point out, one could design a coastal bridge to clear the expected SLR, but if the approach roads become underwater under the normal tide, then the structure is still very vulnerable to climate change. This is also an issue for inland hydrology; for example, the upsizing of an inland culvert to account for climate change could increase flooding at downstream structures. Although the Guide has a high-level discussion of the need to analyze the sensitivity and redundancy of the entire system (e.g., see Figure 11.3), it could provide more specific and actionable tips and tricks for doing a systems-level analysis. For example, what are the potential upstream/downstream effects of culvert upsizing, and under what conditions could they be significant? Complexity: Higher Popularity: Medium
Proposed Revisions Summary	Revise the objective and scope of the Guide to recognizing that designing for climate change does not necessarily mean designing for full functionality under projected conditions. Discuss alternative strategies to address climate change over the asset lifetime such as adaptive design or managed withdrawal.

Attribute	Description
Revision ID	37
Title	Recommend more simple design rules to account for climate change.
Feedback Summary	A pilot participant suggested developing simple design rules to account for climate change in basic (level 1 type) analyses. For example, the participant used results from his pilot project to develop a single lookup table that shows how much culverts upsizing is needed to address climate change (e.g., a 12” diameter pipe that was designed to just meet current standards must be increased to 18”).
Original Comments	*Consider rules of thumb, like “increase pipe diameter 6” to address climate change” [WS]*
Study Team Commentary	Complexity: Higher Popularity: Lower
Proposed Revisions Summary	Develop simple design rules to account for climate change in basic (level 1 type) analyses.

Attribute	Description
Revision ID	38
Title	Add example calculations of the climate change indicator.
Feedback Summary	One pilot participant was confused about the formula for the Climate Change Indicator (CCI). The participant wanted to understand why the CCI used observed data in the denominator instead of simulated data like the change factor. The participant did not think this was explained clearly in the guidelines.
Original Comments	*When requesting and processing data for the climate change projections I relied heavily on the training materials from the orientations. Looking back through the guidelines it does not appear that the FHWA CMIP5 tool to process the data is mentioned in the guidelines. If it is not mentioned, it may be worthwhile since it is a valuable resource for this work and may not be widely known within DOTs [ME].* *I was also trying to find the recorded FHWA CMIP webinar, and I couldn't find it. I would appreciate it if you can send me the link [ME].*
Study Team Commentary	The Study Team helped the pilot participant understand why the CCI and change factor use different types of data in the denominator. The Study Team confirmed

	that the CCI and change factor are correctly defined and described in the Guidelines. At the same time, the Study Team noted that there are no examples of climate change indicator calculations in the Guidelines, which might help future users understand the method and rationale for the CCI calculation. Complexity: Medium Popularity: Lower
Proposed Revisions	Add guidance and discussion about when to use observation data and when to use simulation data in the sections that describe the CCI and change factor. Add a worked example of how the CCI indicator is calculated and used for decision support.

Attribute	**Description**
Revision ID	39
Title	Add guidance on how to consider the effect of climate change on FEMA flood maps that were used in the design.
Feedback Summary	A pilot participant wanted more information on how to consider the effect of climate change on FEMA flood maps that were used in the design.
Original Comments	*FEMA flood maps are used as a source for design. More guidance on how to adapt them or how they compare would be beneficial for some users. [OR]*
Study Team Commentary	The Study Team is not aware of any immediate plans for FEMA to update their flood maps to account for climate change. Further, there is no standard approach for users to update them by themselves. Some regulators have proposed raising the flood elevation by a fixed amount (e.g., 2') to consider climate change. For example, the New York State Community Risk and Resiliency Act (CRRA) recommends considering an additional 2 feet of freeboard over the historic floodplain.[14] Complexity: Medium Popularity: Lower
Proposed Revisions Summary	Provide any available guidance on how to consider the effect of climate change on FEMA flood maps that are used in the design.

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[14] See Table 2 on page 8 in https://www.dec.ny.gov/docs/administration_pdf/crrafloodriskmgmtgdnc.pdf.

