NOAA Fisheries WCR Guidance to Improve the Resilience of Fish Passage Facilities to Climate Change - 2022

NOAA Fisheries West Coast Region Guidance to Improve the Resilience of Fish Passage Facilities to Climate Change - 2022

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ABBREVIATIONS

AWS	auxiliary water supply
BCSD	bias-correction spatial-disaggregation
BPA	Bonneville Power Administration
BFW	bankfull width
BY	brood year
cfs	cubic feet per second
CIG	University of Washington Climate Impacts Group
CMIP	Climate Model Intercomparison Project
Design Manual	*2022 NOAA Fisheries West Coast Region Anadromous Salmonid Passage Design Manual*
DHSVM	Distributed Hydrologic Soil Vegetation Model
DPS	Distinct Population Segment
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
FAQs	frequently asked questions
FERC	Federal Energy Regulatory Commission
GCM	general circulation model or global climate model
GHG	greenhouse gas
$GtCO_2$	$GtCO_2$ refers to gigaton of carbon dioxide; a gigaton is equal to 1 billion metric tons
Improving Resilience	*NOAA Fisheries West Coast Region Guidance to Improve the Resilience of Fish Passage Facilities to Climate Change*
IPCC	Intergovernmental Panel on Climate Change
km	kilometer
LOCA	Localized Constructed Analogs
M&AM	monitoring and adaptive management
MACA	Multivariate Adaptive Constructed Analogs
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
O&M	operations and maintenance
PRMS	Precipitation Runoff Modeling System
RCP	Representative Concentration Pathway
Reclamation	U.S. Bureau of Reclamation
RMJOC	River Management Joint Operating Committee

SSP	Shared Socioeconomic Pathway
USGS	U.S. Geological Survey
USACE	U.S. Army Corps of Engineers
VIC	Variable Infiltration Capacity
WCR	West Coast Region
W/m^2	watts per square meter
WRCS	winter-run Chinook salmon
WRF	Weather Research and Forecasting

1 Introduction

Since 2016, NOAA's National Marine Fisheries Service (NMFS) has been working to include methods to incorporate future climate change into engineering designs of fish passage facilities and stream crossings. This is because future environmental conditions may be substantially different from today and affect the performance of fish passage facilities and the anadromous species and populations that depend on the facilities. The results of these efforts are detailed in this document titled *NOAA Fisheries West Coast Region Guidance to Improve the Resilience of Fish Passage Facilities to Climate Change* subsequently referred to as *Improving Resilience*. The intended users of *Improving Resilience* are NMFS engineers and biologists, along with applicants and their consultants. One of the goals of the document is to assist parties in satisfying NMFS regulatory authorities and NMFS' policy on the treatment of climate change in Endangered Species Act (ESA) decisions. *Improving Resilience* provides the processes and tools needed to incorporate climate resiliency into the design of fish passage facilities and represents the first in a series of documents applicants should use when designing a fish passage project in the West Coast Region (WCR), which encompasses California, Oregon, Washington, and Idaho.

The purpose of *Improving Resilience* is as follows:

- Support the design of fish passage facilities that are resilient to climate change in a region where climate already varies greatly by providing sources of information needed to assess risk to anadromous fish species and facilities across the diversity of climate zones in the WCR. *Improving Resilience* provides guidance on how to obtain specific information on changes in hydrologic and environmental conditions due to climate change at the appropriate geographic scale for a proposed project.
- Inform applicants and designers as to how NMFS engineers and biologists will strive to incorporate climate change resiliency into fish passage designs and the types of analyses that could be requested from project applicants.
- Provide guidance to NMFS engineers and biologists on engineering criteria, biological factors, and monitoring and adaptive management (M&AM) considerations to focus on when reviewing designs of new facilities or modifications to existing fish passage facilities and when considering operations and maintenance (O&M) of facilities following construction.
- Provide NMFS engineers and biologists, and applicants and their consultants, with the resources needed to develop fish passage engineering designs that are resilient to climate change.
- Identify readily available, and routinely updated, downscaled climate product information (Sections 2.3, 2.5, 5, 6, and 7) for all parties to use and discuss. The intent is for applicants to use regionally appropriate, downscaled climate and hydrologic projection products available for public use, as identified in this document. It is not anticipated that applicants would need to perform climate downscaling; information is available for most locations in the WCR.

Furthermore, NMFS recognizes that climate science is evolving, new information and datasets will become available through time, and not every project will be covered by the climate downscaling products identified in *Improving Resilience*. If applicants prefer to use a product other than what NMFS recommends in Sections 2 or 6, they should present the proposed approach to NMFS and discuss the benefits of the approach early in the design development process. NMFS will review the proposed downscaling approach and provide feedback to the applicant.

- Identify methods for addressing and incorporating uncertainty into the design process. NMFS recognizes there is uncertainty associated with climate change projections, hydrologic downscaling, and biological responses to changed environmental conditions, and that through time the understanding of uncertainty and how to manage it will evolve.

The WCR developed a flow chart for how to use their various fish passage guidance documents (Figure 1). For projects located in California, project proponents should use the following documents:

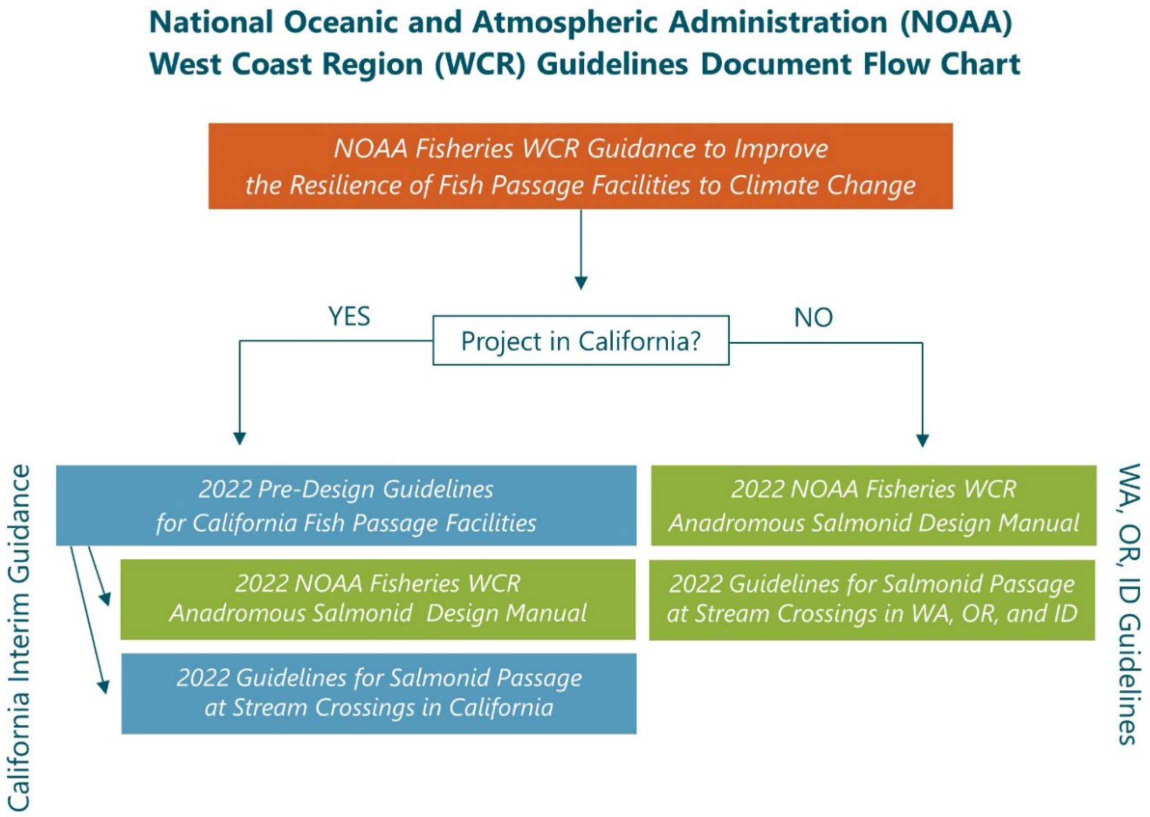
- *NOAA Fisheries WCR Guidance to Improve the Resilience of Fish Passage Facilities to Climate Change;*
- *2022 Pre-Design Guidelines for California Fish Passage Facilities;*
- *2022 NOAA Fisheries West Coast Region Anadromous Salmonid Passage Design Manual;*
- *2022 Guidelines for Salmonid Passage at Stream Crossings in California.*

For projects located in the Pacific Northwest, project proponents should use the following documents:

- *NOAA Fisheries WCR Guidance to Improve the Resilience of Fish Passage Facilities to Climate Change;*
- *2022 NOAA Fisheries West Coast Region Anadromous Salmonid Passage Design Manual;*
- *2022 Guidelines for Salmonid Passage at Stream Crossings in Oregon, Washington, and Idaho.*

If you have questions on how to apply any of the guidelines listed above, please contact NMFS' Engineering & Physical Sciences Branch listed on Page ii of this document.

Figure 1
West Coast Region - Guideline Document Flow Chart



Improving Resilience covers the following key elements:

- The need for, purpose, and intended use of *Improving Resilience* (Section 1);
- The recommended processes and resources available to use when developing fish passage designs that address climate change (Sections 2.1, 2.2, and 2.3);
- Risks to anadromous fish species using fish passage structures due to changes in environmental conditions associated with climate change and potential corrective actions that address the risks and can be incorporated into fish passage facility designs (Section 2.4);
- Case studies for projects with a long-life expectancy, i.e., >10 years (Section 2.5);
- The need for monitoring and adaptively managing fish passage facilities through time due to uncertainties associated with the effects of climate change (Section 2.6);
- NMFS' policies on climate change, how the design process needs to be modified to accommodate climate change, and potential biological responses to climate change that

increase biological risk and need to be factored into facility designs (Section 3; section also addresses sea level rise, subsidence, and conditions following wildfires);

- Definitions of key terms (Section 4);
- Additional information on climate change modeling and links to websites (Section 5);
- Other sources of information an applicant may want to use to provide flexibility in the use of the downscaled climate and hydrology data that are constantly being updated (Section 6).

Improving Resilience has two main sections. The first main section is Section 2 (*Improving Resilience* Process), which is the process for designers to follow in order to incorporate climate resiliency into the design of fish passage facilities. The process identifies how to account for climate change in projects with a short life expectancy (less than 10 years) and for projects with a long-life expectancy (greater than 10 years). Examples of short life expectancy projects are short-term water diversions and temporary fishways. Design flows and water temperatures for short life expectancy projects should rely on recent hydrologic data. Design flows and water temperatures for long life expectancy projects should rely on streamflows and water temperature estimated from global climate models (GCMs). It is anticipated that the vast majority of new projects will have a long-life expectancy. Section 2 provides practical steps, sources of needed information, and case studies. The second main section is Section 3 (Background), which provides background information on NMFS's policies on climate change that were incorporated into *Improving Resilience* and the biological basis for why building facilities that are resilient to climate change is needed.

Fish passage facilities typically have a long design life making them susceptible to extremes from natural variability and climate change (e.g., floods, droughts, and wildfires). Changes in environmental conditions due to climate change are expected to continue and can affect facility performance. NMFS defines a resilient facility as one that will function successfully under a variable range of environmental conditions that may occur as a result of climate change. Therefore, incorporating resilience to climate change into designs is needed to reduce risk to anadromous fish species and ensure a facility will function successfully, meaning that it will provide for the safe, timely, and effective passage of fish over the design life or term of the license associated with a facility. NMFS must acknowledge that climate science is an evolving science and that models are not predictions of what can happen but are rather projections of what can happen from different modeled scenarios. Despite our best efforts, risk remains and even with resiliency designed into our projects, future conditions may render these efforts insufficient. This risk must always be kept in mind, and the need for future adaptive management acknowledges this risk cannot be discounted.

NMFS' requirement for safe, timely, and effective passage derives from the unofficial but reliable definition of a fishway presented by the U.S. Congress in a report related to the Energy Policy Act of 1992. The definition of "safe and timely passage" was expanded to include both passage structures and operations "necessary to ensure the effectiveness" of such structures. None of the terms "safe," "timely," or “effective” are further defined (106 STAT. 2776 PUBLIC LAW 102-486—OCT. 24, 1992). However, in practice, NMFS typically includes provisions which give these terms meaning. Regarding “safe” passage, NMFS requires licensees to design and operate their fishways so that they minimize the occurrence of injury or mortality experienced by fish while attempting to utilize the fishway. Regarding “timely” passage, a fishway prescription may include provisions for reducing the time in which a fish utilizing the fishway is subjected to stressful interactions, such as time spent in a trap or in transit, or a requirement for flows which will attract fish to a passage facility. Regarding “effective” passage, NMFS typically includes provisions requiring the operator to ensure that its facility succeeds in passing as close to 100% of the fish attempting to migrate through the system as possible.

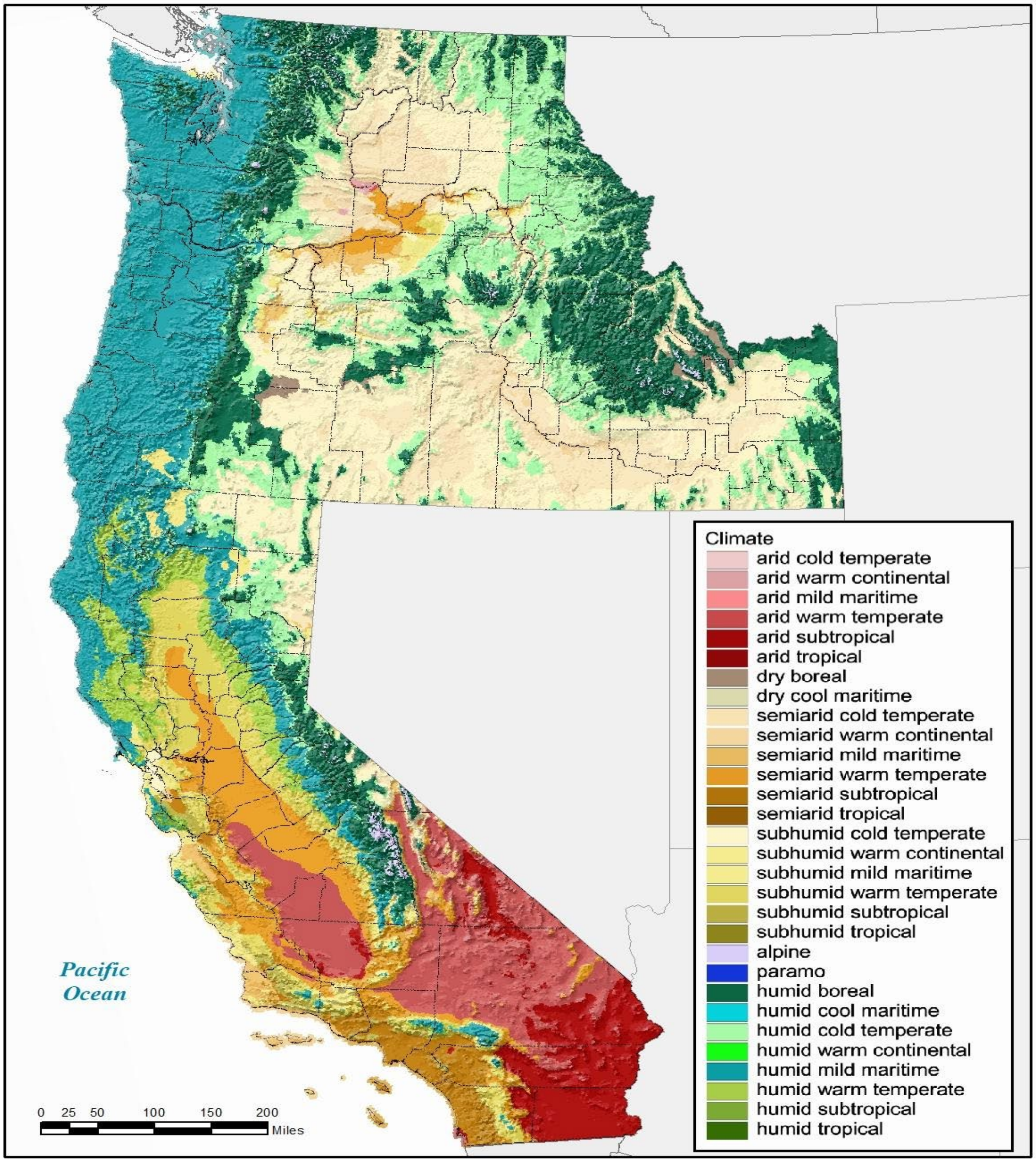
There are also risks to applicants due to a fish passage facility having to be redesigned and rebuilt because it no longer performs as required. For example, NIWA (2018) provides design criteria for fish passage structures in New Zealand and identifies the need for structures to be resilient to extreme events. It suggests that high initial construction costs for more complex designs or larger structures to address climate events may be balanced by lower long-term monitoring and maintenance costs.

NMFS engineers and biologists have recognized the need to address the effects of climate change on fish passage designs in a manner that accounts for different project types, the status and biology of anadromous fish species in different watersheds, and the different climate zones of the WCR (Figure 2*).* *Improving Resilience* has been developed to outline such a process for applicants to follow. The process aligns with NMFS’s policies. Its goal is to provide a defined and transparent process for applicants to use that will ensure for NMFS staff that effects of climate change have been incorporated into fish passage facility designs. This, in turn, will contribute to reducing potential delays in NMFS’s review and approval of applicants’ proposed designs because standard procedures have been used.

NMFS encourages applicants to contact them early in the project application process and often thereafter. The agency wants to work with applicants to come up with agreed upon solutions. Based on NMFS’s experience, the best project outcomes are realized for all parties when NMFS and applicants work together on project designs from the beginning. They recognize that there is no single design solution for large, complex fish passage projects and understand that trade-offs will have to be made to arrive at a scenario that is reasonably feasible and acceptable to all parties, and also protects and conserves anadromous species and their habitat. It is important for applicants to recognize the importance of applying the guidance provided in the WCR documents shown in Figure 1. It is also important for applicants to understand that applying the guidance, in the absence of working with NMFS, does not imply approval of the project by NMFS.

This document addresses how to improve the resilience of fish passage facilities to climate change. NMFS defines fish passage facilities as structures that provide safe, timely, and effective volitional upstream and downstream passage of Endangered Species Act (ESA)-listed species, including fish screens and ladders, nature-like fishways, grade control structures, culverts, bridges, and stream crossings. This includes streams with anadromous and non-anadromous fishes, as well as ephemeral streams that are an important component of freshwater ecosystems.

Figure 2
West Coast Region - Climate Zones



Note: Climate Zone map obtained from The Biota of North America Program (Kartesz 2014).

In 2016, NMFS issued its national *Guidance for Treatment of Climate Change in NMFS Endangered Species Act Decisions* (NMFS 2016). The five key elements of the NMFS ESA policy on climate change (NMFS 2016) are listed and described in Section 3.1. To summarize, NMFS will do the following when incorporating climate change into project designs:

- Review its internal guidance and design criteria (i.e., the guidance documents shown in Figure 1) to ensure that the criteria are adequate for ESA-listed and non-listed anadromous species in light of anticipated future climate conditions.
- Analyze how effects on anadromous species from project designs may change over the life of the project when considering reasonably foreseeable climate change effects. NMFS will consider how climate change can affect the degree to which projects NMFS evaluates under its statutory authorities may accommodate future as well as current needs of anadromous species. Note also that "when structural criteria applied by other agencies are not sufficient, NMFS will engage with those agencies to attempt to find solutions" (NMFS 2016).

Following issuance of the NMFS ESA policy on climate change (NMFS 2016), NMFS regions began evaluating how to incorporate its guidance into ESA Section 7 consultations. For the WCR, climate change treatments in consultations are being addressed on a case-by-case basis where the key factors being considered are the lifespan of the effects of a proposed action on anadromous species and the interaction of the effects with climate change. This includes the effects of an action on anadromous species that continue after the activity itself has been completed.

In 2020, the WCR initiated development of *Improving Resilience* to help applicants do the work necessary to incorporate resilience to the risks of climate change into fish passage designs. However, the science of climate change is quickly evolving and there are knowledge gaps. *Improving Resilience* reflects what is known today about climate change and current products. It provides steps linked to readily available and appropriate climate and hydrologic projection products that are expected to be regularly updated. *Improving Resilience* was developed to provide actionable guidance to inform decisions based on climate information that is routinely being updated. Having accurate climate information helps applicants plan their projects, reduce risk, adapt to changes in the environment, and identify cost-saving opportunities and efficiencies (IGES 2012). However, the steps and links provided are not likely to answer all the questions that practitioners may raise or be faced with in the future as more information on climate becomes available for the large variety of project types and locations within the WCR. Therefore, additional resources that applicants may find helpful are listed in Sections 5, 6 and 7.

As discussed in Sections 3.4 and 3.5, there is uncertainty associated with projecting effects of climate change into mid-century and late-century timeframes and how the changes will affect individual fish and populations. Kunreuther et al. (2014) identify three important aspects of dealing with uncertainty: precaution, risk hedging, and crisis prevention and management. *Improving Resilience* strives to address all three aspects of dealing with uncertainty. *Improving Resilience* is precautionary because NMFS (2016) guidance is to use the RCP8.5 emissions scenario[1], which assumes little change in emissions over time. For example, a precautionary action would be to increase the clear span of a bridge or culvert using downscaled climate data based on RCP8.5. *Improving Resilience* hedges risk by considering different climate futures, advises applicants to consider ensemble (a group of models) means and variability in downscaled climate data (like wet and dry, or warm and cool/less warm) or combinations of extremes (hot-dry vs wet-cool) and assesses hydrologic data from neighboring watersheds (in some cases), and incorporates this information into facility designs. *Improving Resilience* strives to prevent crises by incorporating effects of droughts, wildfires, floods, low summer flows, and increased water temperatures into the design process through consideration of "Actions to Consider" found in the Climate Risk Pathway tables in Section 2.4 (Tables 1 to 10). Thus, uncertainty around climate futures is addressed by incorporating all three aspects of uncertainty into facility designs.

The guidance documents developed by the WCR that are shown in Figure 1 are based on decades of field testing using a trial-and-error approach and results of studies reported in the scientific literature. Designs based on these documents under current conditions and historical hydrology are intended to 1) result in the safe, timely, and effective passage of fish; 2) help maintain and restore habitat connectivity within and among watersheds; and 3) enhance overall population diversity and productivity and thus support species recovery and resilience to natural ecosystem variability. However, as the WCR continues to experience climate change and the effects of increased heat, changes in seasonal flows, longer periods of drought, and increased wildfires, facilities designed under current conditions and historical hydrology may not function as intended and could lead to undesired impacts on trust species. As discussed in Section 3.2, climate change requires a new perspective and approach when designing fish passage facilities, necessitating the development of *Improving Resilience*.

Improving Resilience addresses effects of fish passage structures on both ESA-listed and non-listed anadromous species. It addresses projects of all sizes, Federal Energy Regulatory Commission (FERC) licensed and non-FERC licensed projects, and projects in regulated and non-regulated rivers. It addresses most project types and scales. However, applicants should coordinate directly with NMFS for fish passage project types, scales, elements, or components that are not directly identified or discussed in *Improving Resilience*.

The guidance documents shown in Figure 1 primarily address projects in freshwater environments. The one exception is the *2022 NOAA Fisheries West Coast Region Anadromous Salmonid Passage Design Manual* (NMFS 2022a; Design Manual*)* that discusses near-field hydraulic conditions that affect salmonid passage in tide gates in estuarine and lower reaches of river systems. NMFS recognizes that

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[1] NMFS is currently recommending using RCP8.5 if available. The Intergovernmental Panel on Climate Change is releasing new emissions scenarios related to their latest work, and the emissions scenario or scenarios NMFS recommends may change. If so, this guidance will be updated.

sea level rise due to climate change can have a substantial effect on coastal and estuarine locations; sea level rise and tide gates have been included in Section 2.4 (Climate Risk Pathways) to address these effects. Sea level rise is discussed further in Section 3.6.

The WCR views State agencies as partners in the process of ensuring that fish passage is safe, timely, and effective. States have, or will have, their own approaches for incorporating climate change into fish passage facility designs. Applicants are encouraged to discuss how to develop facility designs that are resilient to climate change with NMFS and the appropriate State agency. NMFS will work with its state partners and applicants to reach agreement on which approach offers more resiliency to climate change and is more conservative from the standpoint of biological risk.

The science of climate change is constantly evolving and expanding rapidly. The GCM's that are the basis for most downscaled climate and hydrology products are updated every few years based on new generations of GCMs released as part of the CMIP and the Intergovernmental Panel on Climate Change reports (Portner et. al, 2022: IPCC 2021, 2013, 2007). Techniques for downscaling are often developed to address specific needs, such as hydrologic extremes, and typically evolve between the IPCC reports. Thus, there are multiple downscaled climate and hydrology products available. Section 6 provides information and links to some products appropriate for design of fish passage. NMFS intends to update this document approximately every 5 years or sooner if new information warrants an earlier update.

NMFS developed this guidance document in close coordination with a steering committee and acknowledges their invaluable contribution to organizing *Improving Resilience*, contributing information on climate change, and reviewing several drafts of the document. The committee also guided a literature review conducted by National Oceanic and Atmospheric Administration's (NOAA's) Central Library that was used to inform the state-of-the-knowledge on incorporating resilience to climate change into engineering designs and design of fish passage facilities. Steering Committee members included: Jeffrey Brown (NMFS), Jean Castillo (NMFS), Keith Kirkendall (NMFS), Bjorn Lake (NMFS), Beth Lawson (California Department of Fish and Wildlife), Andrea Ray (NOAA), and Eric Shott (NMFS). NMFS thanks these individuals for their significant contributions to *Improving Resilience*.

We are also grateful to our reviewers who took the time to provide thoughtful and constructive comments to assist in updating these guidelines.

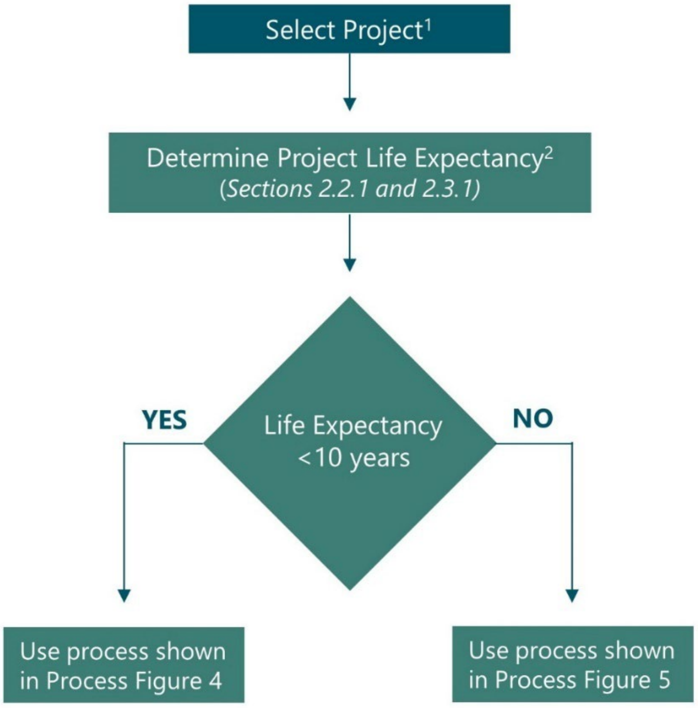
2 Improving Resilience Process

Section 2 outlines the recommended steps and resources available for incorporating climate change resiliency into fish passage facility designs. It provides NMFS's vision on how to incorporate resiliency into designs in a manner that is transparent and consistent across projects and climate zones within the WCR.

2.1 Process Flowcharts

Figures 3, 4, and 5 depict the process NMFS intends applicants to follow when incorporating climate change into fish passage facility designs. Figure 3 reflects the initial steps in the process. Figure 4 presents the design process and sequence to follow for projects with a short life expectancy (generally less than 10 years). Figure 5 presents the design process and sequence to follow for projects with a long-life expectancy (generally more than 10 years).

Figure 3
Process Flowchart – Initial Steps



Notes:

1. Project may include but is not limited to elements such as water diversions, fish screens, fish bypasses, fish ladders, AWS systems, fish traps, juvenile fish collection systems, adult barriers, bridges, culverts, grade control fishways, and roughened channels.
2. Life expectancy is defined as the anticipated duration of time that the project is in place before it is removed or replaced.
3. Applicant should consider the actual project lifespan often exceeds planned life expectancy for the action.

2.2 Design Process for Short Life Expectancy Projects

NMFS recommends different processes for incorporating resilience to climate change into designs for short-term projects compared to long-term projects. Section 2.2 describes the process for projects that are expected to have a life expectancy of 10 years or less (Figure 4). For example, this could include the installation of a portable end-of-pipe screen or a temporary fishway used during construction of a diversion dam. Given that the facility lifespan is short and the design is to be based on observed hydrologic conditions, NMFS is primarily concerned with assessing climate risks to anadromous fish species associated with the changing hydrograph (e.g., shifts in flow timing) and catastrophic events such as floods, droughts, and forest fires that are already increasing in magnitude and frequency.

NMFS made a delineation between short- and long-term projects when developing guidance on how to incorporate resilience to climate change into fish passage facility designs for several reasons. First, for many variables, natural year-to-year variability still dominates the climate change signal over a lead time of about 10 years. In other words, the signal-to-noise ratio may be too low to distinguish climate effects from background variability over this timeframe. While trends in streamflow, high flows, and flooding have been detected, due to natural variability, extrapolating these out over the next 10 years may not be meaningful (Ban et al. 2020). Second, most climate models are not intended to be used for near-term predictions, such as lead times of 10 to 20 years. Work is being conducted on decadal prediction, but the work is in its infancy and very much in the research realm and is not ready for incorporation into fish passage design guidance at this time. As discussed in Section 1, NMFS intends to update this guidance document approximately every 5 years, or sooner, if new information warrants and scientific understanding evolves. Lastly, there are practical reasons for distinguishing between short- and long-term projects that include balancing the level of effort of a full climate analysis with the cost or level of effort for a project with life span of approximately 10 years. Given budgets and costs associated with most short-term projects, using the recent historical data is appropriate.