Attribute	Description
Revision ID	40
Title	Provide information for users to decide between regression equations and rainfall/runoff models.
Feedback Summary	At least one pilot participant asked for a better explanation of when to use regression equations versus when to use rainfall/runoff models and what the differences are of using any of these methodologies.
Original Comments	*Guidance was not clear on when to use regression vs. rainfall/runoff models. [WS]*
Study Team Commentary	The Study Team agrees that the Guide could do more to help users decide which methodology is more appropriate at a given site. Table 4.1 (see Guide, pg. 28) could be expanded to other screening criteria such as the presence of a rainfall variable in the regression equation. For cases where users can choose between using rainfall/runoff models or regression equations, the Guide should explain how to choose between the two. The guide mentions that the USGS reports the standard error for regression equations. Is there any comparable performance metric available for the rainfall/runoff models listed in Table 4.1 (Guide, pg. 28)? Complexity: Medium Popularity: Lower
Proposed Revisions Summary	Add better guidance on how to choose between different hydrologic methods in the Guide.

Attribute	Description
Revision ID	41
Title	Explain how to calculate the Pearson Type III frequency factor for historic gauge analysis.
Feedback Summary	The Guide has an equation to calculate design flow quantiles from the annual maximum series (see Guide pg. 35, Equation 5.2). The equation has a term called the Pearson Type III frequency factor. A pilot participant noted that the Guide does not clearly define this term.

Original Comments	*Need an example of how Kx is calculated with method #5. [WS]*
Study Team Commentary	The frequency factor is a function of the skewness coefficient and return period and can be found using frequency factor tables that are available online. Complexity: Medium Popularity: Lower
Proposed Revisions Summary	Add an example calculation that shows how the frequency factor is used to calculate flow quantiles.

Attribute	**Description**
Revision ID	42
Title	Provide clarity on how to combine projections based on historic gauges with other types of projections.
Feedback Summary	Several pilot participants tried to develop future projections based on trends in historical discharge and had questions about what to conclude from the results. As described in Chapter 5 of the Guidelines, the approach recommends using Mann-Kendall trend analysis to see if there is a positive trend in the historic discharge record. If a trend is detected and attributed to climate change, it could be used to project discharge into the future. The pilot participants applied the Mann-Kendall test to historical stream gage data at their project sites but found no significant upward trend. Based on their initial reading of the Guidelines, the pilots concluded that the design discharge at the project sites will not increase over time due to climate change. On further consideration with the Study Team, the pilots decided it was important to also examine how discharge could be affected by GCM projections of future rainfall, as described in Chapter 6 of the Guidelines. The reasoning was that the GCMs might show a future trend in rainfall that wasn’t detectable in the historic gage record, either because the signal was too inchoate and weak or because it was masked by other changes in the watershed. Based on their experience, the pilots recommended adding guidance on how to proceed if and when projections based on historic data gage data do not show an upward trend.
Original Comments	*It would be valuable to be able to continue analysis for gaged watersheds as outlined in Chapter 5 if there is no statistically significant trend in the flow data. It is possible that hydrologic regimes will change in the future, which would alter the*

	flows. So, even if one cannot determine what future flows are, it may be beneficial to know if future flows would be different. [CO] *Provide additional guidance for cases where Mann-Kendall trend analysis based on existing gage data shows no trend or a decreasing trend. [IA]* *Need guidance for Level 1 analysis when gage data shows no trend. [WS]*
Study Team Commentary	The Study Team agrees that the Design Guidance is unclear about how to proceed if the historical analysis in a gauged watershed shows no significant trend. Specifically, it's not clear if the design team should follow-up with the GCM-informed analysis described in Chapter 6. The text provides ambiguous guidance. On the one hand, the Design Guidance suggests that the Chapter 6 methods are not intended to be used on gauged watersheds (e.g., see Table 4.1). On the other hand, Chapter 5 says that projections based on the extension of historic trends "should not be used for design" (pg. 41), which suggest that other methods must be used for design, such as methods described in Chapter 6. Complexity: Medium Popularity: Medium
Proposed Revisions Summary	Provide additional guidance on how to incorporate the effect of climate change into H&H design in gauged watersheds when there is no significant historic trend.