As discussed in Section 2.3.6.1, NMFS recommends that the ensemble mean of climate model data can be used but also identifies situations where more extreme projections should be considered. Given recent trends of heavier precipitation and higher peak flows (Lall et al, 2018), an applicant may wish to consider erring on the higher end of flows in the recent record as a precautionary action (Kunreuther et al, 2014) to improve resilience when assessing the effects of climate on short-term projects.

For the design of short-term projects, NMFS recommends that the following steps be followed:

- Step 1 – Begin with historical climate conditions to determine project hydrology (e.g., flood recurrence intervals, peak flows, and fish passage design flows [i.e., the design flows recommended in the guidance documents shown in Figure 1 for the project location, which are typically 5% and 95% for most areas of the WCR]) and environmental conditions including water temperature and sediment transport. As a starting point, NMFS considers the previous 25 - 30 years of record, intended to represent the recent trends in hydrology which may have already been shifted due to climate change and other effects. Use of this period is consistent with NOAA's use of Climate Normal[2] values for precipitation, temperature, and other climate variables use a 30-year period of record. (NOAA 2022). For short-term projects, NMFS will consider the 25-30-year record of hydrology and other environmental conditions to extend into the next 10 years so no future climate model projections are necessary. For specific projects NMFS can require analysis of longer record, or an applicant may choose a longer period.

- Step 2 – Use the hydrology and environmental data determined in Step 1 to evaluate conditions expected to occur in the relatively short (approximately 10-year) project period.
- Step 3 – Assess the potential impacts of a project beyond the historical hydrology and environmental data by focusing on the potential for effects to occur from extreme events associated with floods, droughts, and forest fires using the Climate Risk Pathway tables in Section 2.4. Note that the last 25 - 30 years of hydrologic data may not give an accurate picture of what can be expected for extreme events over the next 10 years. To capture the potential (i.e., frequency) magnitude of extreme events, data from a historical period longer than 25 - 30 years may need to be reviewed.[2]

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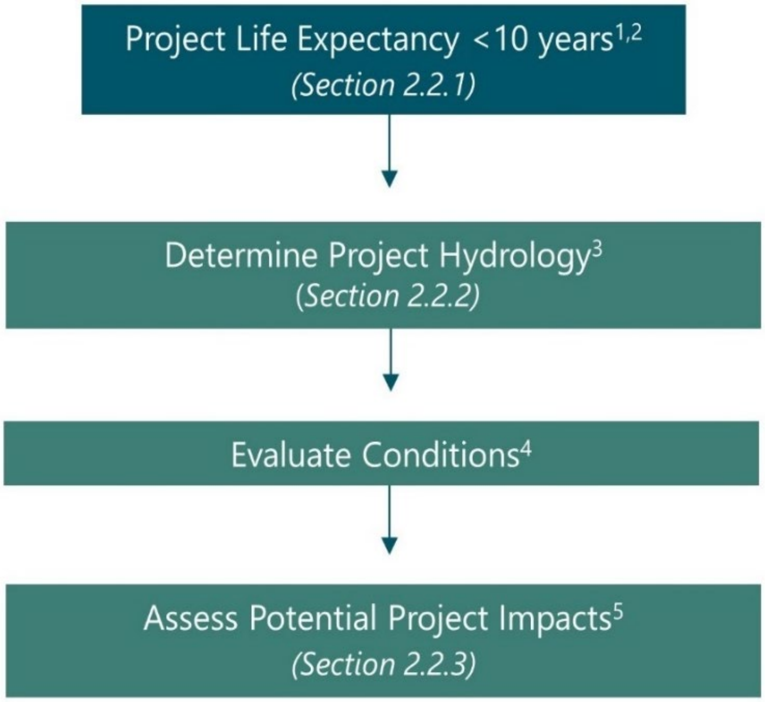
[2] https://www.ncei.noaa.gov/products/land-based-station/us-climate-normals

Figure 4
Process Flowchart for Short-Term Projects (<10 years)



Notes:

1. Project may include but is not limited to elements such as water diversions, fish screens, fish bypasses, fish ladders, AWS systems, fish traps, juvenile fish collection systems, adult barriers, bridges, culverts, grade control fishways, and roughened channels.
2. Life expectancy is defined as the anticipated duration of time that the project is in place before it is removed or replaced.
3. Applicant should consider the actual project lifespan often exceeds planned life expectancy for the action.
4. Use recent climate conditions in the baseline to determine project hydrology (e.g., flood occurrence intervals, peak and low flows, and migratory design flows [i.e.,5% and 95% flow exceedances for most areas of the WCR]) and environmental conditions, including temperature. As a starting point, consider previous 25 - 30 years of record (a record considered as "climate normal")
5. Use the hydrology and environmental data to evaluate conditions expected to occur in the 10-year project period.
6. NMFS will focus on the effects of threats due to climate change associated with floods, droughts, and forest fires when assessing potential project impacts.

2.2.1 Identify Project Element Lifespan

The initial step is for the applicant to review and verify that all project elements are expected to be installed and operated for 10 years or less. Primary facility elements are listed in Tables 1 to 10 in Section 2.4, along with the primary risks associated with each element and potential actions to consider when addressing biological risk associated with the proposed project.

2.2.2 Assess Project Hydrology and Environmental Conditions

The applicant should use available data to assess recent and historical hydrologic and environmental conditions. Hydrologic data sources include stream gages operated by the U.S. Geological Survey (USGS) or others which reflect recent historical variability and extreme years, and where gages do not exist use regression relationships such as provided on the USGS website StreamStats.[3] Environmental data may be obtained from existing water quality studies, water quality databases, and temperature modeling, such as the U.S. Forest Service NorWeST website.[4] The data obtained from the StreamStats and NorWeST websites should be supplemented with data from nearby gaging stations and water quality records for the recent dry and hot years, such as Water Years 2015 and 2021, for the Pacific Northwest and Southwest, respectively. Applicants should consider use of direct measurements of flow and channel dimensions based on surveyed site conditions in addition to these tools. Those years are likely representative of low flow and temperature conditions that will occur in the short term in the Western United States and should be considered in the design of short-term facilities.

The primary data source for estimating peak flows should be long-term gaging records if the project site is close to a gaging station. A flood frequency analysis can be performed on the long-term record. If the project is not close to a gaging station, the USGS StreamStats website is a convenient location to find estimated flood frequencies. An estimate of peak flows using gage data will be more accurate than the StreamStats data, as the estimates at ungaged sites are based on regression relationships developed by USGS to correlate the site location to nearby gaged data. The design should be based on the required flood recurrence interval for the type of structure proposed, per the recommended guidance provided in the documents shown in Figure 1.

2.2.3 Assess Threats from Floods, Droughts, and Forest Fires

Uncertainty analyses should be prepared for estimates of design floods. For example, standard error estimates are provided by USGS StreamStats. A high peak flows value should be used to determine the risk to the structure and provide for a conservative factor of safety that accounts for already occurring climate change impacts.

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[3] USGS website StreamStats website: https://www.usgs.gov/mission-areas/water-resources/science/streamstats-streamflow-statistics-and-spatial-analysis-tools?qt-science_center_objects=0#qt-science_center_objects

[4] U.S. Forest Service NorWeST website: https://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html

Estimated streamflow statistics obtained from the StreamStats and temperature data obtained from the NorWeST websites and used for design should be supplemented with data from nearby gaging stations and water quality records for recent dry and hot years to provide additional information for the level of climate change concern for the site. Note that statistical data such as from StreamStats include atmospheric rivers as part of the record, so these are captured when estimating high peak flows.

The applicant should also review fire history in the project basin. Fires change hydrologic conditions by increasing the rate of runoff and increasing peak flows in streams. They also cause landslides and increase sediment runoff and deposition in streams. Deposition may change stream channel characteristics and increase flood levels. In the case of basins with recent fire history, hydrologic, geomorphic, and temperature analyses should consider the impacts of increased rates of runoff and peak flows. As a precautionary measure in fire-prone areas, applicants should consider designing their projects to accommodate potential future effects from fires. Potential future effects can be estimated using data from basins with similar watershed characteristics that have experienced fires. Additional details on post-wildfire considerations are found in Section 3.8.

2.3 Design Process for Long Life Expectancy Projects

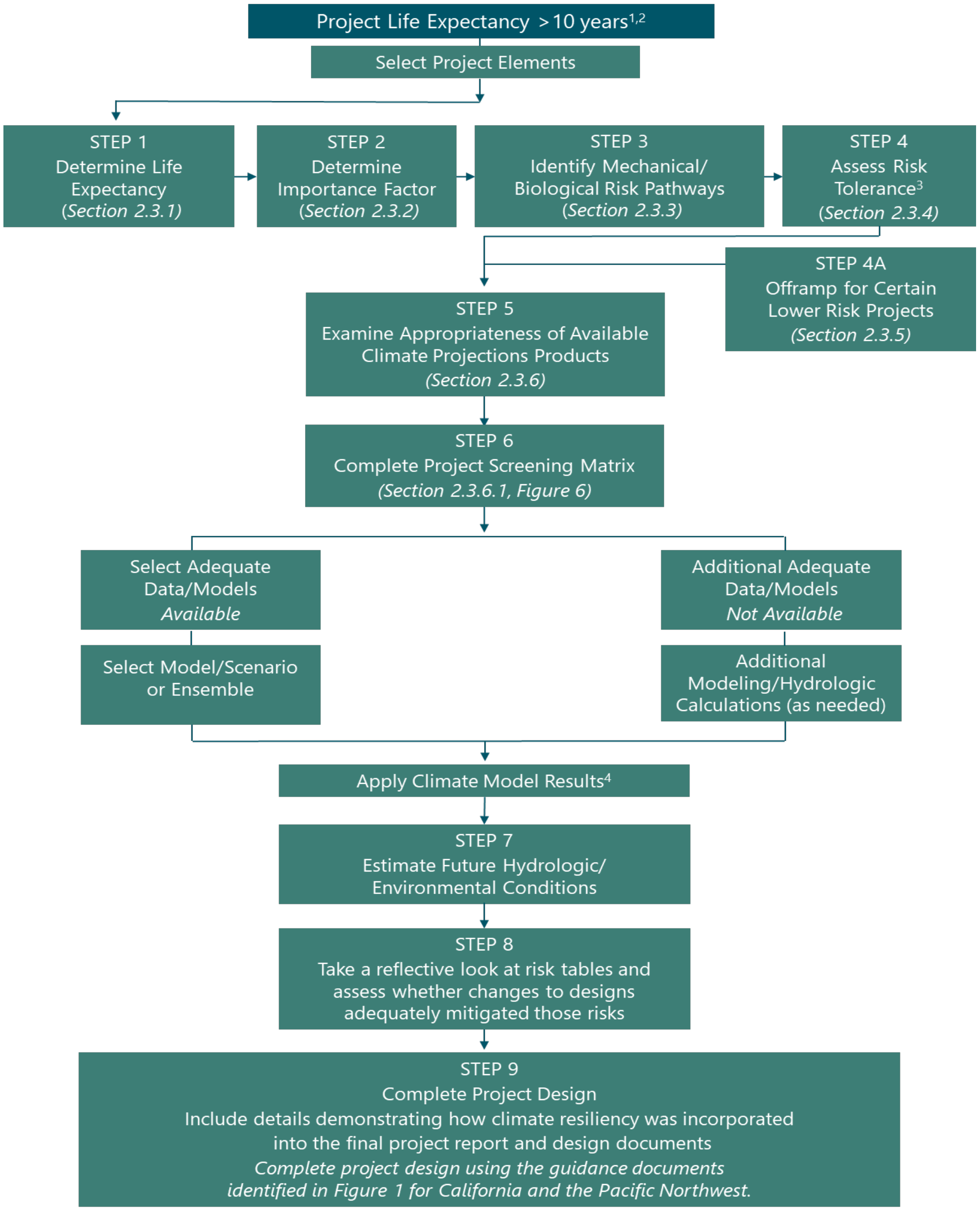
The WCR's approach to incorporating climate change into ESA Section 7 consultations is to consider long- and short-term projects differently when analyzing the effects of climate change on short- and long-term processes. Section 2.3 describes the process for projects that are expected to be installed for more than 10 years (Figure 5). Due to this long timeframe, the process for incorporating resilience to climate change into designs is more involved than the process outlined in Section 2.2 for short-term projects. NMFS assumes and expects that most proposed projects fall into the long-term category. For example, this includes designs for facilities associated with water storage and diversions, including fishways, adult traps, bypass screens, juvenile fish collectors, culverts, and stream crossings. The level of effort NMFS views as being needed for the analysis will depend, in part, on whether climate change is likely to amplify the effects of a particular proposed action. This depends on the following topics to be part of the risk conversation between the applicant and NMFS:

- The duration of the action's effects
- Whether the action's effects on anadromous species and habitat vary in response to any environmental conditions that are likely to change over time (e.g., water temperature, streamflow, sea level height, prevalence of invasive species, etc.)
- Whether the action includes measures to reduce its adverse effects (e.g., through an adaptive management plan) in response to changing environmental conditions (Section 2.6)

Climate change requires a new perspective and approach that considers variability and change when designing fish passage facilities (Section 3.2). Modeled projections of future conditions are needed for developing facility designs that are resilient to climate change and evaluating whether a proposed design can address predicted changes in environmental conditions. Climate change will result in changes in environmental conditions that affect key design criteria. This includes fish passage design flows, peak flows, bankfull flows, water temperature, geomorphology, and sediment transport. In all cases, the potential impacts could require analysis using estimates of hydrologic change along with geomorphic assessments. Some projects, especially those with high importance or low risk tolerance, also may want to hedge risk by considering different climate futures (Kunreuther et al. 2014), i.e., the output of more than one GCM that are likely to be challenging for their design for the risk pathway(s) they are considering.

Figure 5

Process Flowchart for Long-Term Projects (>10 years)



Notes:

1. Project may include but is not limited to elements such as water diversions, fish screens, fish bypasses, fish ladders, AWS systems, fish traps, juvenile fish collection systems, adult barriers, bridges, culverts, grade control fishways, and roughened channels.
2. Life expectancy is defined as the anticipated duration of time that the project is in place before it is removed or replaced.
3. Applicant should consider the actual project lifespan often exceeds planned life expectancy for the action.
4. Assess risk tolerance of NMFS and Applicant.
5. Apply climate model results to estimate percent change from current environmental conditions. Integrate recalculated environmental conditions to Risk Pathways matrix.

2.3.1 *Identify Project Element Lifespan* (Figure 5 Step 1)

The initial step is for the applicant to review all project elements and verify that all elements are expected to be installed and operated for more than 10 years. Primary facility elements are listed in Section 2.4 along with the primary risks associated with each element and potential actions to consider when addressing biological risk associated with the proposed project.