Attribute	**Description**
Revision ID	43
Title	Add formula to approximate areal reduction factors in large watersheds.
Feedback Summary	A pilot participant provided a simple formula that can be used to estimate a rectangular watershed or grid cell area given the latitude and longitude coordinates of the four corners. The watershed area is needed to calculate the areal reduction factor.
Original Comments	*DPG p. 72 – 76 discusses the use of Areal Reduction Factor. There is a simple equation for calculating the area of a "rectangular" patch on the earth's surface: Will note. For patch bounded by lat1 & lat2, lon1 & lon2, earth radius R (3,961.6 mi), lat, lon in decimal degrees. A = {2 x p x R2 x |sin(lat2) – sin(lat1)|} x |lon2 – lon1|/360 [ME]* *Need areal reduction factors for large drainage areas. [WS]*
Study Team Commentary	The formula is derived from here: https://www.pmel.noaa.gov/maillists/tmap/ferret_users/fu_2004/msg00023.html.

	Note that the "R2" term is radius squared and "p" is pi. Complexity: Lower Popularity: Medium
Proposed Revisions Summary	Add a formula to calculate the area of rectangular areas to make it easier to estimate the areal reduction factor.

Attribute	**Description**
Revision ID	44
Title	Add references to StreamStats for the regression equation analysis.
Feedback Summary	Several inland hydrology pilot participants suggested adding links and/or references to the USGS StreamStats Tool to the Guide Chapter 7. StreamStats is an online web application that pilot participants found useful for multiple tasks in the Guide, including watershed delineation, characterization, and flood-frequency-curve (FFC) calculation using the best-available USGS regional regression equation.
Original Comments	*List StreamStats as a reference for regression equations. [OR]* *Since Iowa primarily uses Stream Gage-derived FFC and Regression equations without a precipitation component, the index method utilizing a lumped parameter hydrology model (NRCS TR-20, etc.) appears to be the most practical approach. The USGS StreamStats application provides nearly all of the parameters needed for a lumped parameter model of a resolution adequate for an index method evaluation. The only caveat is the Des Moines lobe, which is not a concern unless your area of interest is between Badger, IA, and Sleepy Eye, MN. [IA]* *Need guidance on suggested sources for design values like FEMA, StreamStats, etc.[WS]* *Add links to StreamStats. [WS]* *The guidance assumes the user knows H&H and design for transportation, but should those subjects be addressed in the guidance? Since the guidance is so long already, perhaps add links to relevant sources, like a link to StreamStats. [FL]*
Study Team Commentary	The Guide already has references to many other helpful third-party tools and datasets including NOAA Atlas-14, the USACE Sea Level Change Curve Calculator, and the USACE ERDC Coastal Hazards System database. Based on the Study Team's experience, StreamStats is an extremely useful "point-and-click" web tool for performing major components of steps 1 thru 4 in the Guide Chapter 7, "Projections Based on Regression Approaches in Ungauged

	Watersheds." The USGS released the first version of StreamStats in 2001 and has plans to continue and expand its service to consider the effects of climate change.[15] StreamStats makes it easy for the engineer to identify the appropriate regional regression equation (step 1), find the range of acceptable independent variable values (step 2), estimate the historic independent variables (step 3), and compute the historic design discharge (step 4). A key limitation of StreamStats is that it does not currently calculate the projected independent variable(s) or the projected design discharge. Complexity: Lower Popularity: Higher
Proposed Revisions Summary	Add references to StreamStats for the regression equation analysis. Consider including examples.