2.3.2 *Determine Importance Factors* (Figure 5 Step 2)

NMFS staff will consider, at a minimum, the following in discussions with applicants and when reviewing proposed designs:

- The number of species present and their overall status and characteristics (ESA status, overall viability of the population/strata/Evolutionarily Significant Unit [ESU], life history characteristics, population trends and overall health, and productivity of the Distinct Population Segment [DPS] or ESU);
- Recovery goals and objectives, and completed, ongoing, or planned actions intended to benefit the populations and species affected by the project;
- Applicable consultation record and Biological Opinions;
- The composition of the population(s) affected by the project (i.e., wild- or natural-origin, hatchery-origin or both);
- How the population and species affected by the project contribute to recreational and commercial fisheries;
- Where the project is located within the watershed (e.g., high or low), the proximity of the project to other diversions or facilities in the watershed, and how the location of the project might affect the DPS or ESU;
- The projected changes in physical and environmental conditions that are estimated to occur (e.g., water temperature, flow timing, and peak and low flows) and how the changes might constrain or impede movement, dispersal, and migration of juvenile through adult life stages and the overall capacity of the watershed to support viable salmonid populations.

2.3.3 *Identify Risk Pathways* (Figure 5 Step 3)

Primary risk pathways associated with each project element are provided in Sec 2.4. The look-up tables describe risks associated with various and potential actions to consider when addressing biological risk associated with the proposed project. Each project type and element may have unique exposures to different changes in environmental conditions as a result of climate change. These risks may be mechanical, structural, or environmental in nature. Tables 1-10 in section 2.4 explore these risk pathways and some suggested ways to mitigate these risks.

2.3.4 Assess Risk Tolerance (Figure 5 Step 4)

Applicants should assess their tolerance for the risk due to climate change of having to redesign and possibly reconstruct a proposed facility in the future. In addition, increased monitoring and O&M requirements (Section 2.6) should be assessed in cooperation with NMFS so that project design, monitoring and biological risks are minimized. NMFS will assess biological risks associated with the project and discuss these with the applicant. Together, the applicant and NMFS should then assess the overall risks associated with project design and monitoring (applicant) and the biological risks (NMFS) from climate change.

2.3.5 Off-Ramp for Lower-Risk Projects (Figure 5 Step 4A)

The "off-ramp" is a simplified alternative approach to incorporating resiliency to the effects of climate change into facility designs for lower-risk projects. The use of this alternative approach is currently limited to a small subset of explicitly identified categories of projects or project elements. However, it is anticipated that as knowledge about the role of dynamic environmental conditions including climate change on impacts increases, the list of project elements that can use this approach and associated criteria correction factors will expand. Correction factors are described in the following paragraphs. The off-ramp approach is not mandatory, and an applicant may elect to work through the complete climate risk framework for a project.

This approach addresses certain categories of fish passage and protection projects whose climate-related risks are reasonably consistent and predictable, and for which a full analysis of the predicted effects of climate change may not be appropriate. This simplified process can be used for frequently installed types of fish passage and protection projects whose climate change risk exposure is well understood. These project types must have a clearly defined engineering pathway to mitigate climate risk through use of conservative correction factors to fish passage criteria. A key underlying principle of this alternative approach is that it must be no less protective against climate change related risks over the lifespan of the project than the conventional approach that works through the complete climate risk framework identified in Section 2.

Project elements that can use this alternative approach and the associated correction factors to design variables include the following:

- Stream crossings designed using the stream simulation design method with measured bankfull width (BFW) of 15 feet or less;
- Fish screens with diverted flow no greater than 5 cubic feet per second (cfs).

The off-ramp approach allows the applicant to avoid any climate change modeling or model interpretation. If the project falls within the sideboards of the off-ramp, the project designer may apply the following correction factors to their designs:

- Culverts less than or equal to 15 feet measured BFW: Increase the required clear span (typically 1.5 times measured BFW) by a minimum of 15%. This will allow for natural stream processes to occur over a broader range of stream flows such that the crossing poses no greater risk to fish passage under changed climate conditions than the adjacent stream channel. The culvert must also be large enough to pass the design peak flow with required freeboard.
- Fish screens that are screening a diversion rate less than or equal to 5 cfs: Increase screen effective area located below the modeled minimum water surface elevation by a minimum of 15%. This will provide additional fish screen area to help maintain compliant approach velocities under reduced water surface elevations coincident with reduced stream flows. This added screen area will also increase the screen’s ability to tolerate partial blockage resulting from increased aquatic vegetation resulting from higher stream water temperatures.

2.3.6 Examine Appropriateness of Available Climate Projections Products (Figure 5 Step 5)

The next step is to determine whether available climate change data can be used to estimate future physical and environmental conditions for the project. Although climate change analyses have been completed for large parts of the Western United States, some of the analyses may not be adequate for the location of the project being proposed. Considerations in assessing the adequacy of the data should include whether the proposed project is on a regulated or unregulated river system, and the extent and quality of available climate modeling performed relative to the size and risk of the project.

In an unregulated river system in the Western United States, projections of future hydrologic conditions are likely to exist and can be used with the guidance provided in Section 2.3.6.1. In regulated river systems, analyses of future operations such as domestic and agricultural water use and hydropower, are less likely to exist because of the complexity of those operations, multiple stakeholders, and complex water rights regimes. An example of where hydrologic modeling of future conditions in regulated systems is available is provided in Section 2.3.6.1 for basins managed by the U.S. Bureau of Reclamation (Reclamation). Where this type of modeling has not been performed, NMFS may require that applicants perform modeling to estimate future physical and environmental conditions. Section 6 provides a list of currently acceptable climate change data. For the purposes of a climate analysis, a regulated river or river reach is one where there are either backwater effects from a downstream water impoundment or hydrograph shaping effects of one or more upstream water impoundments.

2.3.6.1 Cases Where Climate Change Data and Models Are Adequate (Figure 5 Step 6)

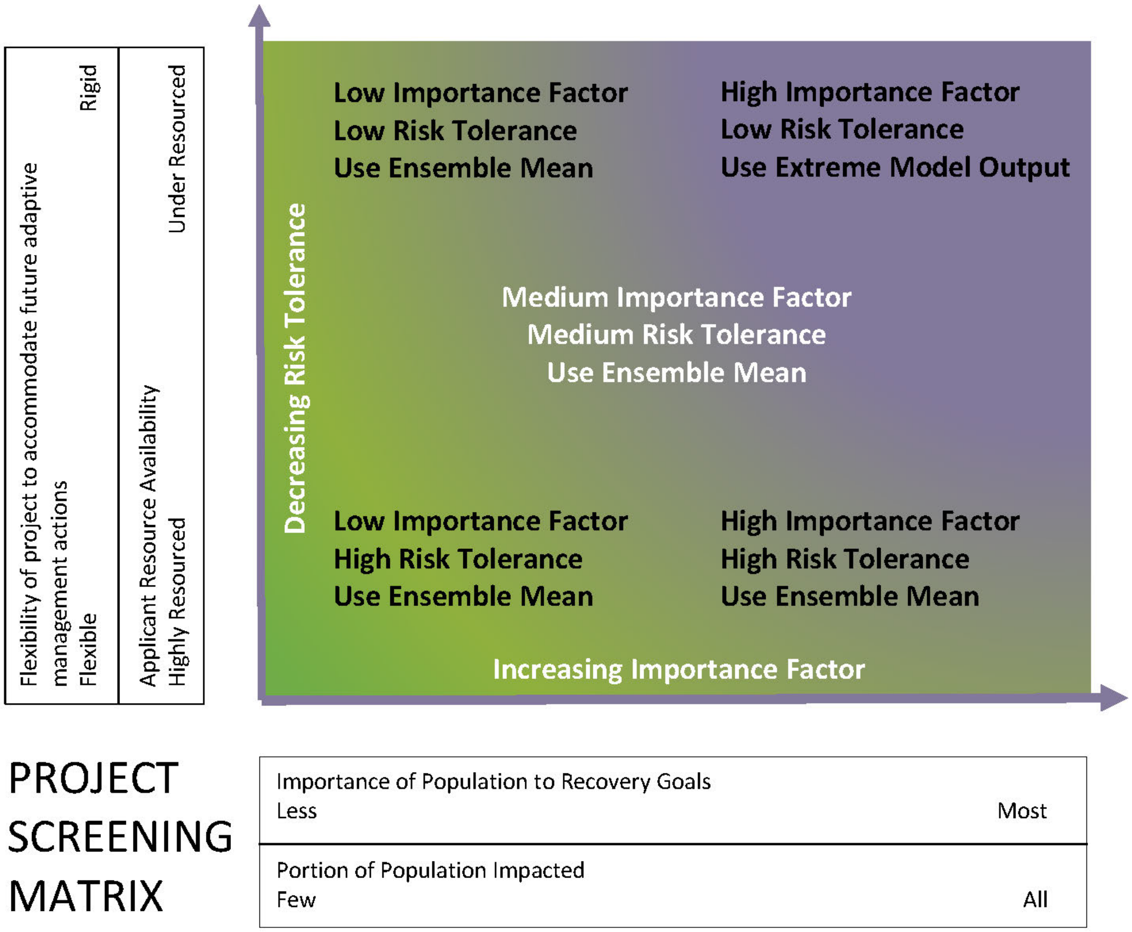
For unregulated rivers, climate change and future streamflow data are likely available, and the applicant should prepare estimates of future physical and environmental conditions using existing data sources. Section 6 provides data sources that are acceptable to NMFS as of 2022. Guidance for selecting climate projections data that are used to develop streamflow estimates is shown in Figure 6. This project screening matrix is a visual tool to assist applicants in determining which climate models would be best suited to use for their design analysis. The matrix was adapted from Figure 1 in Skidmore et al. (2011). For a proposed project, as the importance factor increases along the X-axis, NMFS will be looking for analyses being conducted using climate models with more extreme outputs to adopt a biologically conservative approach. Importance factors include the importance of the population being affected to overall (i.e., ESU) recovery goals or the proportion of the population being affected by the proposed project. Similarly, as the tolerance for risk associated with a proposed project decreases, NMFS will expect that climate models with more extreme outputs will be used. Risk tolerance decreases, for example, when there is no adaptive management plan in place for the proposed project to respond to for future changes or when the applicant is not well resourced in terms of its ability to fund needed studies. The use of an ensemble mean is acceptable to NMFS in many situations, whereas in some situations (Figure 6, upper right-hand quadrant) model extremes should be used and designers may work with NMFS to determine additional climate futures to analyze from the ensemble of the climate model. Use of the ensemble mean is intended to provide a practicable and accessible approach for the engineering practitioners conducting fish passage design who may not have extensive climate experience, and is a balance between adequate protection and reasonable design efforts.

While Figure 6 provides general guidance to applicants, it is important to recognize that maintaining life history diversity increases a population’s ability to persist under changing environmental conditions (Section 3.5). For example, this includes diversity in migration timing, the range in fish sizes within a juvenile age class, and the number of fish in different age classes (e.g., fry, 1-, and 2-year-old juveniles) from a single cohort. For example, Herbold et al. (2018) point out that California’s salmonids are at the southern limits of the individual species’ ranges and display a wide diversity of strategies to survive in California’s highly variable climate. However, increasing temperatures and decreasing snowpacks have produced harsher conditions than these salmon experienced historically. They conclude that the most likely way to promote salmon productivity and population persistence in California is to restore habitat diversity, reconnect migratory corridors to spawning and rearing habitats, and refocus management to replenish the genetic and phenotypic diversity. Therefore, NMFS will discuss population attributes with applicants to ensure that effects of the project on diversity are understood and minimized, even when the overall importance factor of a population is judged to be lower (Figure 6, X-axis).

In regulated river systems, less data is available (Section 2.3.6.1.2). In those river systems lacking analyses of future operations under climate change and with high importance factors, NMFS may require the applicant to perform a range of future operations modeling as a hedging and precautionary action to assess future hydrologic conditions at the project site.

Considerations for the selection and use of data are described in the following sections for project sites on unregulated and regulated rivers.

Figure 6
Project Screening Matrix



Note:
1. The project screening matrix is a visual tool aimed at assisting the project proponent in determining which statistics from an ensemble of climate models would be best suited to use for their design analysis (modified from Skidmore et al. 2011).
2, While this figure often points users to the ensemble mean, it is important to note that the ensemble mean may miss effects of extreme climate impacts. Proponents of higher risk projects should look at multiple models and consider more extreme conditions.
3. For additional information on the importance of populations to recovery goals and portion of population impacted see Section 3.

2.3.6.1.1 Estimate Future Hydrologic Conditions on Unregulated Rivers (Figure 5 Step 7)

Estimates of hydrologic change are available at the time of publication from the U.S. Department of Agriculture Western United States Flow Metrics web page[5], The Climate Toolbox (Climate Toolbox

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[5] U.S. Forest Service, Department of Agriculture, Western U.S. Flow Metrics web page: https://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml

2022), the U.W. Hydro Columbia River Climate Change website[6], and various modeling projects performed by the University of Washington Climate Impacts Group (CIG).[7] Discussions with NMFS staff should occur before selection of the preferred dataset for use in project design. General guidance for the choice of hydrologic data includes the following:

- Use hydrologic modeling results that use the RCP8.5 emissions scenario where available. If only earlier emissions scenarios are available (Climate Model Intercomparison Project [CMIP] 3; National Center for Atmospheric Research Staff 2016), use the highest emission scenario available. Section 3.4.1 compares the emission scenarios from CMIP3 and CMIP5. Results from CMIP6 are currently being downscaled. Consider using CMIP 6 in an analysis once the information is available for your project site.
- Use a climate timeframe (mid- or late-century) that fully includes the project lifespan.
- The most extensive hydrologic modeling datasets available use input from statistically downscaled climate datasets. Generally, the datasets have been developed using an ensemble (group) of 10 or more GCMs. The applicant should use the guidance shown in Figure 6 to select which output(s) among the range of futures should be used. In most cases, the ensemble mean should be used. To select the extreme (challenging) case of an ensemble, a typical approach is to use the 90th percentile range of estimates. This approach has been used by River Management Joint Operating Committee (RMJOC; RMJOC 2010, 2018) for climate scenarios. An alternate approach is to use the Climate Toolbox[8] or the USACE CHAT Tool[9] to view the range of the RCP8.5 ensemble for an extreme GCM for the risk pathway of concern if the system in question is available in the tool (See Sec 6.3.1 and 6.3.2). The method used to select the extreme case should be reviewed by NMFS.
- Most climate and hydrologic projections products available as of late 2021 use statistically downscaled climate datasets. If hydrologic projection datasets are available that were developed using publicly available and vetted dynamically downscaled data, consider using those data instead of or in addition to statistically downscaled climate datasets. Section 3.4.1 provides a discussion of the two downscaling approaches. If only a few dynamically downscaled model results are available, a good practice is to compare the dynamically downscaled model results to the ensemble mean of the statistically downscaled datasets and include the dynamically downscaled model results as part of the range of predictions being considered.
- Use bias-corrected model results rather than uncorrected model results, where available. Oftentimes, both raw- and bias-corrected results are available. Bias correction involves applying factors to model results to improve the representation of historical climate conditions.