Attribute	**Description**
Revision ID	45
Title	Include probabilistic risk-based methodologies for coastal SLR analysis.
Feedback Summary	Several coastal pilot participants strongly recommended using probabilistic approaches to consider SLR in infrastructure design. The guidance recommends probabilistic approaches for level 3 coastal analysis (see Guide, pg. 9). Pilot participants suggested that probabilistic approaches could be appropriate for level 1 and 2 analyses as well; they are better than rigid scenarios; they can incorporate the effect of SLR over the project lifetime; and they permit design plans to be tweaked based on DOT risk tolerance.
Original Comments	*Consider the merits of a risk-based analysis, even if performed at a "light" level. I.e., probabilistic elements can be introduced to a Level 1 or Level 2 analysis, without going to a full Level 3 study. [NC]* *Probabilistic methodology provides a method for introducing practical application of SLR into design. [FL]* *Incorporation of probabilistic methodology for SLR. [FL]* *The guidance does not introduce a probabilistic approach until Level 3. A probabilistic approach will be used with the Level 1 analysis in this section for illustrative purposes. The current approach uses the sea level rise at the end of the structure's design life. This is equivalent to assuming all the SLR will occur*

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[15] See https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/atoms/files/AWRA_GIS_Conf_2016_Ries_part1_508.pdf.

	immediately and be constant through the life of the structure. The probabilistic approach creates the storm chronology during the life of the structure to combine with a chosen SLR scenario. [FL] *Consider a probabilistic approach to assessing risk rather than rigid scenario. [WS]* *Consider adding an examples document with probabilistic analysis (similar to HEC-23). [WS]* *Add a discussion of probability analysis for coastal applications. [WS]* *SLR scenarios should be probabilistic. Design for level of risk appetite. It is very difficult to establish programmatic guidance. [WS]* *Adding probabilistic modeling is a good idea. [FL]* *Need guidance on… relative probabilities (e.g., probability of low, medium, or high SLR). [WS]*
Study Team Commentary	The pilot participants conducted several pilot studies using probabilistic approaches to considering SLR in infrastructure design. The pilots could be a useful companion to the Guide and are described in more detail in a companion report with Best Practices and Lessons Learned. The case studies illustrate how stochastic variables including the amount of SLR, the timing and size of storm surge, and the height of tides can be probabilistically varied to get a better assessment of risk. Note that the Guide makes it clear that there are no true probabilities associated with future climate and SLR scenarios (see Guide pg. 21 and 115). For cases where probabilities cannot be assessed due to deep uncertainty, the Guide could discuss how sensitivity analysis can be done to understand the likely universe of possible future vulnerability and risk. Complexity: Higher Popularity: Medium
Proposed Revisions Summary	Add more practical guidance for probabilistic SLR risk assessment including analytic approaches and specific examples. Add discussion about how to do probabilistic or sensitivity analysis in the face of deep uncertainty about future climate.

Attribute	Description
Revision ID	46
Title	Elaborate on GMSLR (MSL) datum adjustment.

Feedback Summary	Pilot participants asked for better information on where to obtain mean sea level (MSL) data and to provide better descriptions for MSL datum adjustments
Original Comments	*Need better description for MSL datum adjustments and where to get the data. [WS]* *Note that the guidance is not clear on where to obtain the monthly mean sea level values to calculate this conversion and could be improved in future versions of NCHRP 15-61. [FL]*
Study Team Commentary	Complexity: Medium Popularity: Medium
Proposed Revisions Summary	Add better explanation of datum adjustments to the guide or reference outside material. Consider adding a table of publicly available sources for sea level data, such as NOAA's "ECCO Global Mean Sea Level – Monthly Mean" dataset.[16]

Attribute	**Description**
Revision ID	47
Title	Expand guidance for SLR analysis for cases with multiple nearby tide gauges.
Feedback Summary	A pilot participant raised the need for better guidance when conducting SLR analysis on sites where multiple nearby tide gages exists.
Original Comments	*NCHRP 15-61 does not provide clear guidance for SLR cases such as this where multiple nearby tide gauges exist, so the calculations for this example application were performed for both gauges and the highest estimate was selected for further analysis. [FL]*
Study Team Commentary	The Study Team agrees that the Guide should provide clearer guidance on tide gage selection. Note however that the Guide does point users to the Sweet et al. (2017)[17] data at 1-degree intervals along the coastline, which could be used for locations between tide gauge location (see Guide, pg. 118). Also, the Guide Final

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[16] See https://search.earthdata.nasa.gov/search/granules?p=C1991543742-POCLOUD&pg[0][v]=f&tl=1648145822!3!!