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[6] U.W. Hydro Columbia River Climate Change website: https://www.hydro.washington.edu/CRCC/
[7] University of Washington Climate Impacts Group (CIG) website: https://cig.uw.edu/resources/data/
[8] https://climatetoolbox.org/tool/Future-Climate-Scatter
[9] https://climate.sec.usace.army.mil/chat/

- The available hydrologic modeling datasets may have differing time steps (i.e., daily or hourly). Note that results with average daily data will be adequate for estimating fish passage design flows (i.e., the design flows recommended in the guidance documents shown in Figure 1 for the project location, which are typically 5% and 95% for most areas of the WCR), but peak flows required for design of structures may require an hourly or smaller time step because instantaneous peak flows are typically much higher than average daily flows. If only daily flows are available, they will need to be adjusted (increased) to estimate instantaneous flows. The adjustment factor should be based upon comparing instantaneous peak flows to concurrent average daily flows from available streamflow gaging records (see project example in Section 2.5.1).
- Estimates of hydrologic change have been prepared by many agencies and universities using a process that starts with downscaling meteorological data from GCMs and preparing basin-scale hydrologic models that represent historical conditions. Descriptions of, and links to modeling products, are provided in Section 6. Errors in meteorological downscaling to the project's watershed and errors in hydrologic modeling can result in a wide range of results when models attempt to represent historical conditions. Where calibrated or bias-corrected models do not exist or do not appear to accurately represent historical conditions, it is recommended that applicants calculate the percent change in modeled future conditions to modeled historical conditions and apply that change to current hydrologic conditions obtained using methods described in Sections 2.2.2 and 2.2.3 (see project example in Section 2.5.1.8).
- The projected percent changes in streamflow may be much different than nearby and similar basins for no reason other than model setup, downscaling, and calibration of the hydrologic model. Review estimates of percent change predicted for nearby, similar basins to check whether the percent change predicted at the project site appears low (or high) compared to other basins. If large differences exist, the applicant should check on the percent change in nearby basins and consult with NMFS on whether to use one of the other basins or an average of them all.

2.3.6.1.2 Estimate Future Hydrologic Conditions on Regulated Rivers

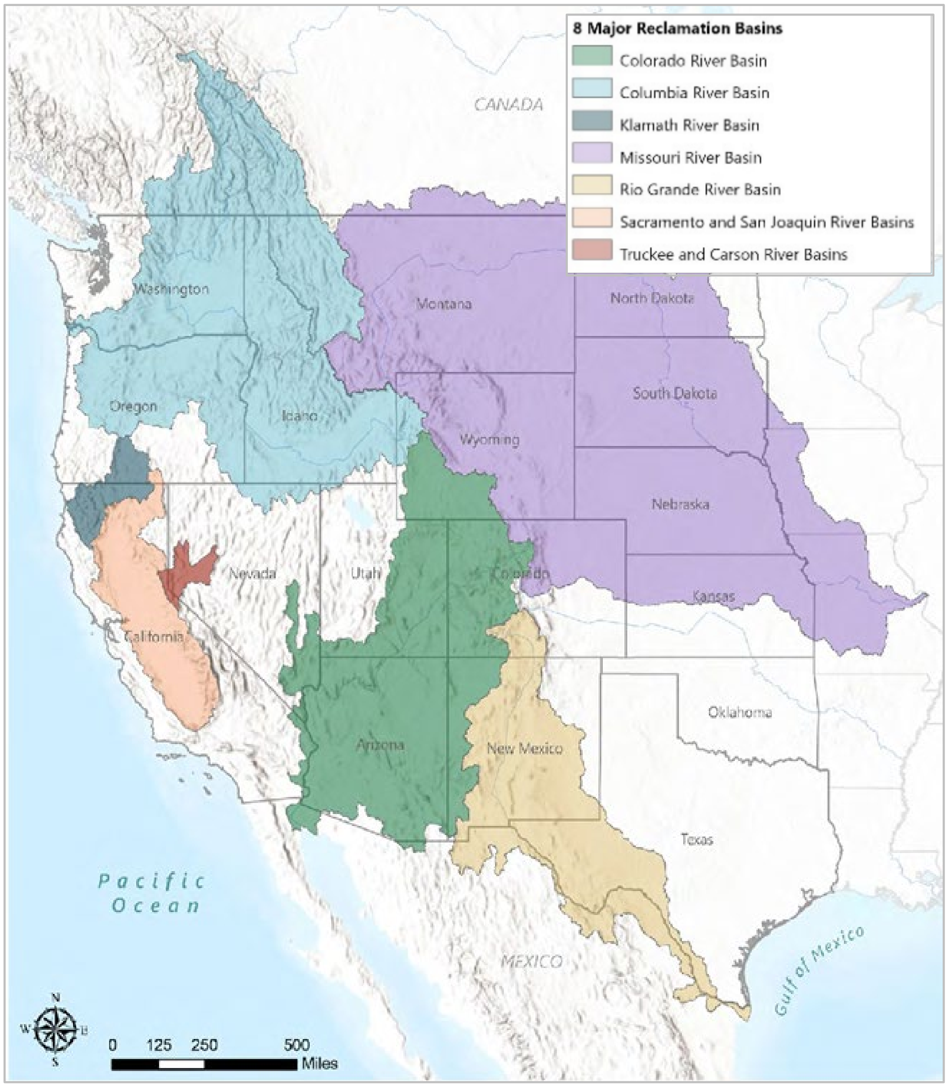
In some regulated river systems, estimates of hydrologic change under future climate conditions are available. For example, Reclamation, the U.S. Army Corps of Engineers (USACE), and Bonneville Power Administration (BPA) have performed reservoir and river operations modeling for the eight major river basins in the Western United States for the 2021 Secure Water Act Report (U.S. Bureau of Reclamation 2021a). The river basins include the following:

- Colorado River Basin;
- Columbia River Basin;
- Klamath River Basin;
- Missouri River Basin;
- Rio Grande Basin;

- Sacramento and San Joaquin Rivers (two basins);
- Truckee and Carson Rivers.

The river basins are shown in Figure 7, and of these, the WCR focuses on projects in the Columbia River, Klamath River, and Sacramento and San Joaquin Rivers basins (U.S. Bureau of Reclamation 2021a). Projections of streamflow were prepared for 43 locations within the eight basins and are described in the *West-Wide Climate and Hydrology Assessment* (U.S. Bureau of Reclamation 2021b). The results were summarized in the report, but the streamflow data do not appear to be available online and must be requested from Reclamation.

Figure 7
Regulated River Basins with Estimates of Climate Change



Note: Map acquired from Reclamation (U.S. Bureau of Reclamation 2021a).

2.3.6.2 Cases Where Climate Change Data and Models Are Not Adequate

At project sites where climate change modeling is not available or does not adequately represent operations of a regulated river system, the applicant may be required to perform additional analyses. The results of the initial step of the design process (Sections 2.3.1 to 2.3.4) will inform the requirement for modeling of projects with a longer lifespan, greater importance, and low risk tolerance; in these systems a more detailed modeling may be required. Figure 6 is provided to help inform the selection of the climate model data.

2.3.6.2.1 Estimate Future Hydrologic Conditions on Unregulated Rivers (Figure 5 Step 7)

For unregulated rivers or streams where climate modeling does not currently exist, the applicant should discuss the approach to estimating future hydrologic conditions with NMFS. For projects with high risk tolerance, simpler methodologies might be acceptable, such as applying percentage changes from nearby and similar basins to adjust hydrologic estimates. For projects with lower risk tolerance, the guidance for regulated river basins described in the Section 2.3.6.2.2 may be applied.

2.3.6.2.2 Estimate Future Hydrologic Conditions on Regulated Rivers (Figure 5 Step 7)

For larger projects on regulated river systems, use models and downscaled climate datasets. Most regulated rivers have existing reservoir and river operations models that can be modified with projected streamflow obtained through basin hydrologic modeling. The analyses may require the following:

- Prepare a basin hydrologic model using downscaled data from GCMs (dynamically downscaled data are preferred). Basin models may be Variable Infiltration Capacity (VIC), Distributed Hydrologic Soil Vegetation Model (DHSVM), Precipitation Runoff Modeling System (PRMS), or another widely accepted model. Use emissions scenario RCP8.5. Run an ensemble of models to estimate means and range of potential flows if possible. If not, select a GCM with higher changes so that the facility or action planned is conservative or precautionary (Kunreuther et al. 2014) regarding its protection of fish.
- Prepare reservoir and river operations models using RiverWare, HEC-ResSim, Water Evaluation and Planning, or other widely accepted models using output from the basin hydrologic model.
- Prepare stream temperature models using downscaled temperature data incorporating rivers and reservoirs, such as CE-QUAL-W2, HEC-RAS, or other widely accepted models.
- Analyses should follow generally accepted procedures for model assembly and calibration and produce results within acceptable error limits.

The output from basin hydrologic, reservoir, and river operations models should be used in hydraulic, water quality, and sediment transport analyses of streams and fish passage facilities.

2.3.7 Apply Projected Changes in Environmental Conditions to Design Variables Identified in Climate Results to Risk Pathways (Figure 5 Step 8)

Relate physical environmental changes to biological and facility risks (Section 2.4), an example of which is provided in Section 2.5.3 for stream crossings.

2.3.8 Complete Project Design (Figure 5 Step 9)

After conferring with NMFS, incorporate estimates of percent change in future environmental conditions into the design process and complete the project design as appropriate for the project location following the guidance in the WCR design documents shown in Figure 1. The project design report should include details demonstrating how climate resiliency was incorporated into the design based on the guidance in this document.

2.4 Climate Risk Pathways

Tables 1 to 10 are a series of look-up tables for each project element (e.g., fishways, auxiliary water supply (AWS), and bypass screens) that describe the risks associated with different climate change factors and potential corrective actions to address the risks. Actions to consider are provided for each risk identified for project elements and should be taken into consideration and incorporated into both the short-term (less than 10 years) and long-term (greater than 10 years) project design as practicable.

Table 1
Fish Element Risk Pathways
Element: Fish Ladders

Wet/Dry Periods		Streamflows			Water Temperature	Wildfires	
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**	**Runoff Timing Shift**	**Increase**	**Effects**	**Sediment and Debris**
Volitional Passage							
RISK: The biggest risk to volitional passage from wet extremes is structure protection, both from increased debris clogging structures and washing out of facilities. ACTIONS TO CONSIDER: Use a higher design flow. Increase maintenance checks after high flow events. Enhance debris collection and removal facilities.	RISK: Volitional passage may not be possible in stream reaches having very low flow rates. ACTIONS TO CONSIDER: Transporting of juveniles and adults around these reaches may be required if natural flows cannot be augmented.	RISK: Volitional passage at dam may be temporarily delayed by peak flow events. ACTIONS TO CONSIDER: Minimize turbulence and maximize attraction flows at fishway entrances. Modify spill patterns to enhance attraction and to not obscure fishway entrances.	RISK: Volitional passage may not be possible in stream reaches having very low flow rates. ACTIONS TO CONSIDER: Transporting of juveniles and adults around these reaches may be required if natural flows cannot be augmented with sufficient cold water.	RISK: Volitional passage dates may shift with runoff timing. Presumably the shift would be earlier, which could result in misalignment between runoff and migration timing (e.g., spring migrants moving upstream). Also, allowable maintenance periods may shift or shrink with changes in run timing (Section 3.5). ACTIONS TO CONSIDER: Complete winter maintenance earlier to ensure fishways are operational during earlier runoff and migration.	RISK: Excessively warm water in streams and reservoirs can become a barrier to fish passage. Volitional passage may not be possible in stream reaches with water temperatures that exceed certain critical temperatures. ACTIONS TO CONSIDER: Transporting of juveniles and adults around these reaches may be required if sufficient cold-water flows cannot be provided.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance. [1]	RISK: Increased peak flows and floods may increase sediment and debris movement, occlude fishway entrances, and affect volitional passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance. [1]
Fishway Entrances							
RISK: Excessively high flows passing over dams can hydraulically obscure fishway entrances. ACTIONS TO CONSIDER: Existing dams may need to be modified to ensure entrances are effective during high flows. Ensure that new facilities are designed to accommodate predicted high flows.	RISK: Reduced river stage may create excessively large jump height for fish entering the fishway. ACTIONS TO CONSIDER: Existing fishway entrances may need to be modified (lowered inverts) to accommodate lowered tailrace water levels. Ensure that new entrances are designed to accommodate future low tailrace river stages.	RISK: Excessively high flows passing over dams can hydraulically obscure fishway entrances. ACTIONS TO CONSIDER: Existing dams may need to be modified to ensure entrances are effective during high flows. Ensure that new facilities are designed to accommodate predicted high flows.	RISK: Reduced river stage may create excessively large jump height for fish entering fishway. ACTIONS TO CONSIDER: Existing fishway entrances may need to be modified (lowered inverts) to accommodate lowered tailrace water levels. Ensure that new entrances are designed to accommodate future low tailrace river stages.	RISK: Volitional passage dates may shift with runoff timing. Presumably, the shift would be earlier, which could result in misalignment between runoff and migration timing (e.g., spring migrants moving upstream). Also, allowable maintenance periods may shift or shrink with changes in run timing (Section 3.5). ACTIONS TO CONSIDER: Complete winter maintenance earlier to ensure fishways are operational during earlier runoff and migration.	RISK: Fish passage can be blocked if the fishway entrances discharge warm water. ACTIONS TO CONSIDER: Explore methods for introducing cold water into the fishway pools and fishway entrances. Warm water may require design changes to reduce the jump height into the fishway entrances and increase entrance attraction flow rates (See Auxiliary Water Supply).	No additional risks due to climate change effects are identified at this time.	RISK: Increased peak flows and floods may increase sediment and debris movement, occlude fishway entrances, and affect volitional passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.