[17] See Sweet, W., R. Kopp, C. Weaver, J. Obeysekera, R. Horton, R. Thieler, and C. Zervas. 2017a. "Global and Regional Sea Level Rise Scenarios for the United States." NOAA Technical Report NOS CO-OPS 083.EC

	Report recommend that engineers use the tide gauge that is “nearest to the project site” (Guide Final Report, pg. 118). Complexity: Medium Popularity: Lower
Proposed Revisions Summary	Provide clearer guidance on tidal gauge selection.

Attribute	Description
Revision ID	48
Title	Expand guidance on how to account for storm intensification in hydrodynamic models.
Feedback Summary	The Guide says that it is important to use hydrodynamic models to model the non-linear effects that SLR can have on storm surges. These non-linear effects are referred to as storm intensification. A pilot participant asked for more information on how hydrodynamic models could be used to simulate storm intensification.
Original Comments	*Need more guidance on hydrodynamic models and storm intensification. [WS]*
Study Team Commentary	The pilot participant might have missed the discussion of hydrodynamic models in the Guide Final Report (see Guide Final Report, pg. 160), as well as the reference to HEC-25 (Douglass et al 2014) for more information about coastal hydrodynamic models (see Guide pg. 104). It might be useful to summarize some of that information in the Guide. Complexity: Medium Popularity: Lower
Proposed Revisions Summary	Add guidance on hydrodynamic models used to measure storm intensification due to SLR.

Attribute	Description
Revision ID	49
Title	Provide an alternative equation for future coastal flood elevation.

Feedback Summary	One pilot analysis suggested changing the approach in the Guidelines to estimate the future coastal flood elevation. The approach in the Guidelines is embodied in Equation 12.1: $\eta_2 = \eta_1 + (AR)(SLR)$ Where η_2 is the flood elevation of interest in the future, η_1 is the flood elevation of interest today, SLR is the relative sea level rise increment in the future, and AR is a kind of correction factor called the amplification ratio, which generally falls between 0.7 and 1.5. The pilot analyses proposed using an alternative approach with a different equation: $\eta_2 = (NF)(\eta_1) + SLR$ Where NF is another kind of correction factor called the non-linearity factor. The value is NF can be written as a polynomial function of SLR: $NF = a(SLR)^3 + b(SLR)^2 + c(SLR) + d$ Where the values of a, b, c, and d are fit to model simulation results. The pilot analysis argues that this approach is better than Equation 12.1 for two reasons. First, it is more physically meaningful to apply the correction factor to the surge amplitude, and not SLR, because it represents a correction to the storm surge due to the reduction in near-shore surge attenuation by SLR. Second, it relaxes the assumption that the correction value is constant and defines it as a function of SLR. Based on their modeling results, the pilot analysis finds that the NF tends to increase as SLR gets bigger. The pilot participant recommends replacing the existing formula with the proposed formula and does not recommend presenting both formulas together as dual alternatives because (1) it would add unnecessary confusion to have to explain the difference between the two equations and (2) the original equation would probably not make sense or be helpful to many coastal engineers.
Original Comments	*Developed new recommended non-linearity factors for SLR and surge and waves [NC]* *The nonlinear interaction between storm surge amplitude and SLR was incorporated through a parametric coastal modeling study, which considered a range of future SLR water levels, each with three different storm surge amplitudes (reflecting present-day and future storm conditions). Based on the modeling results an empirical relationship was calculated for a "Nonlinearity Factor" that expresses the increase in storm surge amplitude that will result from SLR. The Nonlinearity Factor proposed herein differs from the Amplification Ratio proposed by NCHRP 15-61; however, as argued in the text above, the proposed Nonlinearity Factor provides a more rational way of incorporating nonlinear effects. The Nonlinearity Factor was applied in the Monte Carlo Simulations used for the probabilistic storm surge modeling. [NC]*

	Suggested improvement to nonlinearity factor for storm surge. [NC] *Non-Linear functions for waves and surge due to SLR need adjustment or further explanation. [WS]*
Study Team Commentary	Complexity: Medium Popularity: Medium
Proposed Revisions Summary	Recommend using the alternative equation to calculate future storm surge.