Table 1
Fish Element Risk Pathways
Element: Fish Ladders

Wet/Dry Periods		Streamflows		Runoff Timing Shift	Water Temperature	Wildfires	Sediment and Debris
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**		**Increase**	**Effects**	
Fishway Exits and AWS Intakes							
RISK: Extended wet periods and extreme high flows will increase debris load on fish ladder exit trash racks and auxiliary water intakes. ACTIONS TO CONSIDER: Ensure that fishway exits are equipped with sufficient equipment to remove trash from exit trash racks.	RISK: Low forebay water levels may impact ability of passing forebay water into the fishway. ACTIONS TO CONSIDER: For new facilities and for some existing fishways, consider installing exit openings at multiple elevations in the forebay.	RISK: Extended wet periods and extreme high flows will increase debris load on exit trash racks. ACTIONS TO CONSIDER: Ensure that fishway exit and dam have sufficient freeboard and spill routes to ensure fishway is not flooded during extreme high flows.	RISK: Low forebay water levels may impact ability of passing forebay water to flow into the fishway. ACTIONS TO CONSIDER: For new facilities and for some existing fishways, consider installing exit openings at multiple elevations in the forebay.	No additional risks due to climate change effects are identified at this time.	RISK: Fish passage can be blocked if the exits intake warm water. ACTIONS TO CONSIDER: Explore methods for introducing cold water into the fishway pools and fishway exits.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces flow through the fishway pools and can block fish within the fishway and at the fishway entrances. This can also result in increased opportunities for predation. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.	RISK: Excessive debris caught on fishway exit trash racks can increase head loss, reduce fishway flow, and injure fish passing through the trash rack and block fish in the ladder and at the fishway entrances. This can also result in increased opportunities for predation. ACTIONS TO CONSIDER: Ensure that fishway exits are equipped with sufficient equipment used to prevent blockage of exit trash racks by trash and debris. Installing automatic trash rakes may be an option.
Fishway Ladder Pool Design							
No additional risks due to climate change effects are identified at this time.	RISK: Extreme dry periods may result in limited in-ladder water supply and as a result, changes in pool hydraulic conditions. ACTIONS TO CONSIDER: Modify pool design to operate safely at lower flow rates. Install weirs that are adjustable to account for uncertainty of future water surface elevations.	RISK: Fishway pools and other fish-conveying channels can be overtopped in extreme floods. Extended wet periods and extreme high flows will increase debris load in pools. ACTIONS TO CONSIDER: Ensure that fishway pools have sufficient freeboard to ensure pools are not flooded during extreme high flows. Install weirs that are adjustable to account for uncertainty of future water surface elevations.	RISK: Low flows may result in limited in-ladder water supply and as a result, changes in pool hydraulic conditions. ACTIONS TO CONSIDER: Modify pool design to operate safely at lower flow rates. Install weirs that are adjustable to account for uncertainty of future water surface elevations.	No additional risks due to climate change effects are identified at this time.	RISK: Increased pool water temperatures may lead to reduced fish energetics and dissolved oxygen. Also, increased air temperatures may lead to unacceptable pool temperature increases along the length of the fishway, especially in long fishways with many pools. ACTIONS TO CONSIDER: Change designs of pool-pool jump height, resting pool volumes, and energy dissipation factor, and provide shading of pools.	No additional risks due to climate change effects are identified at this time.	RISK: Extended wet periods and extreme high flows will increase debris load in pools and require more frequent inspection of orifices and removal of debris. ACTIONS TO CONSIDER: Increase frequency of inspections of pools and trash racks at fishway exit. Install automated trash rake cleaning system at fishway exit.

Table 1
Fish Element Risk Pathways
Element: Fish Ladders

Wet/Dry Periods		Streamflows			Water Temperature	Wildfires	
Wet Extremes	Dry Extremes	Increased Max Flow	Decreased Min Flow	Runoff Timing Shift	Increase	Effects	Sediment and Debris
Auxiliary Water Supply							
RISK: Extended wet periods and extreme high flows will increase debris load on exit trash racks and auxiliary water intakes. Increased high flows may also intensify false attraction over a spillway. ACTIONS TO CONSIDER: Ensure that fishway exits are equipped with sufficient equipment to remove trash from exit trash racks. Ensure that competing flows (such as spillway flows and flows exiting hydroelectric turbines) are configured to maximize attraction to the fishway entrances.	RISK: Extreme dry periods and low flow periods could result in reducing the effectiveness (for fish attraction) of the AWS. ACTIONS TO CONSIDER: Ensure that low flow channels in the tailrace convey fish to the vicinity of the fishway entrances.	RISK: Higher maximum flows may require the increase in auxiliary flows to ensure fish maintain ability to find fishway entrance at these high flows. ACTIONS TO CONSIDER: Design AWS intake, conveyance, and outlet structures to be able to pass additional flow in future if necessary. Ensure that competing flows (such as spillway flows and flows exiting hydroelectric turbines) are configured to maximize attraction to the fishway entrances.	RISK: Extreme dry periods and low flow periods could result in reducing the effectiveness (for fish attraction) of the AWS. ACTIONS TO CONSIDER: Ensure that low flow channels in the tailrace convey fish to the vicinity of the fishway entrances. Ensure that competing flows (such as hydro flows) are configured to maximize attraction to the fishway entrances.	No additional risks due to climate change effects are identified at this time.	RISK: AWS systems can provide excessive warm water at fishway entrances and exits, possibly resulting in rejection issues at temperature transitions such as the introduction of auxiliary water. ACTIONS TO CONSIDER: Investigate providing cooler water from below the thermocline in the forebay, as shown in Figures 14 and 15, or from or near turbine draft tube outlets in the tailrace.	No additional risks due to climate change effects are identified at this time.	RISK: Increased debris flows may cause occlusion of AWS intake structures. ACTIONS TO CONSIDER: For tributary-scale projects, design the entrance area to accommodate debris removal equipment. This could include platforms and work pads to support backhoes and loaders to facilitate removal of excess gravel deposits.

Note:
1. Disturbance events like fires, high flows, or debris flows can reset stream systems and the complexity of these systems. Where sediment or woody debris removal is being considered, maintaining the delivery of the debris to locations downstream from the diversion should be discussed with NMFS and incorporated into the actions to support maintenance of fish habitat-forming processing below the diversion.

Table 2
Fish Element Risk Pathways
Element: Water Diversions

Wet/Dry Periods		Streamflows			Water Temperature	Wildfires	
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**	**Runoff Timing Shift**	**Increase**	**Effects**	**Sediment and Debris**
Water Rights and Ability to Divert Water							
RISK: Wet extremes and increased maximum flows increase the risk of overtopping and damaging the diversion facilities. ACTIONS TO CONSIDER: Floodproof the diversion through such actions as raising walls and raising electrical equipment.	RISK: For gravity diversions, dry periods may jeopardize ability to divert water at necessary head. ACTIONS TO CONSIDER: Investigate alternatives such as moving the headgate upstream, pumping, and combining diversions on the same stream system.	RISK: Increased channel-forming flows may widen channel or incise channel, both resulting in lowered water surface elevation, potentially jeopardizing ability to divert water at necessary head. Wet extremes and increased maximum flows increase the risk of overtopping and damaging the diversion facilities. ACTIONS TO CONSIDER: Use fluvial geomorphology techniques to modify the channel to reduce deposition at the point of diversion, maintain continuity of sediment discharge to downstream reaches during high flows, while maintaining bank stability and fish passage. Floodproof the diversion through such actions as raising walls and raising electrical equipment.	RISK: For gravity diversions, dry periods may jeopardize ability to divert water at necessary head. ACTIONS TO CONSIDER: Investigate moving the headgate upstream to avoid the need to build a push-up dam or to raise existing barriers. Consider reducing diversion flow rate. Also, consider consolidating multiple points of diversion into one modern headgate with sufficient head to serve all users. Pipe all diverted water to the points of use to minimize seepage and evaporation losses.	RISK: Water rights are often tied to calendar dates. Irrigators may not be able to divert water if the runoff period has shifted outside of allowed diversion dates. Also, with climate change, the optimum time for irrigating crops may not align with runoff timing. Volitional passage dates may shift with runoff timing. Presumably, the shift would be earlier which could result in misalignment between runoff and migration timing. Also, allowable maintenance periods may shift or shrink with changes in run timing. ACTIONS TO CONSIDER: Complete winter maintenance earlier to ensure fishways are operational during earlier runoff and migration. Design facilities to protect screens from debris and sediment loading.	No additional risks for water rights due to climate change effects are identified at this time.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.[1]	RISK: Increased peak flows and floods may increase sediment and debris movement, occlude headgates, and affect fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance. [1]

Table 2
Fish Element Risk Pathways
Element: Water Diversions

Wet/Dry Periods		Streamflows			Water Temperature	Wildfires	
Wet Extremes	Dry Extremes	Increased Max Flow	Decreased Min Flow	Runoff Timing Shift	Increase	Effects	Sediment and Debris
Channel Stability							
RISK: High flows in gravel bed rivers can move the main channel away from the headgate. In such cases, the owners of the diversions often desire to perform emergency modifications of the river channel using excavators to build push-up dams to redirect water to the headgate. This activity degrades fish habitat, fish passage, and long-term channel stability. ACTIONS TO CONSIDER: Use fluvial geomorphology techniques to modify the channel to reduce deposition at the point of diversion and maintain continuity of sediment discharge during high flows, while maintaining bank stability and fish passage.	No additional risks due to climate change effects are identified at this time.	RISK: High flows in gravel bed rivers can move the main channel away from the headgate. In such cases, the owners of the diversions often desire to perform emergency modifications of the river channel using excavators to redirect water to the headgate. This activity often degrades fish habitat, fish passage, and long-term channel stability. ACTIONS TO CONSIDER: Use fluvial geomorphology techniques to modify the channel to reduce deposition at the point of diversion and maintain continuity of sediment discharge to downstream reaches during high flows, while maintaining bank stability and fish passage.	RISK: Extreme low flows may create dry river channel between thalweg and headgate. This can create the need for the irrigator to use excavators to dig a channel from the thalweg to the headgate. This activity degrades fish habitat, fish passage, and long-term channel stability. If diversions are changed to wells and pumping when surface flow is not available, this may result in subsidence in the area and cause canal instability. ACTIONS TO CONSIDER: Use fluvial geomorphology techniques to modify the channel to maintain the thalweg at the point of diversion and maintain continuity of sediment to downstream reaches discharge during high flows, while maintaining bank stability and fish passage. Design fishways to account for subsidence in areas where overdrafting of the aquifer occurs.	No additional risks due to climate change effects are identified at this time.	RISK: Diversion dams can increase the top width of the channel at the point of diversion. This can exacerbate warm water temperatures by increasing the solar heat input. ACTIONS TO CONSIDER: Use fluvial geomorphology techniques to modify the channel to maintain dynamic equilibrium (continuity of sediment discharge) during high flows, while maintaining bank stability and fish passage.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces flow capacity, can lead to local bed and bank scour, and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance. [1]	RISK: Increased max flows may mobilize sediment and debris at higher levels than currently occurs, risking blockage of water diversion, head gate, trash racks, bypass outfall, and fishway. Sediment deposits may also widen a river channel and decrease depth, leading to increased warming of water through solar inputs. ACTIONS TO CONSIDER: Use fluvial geomorphology techniques to modify the channel to maintain dynamic equilibrium (continuity of sediment discharge) during high flows, while maintaining bank stability and fish passage. [1]

Table 2
Fish Element Risk Pathways
Element: Water Diversions

Wet/Dry Periods		**Streamflows**			**Water Temperature**	**Wildfires**	
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**	**Runoff Timing Shift**	**Increase**	**Effects**	**Sediment and Debris**
Predation							
No additional risks due to climate change effects are identified at this time.	RISK: Low velocities and shallow depths can increase interactions between anadromous fish species and predator birds, predator fish species, and mammals, including humans. ACTIONS TO CONSIDER: Trap and transport juveniles and adults around dry and warm river reaches.	No additional risks due to climate change effects are identified at this time.	RISK: Low velocities and shallow depths can increase interactions between anadromous fish species and predator birds, predator fish species, and mammals, including humans. ACTIONS TO CONSIDER: Trap and transport juveniles and adults around dry and warm river reaches. Provide additional overhead cover to protect against avian predation. Design headgates and other diversion components with the flexibility to allow juveniles and adults to egress back upstream via the point of diversion.	No additional risks due to climate change effects are identified at this time.	RISK: Warm water and shallow depths can increase interactions between anadromous fish species and predator fish such as bass, northern pikeminnow, northern pike, and walleye. Through time, spatial distributions of native and invasive predators may extend further upstream in watersheds and into salmonid rearing habitats. ACTIONS TO CONSIDER: Transporting of juveniles and adults around these reaches may be required if sufficient cold-water flow cannot be provided.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.
Hyporheic Flow							
No additional risks due to climate change effects are identified at this time.	RISK: The foundations of hardscape diversion structures can cut off hyporheic flow. ACTIONS TO CONSIDER: Hyporheic flow is critical for fish habitat, migration, rearing and cold-water refugia. Ensure that the design of diversion structure does not interrupt or divert hyporheic flow.	No additional risks due to climate change effects are identified at this time.	RISK: The foundations of hardscape diversion structures can cut off hyporheic flow. ACTIONS TO CONSIDER: Hyporheic flow is critical for fish habitat, migration, rearing and cold-water refugia. Ensure that the design of diversion structure does not interrupt or divert hyporheic flow.	RISK: Earlier runoff may result in reduced hyporheic flow during summer. ACTIONS TO CONSIDER: Augment instream flows as needed to maintain hyporheic flow. Monitor groundwater pumping and infiltration galleries to ensure they are not extracting hyporheic flow. Ensure diversion dams are not blocking and diverting hyporheic flow.	RISK: Hyporheic flow may be only source of cold water during periods of prolonged low flows with warm surface water. ACTIONS TO CONSIDER: Hyporheic flow is critical for fish habitat, migration, rearing and cold-water refugia. Design should ensure the conservation of cold hyporheic flows.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.
On-Channel vs. Off-Channel Screens							
For migrating anadromous fish species, on-channel screens provide significantly greater protection when compared against off-channel screens. When designing new or upgraded water diversions, the fish safety benefits of on-channel screens should be given high priority.							

Note:

1. Disturbance events like fires, high flows, or debris flows can reset stream systems and the complexity of these systems. Where sediment or woody debris removal is being considered, maintaining the delivery of the debris to locations downstream from the diversion should be discussed with NMFS and incorporated into the actions to support maintenance of fish habitat-forming processing below the diversion.

Table 3
Fish Element Risk Pathways
Element: Fish Screens in River Environments (for Screen Bypasses, see Table 4)

Wet/Dry Periods		Streamflows			Water Temperature	Wildfires	
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**	**Runoff Timing Shift**	**Increase**	**Effects**	**Sediment and Debris**
Screen Design							
RISK: Increased channel-forming flows may widen or incise channel, both resulting in lowered water surface elevation, potentially reducing screen area, particularly for instream installations. ACTIONS TO CONSIDER: Increase screen surface area, particularly at lower elevations, to maintain criteria approach velocity at lower water surface elevations.	RISK: Dry extremes and decreased minimum flows can result in lowered water surface elevation, potentially reducing screen area, particularly for instream installations. ACTIONS TO CONSIDER: Increase screen surface area, particularly at lower elevations, to maintain criteria approach velocity at lower water surface elevations.	RISK: Increased channel-forming flows may widen or incise channel, both resulting in lowered water surface elevation, potentially reducing screen area, particularly for instream installations. ACTIONS TO CONSIDER: Increase screen surface area, particularly at lower elevations, to maintain criteria approach velocity at lower water surface elevations. Coordinate maintenance timing with in-water work windows and consider updated sediment management options including sluicing, training wells, etc.	RISK: Dry extremes and decreased minimum flows can result in lowered water surface elevation, potentially reducing screen area, particularly for instream installations. ACTIONS TO CONSIDER: Increase screen surface area, particularly at lower elevations, to maintain criteria approach velocity at lower water surface elevations.	RISK: Volitional passage dates may shift with runoff timing. Presumably, the shift would be earlier which could result in misalignment between runoff and migration timing. Also, allowable maintenance periods may shift or shrink with changes in run timing (Section 3.5). Earlier freshets could lead to the transport of smaller, weaker-swimming salmonid fry to the screen site. ACTIONS TO CONSIDER: Complete winter maintenance earlier to ensure fishways are operational during earlier runoff and migration. Re-evaluation of screen velocities, mesh openings, and allowable delay times may be required.	RISK: Increased water temperatures may increase growth of biofouling species, possibly occluding screens or overwhelming cleaning systems. Earlier runoff and increased water temperatures may result in earlier emergence from gravels, increased growth of parr, and shifts in smolt migration timing. ACTIONS TO CONSIDER: Improve the cleaning capability of screen cleaning system, if necessary. Add a remote screen head loss monitoring, control, and telemetry system.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.[1]	RISK: Increased channel-forming flows may widen channel or incise channel, both resulting in lowered water surface elevation, potentially reducing screen area, particularly for instream installations. Increased risk of plugging screens and increasing through-screen velocities and impingement. ACTIONS TO CONSIDER: Increase screen surface area, particularly at lower elevations to maintain criteria approach velocity at lower water surface elevations.[1]
Screen Cleaning							
RISK: Increased debris load on trash racks, screens, screen cleaners, and bypasses. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.	No additional risks due to climate change effects are identified at this time.	RISK: Increased debris load on trash racks, screens, screen cleaners, and bypasses. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.	No additional risks due to climate change effects are identified at this time.	RISK: Juvenile outmigration dates may shift with runoff timing. Presumably the shift would be earlier. Allowable maintenance periods may shift or shrink with changes in run timing. ACTIONS TO CONSIDER: Complete winter maintenance earlier to ensure screens are operational during earlier runoff and migration.	RISK: Increased water temperatures may reduce swimming performance of weaker species, possibly leading to requirement to reduce allowable approach velocity. Increased water temperatures may increase algae growth, requiring more frequent cleaning cycles and increased screen maintenance. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.[1]	RISK: Increased sedimentation and bedload movement may interfere with lower end of certain types of cleaning systems. Increased risk of plugging screens and increasing through-screen velocities and impingement. ACTIONS TO CONSIDER: Install equipment to remove the sediment that deposits at the base of the screen cleaning hardware. Strategies could include installing front end loaders to access the accumulated sediment, and hydraulic dredging systems.[1]

Table 3
Fish Element Risk Pathways
Element: Fish Screens in River Environments (for Screen Bypasses, see Table 4)

Wet/Dry Periods		Streamflows		Runoff Timing Shift	Water Temperature	Wildfires	Sediment and Debris
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**		**Increase**	**Effects**	
Predation							
No additional risks due to climate change effects are identified at this time.	RISK: Low velocities and shallow depths can increase interactions between anadromous fish species and predator birds, predator fish species, and mammals, including humans. ACTIONS TO CONSIDER: Replace off-channel screens with on-channel screens.	No additional risks due to climate change effects are identified at this time.	RISK: Low velocities and shallow depths can increase interactions between anadromous fish species and predator birds, predator fish species, and mammals, including humans. ACTIONS TO CONSIDER: Replace off-channel screens with on-channel screens.	No additional risks due to climate change effects are identified at this time.	RISK: Increased water temperatures cause increased bioenergetic requirements and food consumption by predators, and high temperatures impact swimming performance (predator avoidance) of juvenile salmon. ACTIONS TO CONSIDER: Maximize hydraulic efficiency and design screen channels to preclude low velocity areas where predator fish and juvenile anadromous species can hold. Provide shade in locations where juveniles may tend to concentrate.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.
Structural							
No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	RISK: Increased maximum flows may cause flooding of the diversion structure, diversion canal, and screens. ACTIONS TO CONSIDER: Freeboard of diverting structure, diversion canal, and screen structure may need to be raised. Design main screen structures to withstand fully occluded screens and consider relief panels if necessary.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	RISK: Effects of wildfires are increased sediment and wood accumulation. Debris accumulation reduces flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring and maintenance prescribed after in-watershed fire events. Re-examine structural analysis of trash racks. There may be a need for enhanced trash rack cleaning equipment.	No additional risks due to climate change effects are identified at this time.

Table 3
Fish Element Risk Pathways
Element: Fish Screens in River Environments (for Screen Bypasses, see Table 4)

Wet/Dry Periods		Streamflows			Water Temperature	Wildfires	
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**	**Runoff Timing Shift**	**Increase**	**Effects**	**Sediment and Debris**
Irrigation Withdrawals							
No additional risks due to climate change effects are identified at this time.	RISK: Drier than normal precipitation regimes may necessitate increased irrigation flows over historical needs. This may be more pronounced where a water diverter has historically diverted less than allowed by their water right. ACTIONS TO CONSIDER: Convey all diverted water in pipelines rather than in open channel ditches and canals. This would significantly reduce evaporation losses and canal seepage losses. This increase in efficiency could provide more water at the irrigator's point of delivery while remaining within the existing water right.	No additional risks due to climate change effects are identified at this time.	RISK: Irrigation withdrawals will further exacerbate effects of decreased minimum flows. ACTIONS TO CONSIDER: Convey all diverted water in pipelines rather than in open channel ditches and canals. This would significantly reduce evaporation losses and canal seepage losses. This could both satisfy the irrigators' water supply requirements and likely leave more water in the river.	RISK: Water rights may not permit diversion of water during shifted need periods.	RISK: Irrigation withdrawals will further exacerbate effects of decreased minimum flows. ACTIONS TO CONSIDER: Convey all diverted water in pipelines rather than in open channel ditches and canals. This would significantly reduce evaporation losses and canal seepage losses. This could both satisfy the irrigators' water supply requirements and would likely leave more water in the river.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.	RISK: Increased peak flows and floods may increase sediment and debris movement, occlude screens and bypasses, and affect fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.

Note:

1. Disturbance events like fires, high flows, or debris flows can reset stream systems and the complexity of these systems. Where sediment or woody debris removal is being considered, maintaining the delivery of the debris to locations downstream from the diversion should be discussed with NMFS and incorporated into the actions to support maintenance of fish habitat-forming processing below the diversion.

Table 4
Fish Element Risk Pathways
Element: Screen Bypass Systems

Wet/Dry Periods		Streamflows		Runoff Timing Shift	Water Temperature	Wildfires	Sediment and Debris
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**		**Increase**	**Effects**	
Transportation Systems[1]							
No additional risks due to climate change effects are identified at this time.	RISK: In some cases, water diversions can remove most or all of the flow from the stream. The flow rate in the bypass can be insufficient to pass fish downstream of the bypass discharge point. ACTIONS TO CONSIDER: Transportation of juveniles and adults may be required if the stream has insufficient instream flow downstream of the screen bypass discharge point. Possibility of temporarily closing bypass during non-fish-migration periods to reduce potential for resident fish to be bypassed downstream into a dewater reach. Design headgates and other diversion components with the flexibility to allow juveniles and adults to egress back upstream.	No additional risks due to climate change effects are identified at this time.	RISK: In some cases, water diversions can remove most or all of the flow from the stream. The flow rate in the bypass can be insufficient to pass fish downstream of the bypass discharge point. ACTIONS TO CONSIDER: Transportation of juveniles and adults may be required if the stream has insufficient instream flow downstream of the screen bypass discharge point. Possibility of temporarily closing bypass during non-fish-migration periods to reduce potential for resident fish to be bypassed downstream into a dewater reach. Design headgates and other diversion components with the flexibility to allow juveniles and adults to egress back upstream.	RISK: Juvenile outmigration dates may shift with runoff timing. Presumably the shift would be earlier. Allowable maintenance periods may shift or shrink with changes in run timing. ACTIONS TO CONSIDER: Complete winter maintenance earlier to ensure screens are operational during earlier runoff and migration.	RISK: In some cases, water diversions can remove most or all of the flow from the stream. The water temperature in the bypass and in the river below the bypass can be too warm to safely pass fish downstream of the bypass discharge point. ACTIONS TO CONSIDER: Transportation of juveniles and adults may be required if water is too warm downstream of the screen bypass discharge point.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.	RISK: Increased peak flows and floods may increase sediment and debris movement, occlude fishway entrances, and affect volitional passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.
Channel Stability							
RISK: High flows in gravel bed rivers can destroy the outfall and move the main channel away from the bypass outfall discharge location. ACTIONS TO CONSIDER: Use fluvial geomorphology design techniques to modify the channel to maintain dynamic equilibrium (continuity of sediment discharge) during high flows, while maintaining bank stability and fish passage.	No additional risks due to climate change effects are identified at this time.	RISK: High flows in gravel bed rivers can destroy the outfall and move the main channel away from the bypass outfall discharge location. ACTIONS TO CONSIDER: Use fluvial geomorphology design techniques to modify the channel to maintain dynamic equilibrium (continuity of sediment discharge) during high flows, while maintaining bank stability and fish passage.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.	RISK: Increased max flows may mobilize sediment and debris at higher levels than currently occurs, risking blockage of bypass outfall. ACTIONS TO CONSIDER: Use fluvial geomorphology design techniques to modify the channel to maintain dynamic equilibrium (continuity of sediment discharge) during high flows, while maintaining bank stability and fish passage.

Table 4
Fish Element Risk Pathways
Element: Screen Bypass Systems

Wet/Dry Periods		Streamflows			Water Temperature	Wildfires	
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**	**Runoff Timing Shift**	**Increase**	**Effects**	**Sediment and Debris**
Bypass Flow Rates							
No additional risks due to climate change effects are identified at this time.	RISK: In some cases, water diversions can remove most or all of the flow from the stream. The flow rate in the bypass can be insufficient to pass fish downstream of the bypass discharge point. ACTIONS TO CONSIDER: Transportation of juveniles and adults may be required if the stream has insufficient instream flow downstream of the screen bypass discharge point. Also consider moving the fish screens to an on-channel location, thereby obviating the need for a bypass system. Possibility of temporarily closing bypass during non-fish-migration periods to reduce potential for resident fish to be bypassed downstream into a dewater reach. Design headgates and other diversion components with the flexibility to allow juveniles and adults to egress back upstream.	No additional risks due to climate change effects are identified at this time.	RISK: Decreased minimum flow may result in less flow available for the bypass system. Decreased minimum flow may lower water surface elevation at stream outfall, resulting in excessive impact velocities and insufficient flow for fish passage. ACTIONS TO CONSIDER: Transportation of juveniles may be required if the stream has insufficient instream flow at or downstream of the bypass outfall. Also consider moving the fish screens to an on-channel location, thereby obviating the need for a bypass system. Possibility of temporarily closing bypass during non-fish-migration periods to reduce potential for resident fish to be bypassed downstream into a dewater reach. Design headgates and other diversion components with the flexibility to allow juveniles and adults to egress back upstream.	No additional risks due to climate change effects are identified at this time.	RISK: In some cases, water diversions can remove most or all of the flow from the stream. The flow rate in the bypass can be insufficient to pass fish downstream of the bypass discharge point. ACTIONS TO CONSIDER: Transportation of juveniles and adults may be required if the stream has insufficient instream flow downstream of the screen bypass discharge point.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.	RISK: Increased peak flows and floods may increase sediment and debris movement and occlude bypass entrances and bypass outfall structures. ACTIONS TO CONSIDER: For tributary-scale projects, design the bypass entrance area and outfall site to accommodate debris removal equipment.

Table 4
Fish Element Risk Pathways
Element: Screen Bypass Systems

Wet/Dry Periods		Streamflows			Water Temperature	Wildfires	
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**	**Runoff Timing Shift**	**Increase**	**Effects**	**Sediment and Debris**
Predation							
No additional risks due to climate change effects are identified at this time.	RISK: Low velocities and shallow depths can increase interactions between anadromous fish species and predator birds, predator fish species, and mammals, including humans. ACTIONS TO CONSIDER: Transportation of juveniles may be required if the stream has insufficient instream flow or warm temperatures at or downstream of the bypass outfall. Also consider moving the fish screens to an on-channel location, thereby obviating the need for a bypass system. Screen forebays must be carefully designed to eliminate inefficient flow zones that promote holding behavior.	No additional risks due to climate change effects are identified at this time.	RISK: Low velocities and shallow depths can increase interactions between anadromous fish species and predator birds, predator fish species, and mammals, including humans. ACTIONS TO CONSIDER: Transportation of juveniles may be required if the stream has insufficient instream flow or warm temperatures at or downstream of the bypass outfall. Also consider moving the fish screens to an on-channel location, thereby obviating the need for a bypass system. Screen forebays must be carefully designed to eliminate inefficient flow zones that promote holding behavior.	No additional risks due to climate change effects are identified at this time.	RISK: Increase in water temperatures may create more ideal conditions for predator holding within the bypass system and in the main channel downstream of the outfall. Increased water temperature, reduced streamflow at outfall, and sedimentation at outfall can result in the combined effect of higher predation of bypassed fish exiting the outfall. ACTIONS TO CONSIDER: Transportation of juveniles may be required if the stream has insufficient instream flow or warm temperatures at or downstream of bypass outfall.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.

Note:
1. Transportation systems are used when there is insufficient flow in the stream downstream of the diversion screens to safely return screened fish back to the stream. Fish are transferred to a hopper or tank that is loaded onto a truck. The fish are carried downstream and released at a location on the stream that has appropriate flow and habitat.

Table 5
Fish Element Risk Pathways
Element: Adult Fish Barriers

Wet/Dry Periods		Streamflows			Water Temperature	Wildfires	
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**	**Runoff Timing Shift**	**Increase**	**Effects**	**Sediment and Debris**
Picket Design[1]							
RISK: High flows may lead to exceedance of maximum allowable velocity between pickets. ACTIONS TO CONSIDER: Reduce velocities by increasing width and depth of the picket array.	RISK: Insufficient depth to float pickets. ACTIONS TO CONSIDER: Use alternate trapping techniques if trapping remains necessary at site under climate extremes.	RISK: Exceed maximum allowable bending stress of pickets. Fish can become trapped (pressed against) on upstream side of pickets. ACTIONS TO CONSIDER: Remove pickets during highest flows. Expand cross-sectional area of picket array.	RISK: Insufficient depth to float pickets. Insufficient velocity to clear debris off of pickets. ACTIONS TO CONSIDER: Use alternate trapping methods if trapping remains necessary at site under climate extremes.	RISK: Shift in runoff timing may result in shifts in migration timing. ACTIONS TO CONSIDER: Adjust picket weir operational period.	RISK: Fish trapped behind barrier in warm water may become stressed and exhausted. ACTIONS TO CONSIDER: Ensure that design, installation, monitoring, and staffing are adequate to minimize delay.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance. [2]	RISK: Debris and gravel deposition can sink pickets, allowing adults to swim over the barrier. ACTIONS TO CONSIDER: Provide sufficient staffing, inspection frequency, and equipment to remove debris from pickets. [2]
Velocity-Drop Barriers[1]							
No additional risks due to climate change effects are identified at this time.	RISK: Velocity-drop barriers, especially in tailrace barriers, can create a source of false attraction for upstream-migrating adults, leading to significant migration delays and unnecessary energy expenditure. ACTIONS TO CONSIDER: Construct the barrier on the banks of and parallel to the banks of the main river channel.	RISK: Reduced barrier performance (fish can swim over the barrier). ACTIONS TO CONSIDER: Redesign and modify the drop barrier weir and apron to accommodate the expected higher flows.	RISK: Velocity-drop barriers, especially in tailrace barriers, can create a source of false attraction for upstream-migrating adults, leading to significant migration delays and unnecessary energy expenditure. ACTIONS TO CONSIDER: Construct the barrier on the banks of and parallel to the banks of the main river channel.	No additional risks due to climate change effects are identified at this time.	RISK: Fish jumping at barriers in warm water may become stressed and exhausted. ACTIONS TO CONSIDER: Ensure that design, installation, monitoring, and staffing are adequate to minimize delay.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance. [2]	RISK: Debris stranded on apron can abrade and trap fish trying to pass over the apron. ACTIONS TO CONSIDER: Provide sufficient staffing, inspection frequency, and equipment to remove debris from the apron. [2]

Table 5
Fish Element Risk Pathways
Element: Adult Fish Barriers

Wet/Dry Periods		Streamflows		Runoff Timing Shift	Water Temperature	Wildfires	Sediment and Debris
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**		**Increase**	**Effects**	
Tailrace Barrier[1]							
No additional risks due to climate change effects are identified at this time.	RISK: Tailrace barriers can create a source of false attraction for upstream-migrating adults, leading to significant migration delays and unnecessary energy expenditure. ACTIONS TO CONSIDER: Construct the barrier on the banks of and parallel to the banks of the main river channel.	No additional risks due to climate change effects are identified at this time.	RISK: Tailrace barriers can create a source of false attraction for upstream-migrating adults, leading to significant migration delays and unnecessary energy expenditure. ACTIONS TO CONSIDER: Construct the barrier on the banks of and parallel to the banks of the main river channel.	No additional risks due to climate change effects are identified at this time.	RISK: Water temperatures can be lethal for fish jumping too long at barrier screens. ACTIONS TO CONSIDER: Ensure that design, installation, monitoring, and staffing are adequate to minimize delay.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation causes excessive head loss at barrier bar racks, and excessive fish jumping toward the bar racks. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance. Improve debris removal capability of powerhouse trash racks.	RISK: Increased peak flows and floods may increase sediment and debris movement and occlude the upstream side of the barrier racks. Debris accumulation causes excessive head loss at barrier bar racks and excessive fish jumping toward the bar racks. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance. Improve debris removal capability of powerhouse trash racks.