Attribute	**Description**
Revision ID	50
Title	Keep the coastal applications section general and non-prescriptive.
Feedback Summary	Some pilot participants praised the coastal applications section of the guidelines for being general and non-prescriptive. They appreciated that the Guide allows coastal engineers to use their own engineering judgement.
Original Comments	*The guidelines for coastal analysis are not overly prescriptive, allowing for coastal engineers to use reasonable judgement. [NC]* *For coastal applications, leave guidance as is – general and non-prescriptive. [WS]*
Study Team Commentary	The Study Team thinks it could be useful to dig deeper into why coastal applications are seen to require a more general approach than inland hydrology. Is the issue that coastal applications are too technically complex for rigid workflows? Or that coastal applications involve significantly higher risks with more value-laden design tradeoffs? The answer could suggest ways to strengthen the coastal applications section without making it overly general or prescriptive. Complexity: Lower Popularity: Medium
Proposed Revisions Summary	No revisions needed. This is a counterpoint to other revisions that suggest adding more detail to the coastal applications section.

Attribute	**Description**
Revision ID	51
Title	Add guidance on connecting with communities.
Feedback Summary	Pilot participants suggested adding recommendations for reaching out to communities to discuss climate change and future infrastructure risk.
Original Comments	*Add guidance on connecting with communities. [WS]*
Study Team Commentary	The Study Team agrees that community engagement is important, especially in communities where projected climate change poses a significant threat to infrastructure. Nevertheless, the topic of community engagement may be outside the scope of the Guide. Complexity: Higher Popularity: Lower
Proposed Revisions Summary	Add guidance on connecting with communities.

Attribute	**Description**
Revision ID	52
Title	Add guidance on how to engage with climate scientists.
Feedback Summary	The Guide recommends that users engage with climate scientists to help with GCM selection in areas with regional-scale weather phenomena (see Guide, pg. 20) or with higher-level analysis (see Guide, pg. 97-98). However, most of the pilot participants said that it would be difficult to get support from a climate scientist for a DOT project. The Guide should give practical advice on how DOTs could identify and engage climate scientists for support.
Original Comments	*Need guidance on how to coordinate with climate scientists. [WS]* *Consult climate scientists for model selection. [WS]* *Explain how to connect the climate science community to the engineering community. [WS]* *DOTs should consider going to their state climatologist to identify GCMs most suitable for their state. [WS]*

	Although the guidelines recommend that the state climatologist help answer questions about local conditions, the climatologist might not be resourced to help as much as envisioned. [AZ]
Study Team Commentary	Pilot project participants did not work with climate scientists to implement the steps in the Guide, even though they asked the Study Team a lot of questions that climate scientists could have addressed. It seems that the DOTs do not have an easy line of communication with these kinds of experts. It may be reasonable for the Guide to assume that it will be implemented without support from climate scientists. Complexity: Medium Popularity: Medium
Proposed Revisions Summary	Add more information and advice on how to contact and engage climate scientists for the DOT project.

Attribute	**Description**
Revision ID	53
Title	Discuss ways for DOTs to determine the cost/benefit of Guide implementation.
Feedback Summary	A pilot participant asked for ways to incorporate climate change into the design without having to implement the Guide on every project.
Original Comments	*It may not be practical to apply the guidance to every project – too time-consuming. A question is, is it always worth the effort to do the analysis, especially if the results do not change the design in the end? [WS]*
Study Team Commentary	The Study Team is developing a companion document with basic information about the effort required to implement the guidelines. The results should help DOTs estimate implementation costs and weight that against any design benefits that can be quantified. Complexity: Lower Popularity: Medium
Proposed Revisions Summary	Discuss the costs and benefits associated with the implementation of the Guide.