Notes:
1. All barriers cause delay and excessive energy expenditure. These can be lethal, especially in warm water. Barriers should be designed, operated, and monitored to minimize delay.
2. Disturbance events like fires, high flows, or debris flows can reset stream systems and the complexity of these systems. Where sediment or woody debris removal is being considered, maintaining the delivery of the debris to locations downstream from the diversion should be discussed with NMFS and incorporated into the actions to support maintenance of fish habitat-forming processing below the diversion.

Table 6
Fish Element Risk Pathways
Element: Adult Trap and Transport

Wet/Dry Periods		Streamflows			Water Temperature	Wildfires	
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**	**Runoff Timing Shift**	**Increase**	**Effects**	**Sediment and Debris**
Attraction and Holding Water							
No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	RISK: Staffing and facilities may not be prepared to manage migrating fish that are affected by runoff timing shift. ACTIONS TO CONSIDER: Complete winter maintenance earlier to ensure fishways are operational during earlier runoff and migration.	RISK: Warmer water could significantly reduce the length of time that trapped fish can be safely held in pools and raceways. Water temperatures can be lethal for fish held too long in the trap box. ACTIONS TO CONSIDER: May require more frequent trap monitoring, emptying of holding tanks, and transport.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.	RISK: Increased peak flows and floods may increase sediment and debris movement, occlude fishway entrances, and affect volitional passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.
Holding Pools							
No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	RISK: Staffing and facilities may not be prepared to manage migrating fish that are affected by runoff timing shift. ACTIONS TO CONSIDER: Complete winter maintenance earlier to ensure fishways are operational during earlier runoff and migration.	RISK: Warmer water will significantly increase the volume of holding pool water required ACTIONS TO CONSIDER: Reduce solar heat load on water channels holding fish. Provide shade and reduce numbers of fish allowed to be held in pools.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.	RISK: Increased peak flows and floods may increase sediment and debris movement and occlude fishway entrances and affect volitional passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.
Debris Management							
RISK: Expect increased debris load during higher flows. Debris entrained in the turbulent water in holding pools will injure fish. ACTIONS TO CONSIDER: Monitor pools and remove damaging debris immediately.	No additional risks due to climate change effects are identified at this time.	RISK: Expect increased debris load during higher flows. Debris entrained in the turbulent water in holding pools will injure fish. ACTIONS TO CONSIDER: Monitor pools and remove damaging debris immediately.	No additional risks due to climate change effects are identified at this time.	RISK: Staffing and facilities may not be prepared to manage migrating fish that are affected by runoff timing shift. ACTIONS TO CONSIDER: Complete winter maintenance earlier to ensure fishways are operational during earlier runoff and migration.	No additional risks due to climate change effects are identified at this time.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.[1]	RISK: Expect increased debris load during higher flows. Debris entrained in the turbulent water in holding pools will injure fish. Monitor pools and remove damaging debris immediately. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.[1]

Table 6
Fish Element Risk Pathways
Element: Adult Trap and Transport

Wet/Dry Periods		Streamflows			Water Temperature	Wildfires	
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**	**Runoff Timing Shift**	**Increase**	**Effects**	**Sediment and Debris**
Fish Handling and Anesthesia							
No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	RISK: Staffing and facilities may not be prepared to manage migrating fish that are affected by runoff timing shift. ACTIONS TO CONSIDER: Complete winter maintenance earlier to ensure fishways are operational during earlier runoff and migration.	RISK: Anesthesia recovery time is increased by warm water. ACTIONS TO CONSIDER: Cease handling fish when safe water temperatures are exceeded.	No additional risks due to climate change effects were identified.	No additional risks due to climate change effects are identified at this time.
Transportation and Unloading							
No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	Lifting hopper and truck tank loading densities must be reduced when water temperatures are elevated. Supplemental oxygen and water chillers may be required to provide safe water quality during transport.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.
Release Location							
No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	Release location must provide safe water depth, velocity, and water quality (especially oxygen and temperatures) and must be free from predators.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.

Note:

1. Disturbance events like fires, high flows, or debris flows can reset stream systems and the complexity of these systems. Where sediment or woody debris removal is being considered, maintaining the delivery of the debris to locations downstream from the diversion should be discussed with NMFS and incorporated into the actions to support maintenance of fish habitat-forming processing below the diversion.

Table 7
Fish Element Risk Pathways
Element: Juvenile Collection Systems (in Reservoir Settings)

Wet/Dry Periods		Streamflows			Water Temperature	Wildfires	
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**	**Runoff Timing Shift**	**Increase**	**Effects**	**Sediment and Debris**
Forebay							
RISK: Increased high flows will bring large volumes of debris and trash to the trash racks and fish screens. ACTIONS TO CONSIDER: Automatic and extra-robust cleaning systems and methods for removing the accumulated debris from the site could be required.	RISK: Significantly reduced flow rate between head of reservoir and collection system entrances can significantly increase fish reservoir transit time, and prolonged exposure to predators and warm water. ACTIONS TO CONSIDER: Transport juveniles around low flow and warm reservoirs.	RISK: Increased high flows will bring large volumes of debris and trash to the trash racks and fish screens. ACTIONS TO CONSIDER: Automatic and extra-robust cleaning systems and methods for removing the accumulated debris from the site could be required.	RISK: Significantly reduced flow rate between head of reservoir and collection system entrances can increase fish reservoir transit time and prolong exposure to predators and warm water. ACTIONS TO CONSIDER: Transport juveniles around low flow and warm reservoirs.	RISK: Volitional passage dates may shift with runoff timing. Presumably, the shift would be earlier, which could result in misalignment between runoff and migration timing. Also, allowable maintenance periods may shift or shrink with changes in run timing. ACTIONS TO CONSIDER: Complete winter maintenance earlier to ensure fishways are operational during earlier runoff and migration.	RISK: Increased reservoir holding under high temperatures can increase risk of disease. ACTIONS TO CONSIDER: Transport juveniles around low flow and warm reservoirs.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance.[1]	RISK: Increased high flows will bring large volumes of debris and trash to the trash racks and fish screens. ACTIONS TO CONSIDER: Automatic and extra-robust cleaning systems could be required.[1]
Depth of Thermocline							
RISK: In strongly thermally stratified reservoirs, it is common for fish to migrate in the relatively cooler reservoir water located below the thermocline. Juveniles may not find the screen/bypass intakes (reservoir outlet) if the intakes are wholly contained above the thermocline. ACTIONS TO CONSIDER: Even in wet years, planners should determine whether the reservoir is likely to become thermally stratified during the warm months of the year. The design of the juvenile collector will depend upon whether the reservoir stays mixed or becomes strongly stratified. See discussion under Dry Extremes.	RISK: In strongly thermally stratified reservoirs, it is common for fish to migrate in the relatively cooler reservoir water located below the thermocline. Juveniles may not find the screen/bypass intakes (reservoir outlet) if the intakes are wholly contained above the thermocline. ACTIONS TO CONSIDER: Investigate techniques to provide a cold-water route for migration, such as deep intakes or bypassing the reservoir by collection and transportation.	RISK: In strongly thermally stratified reservoirs, it is common for fish to migrate in the relatively cooler reservoir water located below the thermocline. Juveniles may not find the screen/bypass intakes (reservoir outlet) if the intakes are wholly contained above the thermocline. ACTIONS TO CONSIDER: Even when maximum flows during winter increase, planners should determine whether the reservoir is likely to become thermally stratified during the warm months of the year. The design of the juvenile collector will depend upon whether the reservoir stays mixed or becomes strongly stratified. See discussion under Dry Extremes.	RISK: Extreme low flows increase the probability of strongly thermally stratified reservoirs. It is common for fish to migrate in the relatively cooler reservoir water located below the thermocline. Juveniles may not find the screen/bypass intakes (reservoir outlet) if the intakes are wholly contained above the thermocline. ACTIONS TO CONSIDER: Investigate techniques to provide a cold-water route for migration, such as deep intakes or bypassing the reservoir by collection and transportation.	RISK: Juvenile outmigration dates may shift with runoff timing. Presumably the shift would be earlier. ACTIONS TO CONSIDER: Investigate the relative timing of juvenile outmigration, reservoir levels, and potential for stratified reservoir.	RISK: In strongly thermally stratified reservoirs, it is common for fish to migrate in the relatively cooler reservoir water located below the thermocline. Juveniles may not find the screen/bypass intakes (reservoir outlet) if the intakes are wholly contained above the thermocline. ACTIONS TO CONSIDER: Investigate techniques to provide a cold-water route for migration, such as deep intakes or bypassing the reservoir by collection and transportation.	No additional risks due to climate change effects identified are identified at this time.	No additional risks due to climate change effects are identified at this time.

Table 7
Fish Element Risk Pathways
Element: Juvenile Collection Systems (in Reservoir Settings)

Wet/Dry Periods		Streamflows			Water Temperature	Wildfires	
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**	**Runoff Timing Shift**	**Increase**	**Effects**	**Sediment and Debris**
Reservoir Fluctuations							
RISK: Flood control and water storage reservoirs can have very large fluctuations of their water surface elevations (often concurrently with warm surface water temperatures). Water levels can be below the openings/intakes of the bypass systems. ACTIONS TO CONSIDER: A floating collector at the dam may be appropriate if the reservoir currents provide an unambiguous flow path toward the dam.	RISK: Flood control and water storage reservoirs can have very large fluctuations of their water surface elevations (often concurrently with very warm surface water temperatures). Water levels can be below the openings/intakes of the bypass systems. ACTIONS TO CONSIDER: Fish collection at head of reservoir may be required.	A significant proportion of the juvenile fish could pass over the spillway of the dam rather than through the collection system.	RISK: Flood control and water storage reservoirs can have very large fluctuations of their water surface elevations (often concurrently with very warm surface water temperatures). Water levels can be below the openings/intakes of the bypass systems. ACTIONS TO CONSIDER: Fish collection at head of reservoir may be required.	RISK: Juvenile outmigration dates may shift with runoff timing. Presumably the shift would be earlier. ACTIONS TO CONSIDER: Investigate the relative timing of juvenile outmigration, reservoir levels, and potential for stratified reservoir.	RISK: Flood control and water storage reservoirs can have very large fluctuations of their water surface elevations (often concurrently with very warm surface water temperatures). Water levels can be below the openings/intakes of the bypass systems. ACTIONS TO CONSIDER: Fish collection at head of reservoir may be required.	RISK: Effects of wildfires are increased sediment and wood accumulation. Lowered reservoir levels may concentrate floating debris at site of juvenile collector. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance of juvenile collection facilities.	RISK: Increased peak flows and floods may increase sediment and debris movement and occlude collector entrances and affect juvenile passage. ACTIONS TO CONSIDER: Design the entrance area to accommodate debris removal equipment.

Note:
1. Disturbance events like fires, high flows, or debris flows can reset stream systems and the complexity of these systems. Where sediment or woody debris removal is being considered, maintaining the delivery of the debris to locations downstream from the diversion should be discussed with NMFS and incorporated into the actions to support maintenance of fish habitat-forming processing below the diversion.

Table 8
Fish Element Risk Pathways
Element: Culverts

Wet/Dry Periods		Streamflows			Water Temperature	Wildfires	
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**	**Runoff Timing Shift**	**Increase**	**Effects**	**Sediment and Debris**
Flood Capacity							
RISK: Fish passage can be blocked for significant periods of time when culverts are damaged or destroyed by high flows. Increased wet extremes and increased maximum flows under climate change can increase the frequency and duration of culverts becoming impassable for fish. ACTIONS TO CONSIDER: All stream crossings and grade control fishways should be designed to withstand 100-year peak flood flow without failure of the crossing. Estimate 100-year peak flood flow using techniques presented in this report. Include allowance for debris and sediment transport.	No additional culvert risks due to climate change effects are identified at this time beyond those that would already exist in the stream.	RISK: Fish passage can be blocked for significant periods of time when culverts are damaged or destroyed by high flows. Increased wet extremes and increased maximum flows under climate change can increase the frequency and duration of culverts becoming impassable for fish. High flood flows could erode stream banks widening bankfull width. ACTIONS TO CONSIDER: All stream crossings and grade control fishways should be designed to withstand 100-year peak flood flow without failure of the crossing. Estimate 100-year peak flood flow using techniques presented in this report. Include allowance for debris and sediment transport. Increase span width of culvert or bridge to accommodate widened stream banks. 1.5-year recurrence interval flood is a useful metric for assessing bankfull width changes	No additional culvert risks due to climate change effects are identified at this time beyond those that would already exist in the stream.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces culvert flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance of culverts. [1]	RISK: Increased risk of blocking fish passage due to plugging of culverts with debris and sediment. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance of culverts. [1]

Table 8
Fish Element Risk Pathways
Element: Culverts

Wet/Dry Periods		Streamflows		Runoff Timing Shift	Water Temperature	Wildfires	Sediment and Debris
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**		**Increase**	**Effects**	
Embedded Pipe Design Method[2, 3]							
RISK: Relies on accurate estimates of future active channel widths, which relies on accurate estimates of future channel-forming flow rates. Underestimation of these values could result in blocking fish passage and structural damage.[3] ACTIONS TO CONSIDER: Ensure design meets current methodology described in this report for addressing future climate.	RISK: Risk of decreased minimum flow could include subsurface flow if simulated streambed is poorly designed/constructed and is too permeable. ACTIONS TO CONSIDER: For existing facility, consider re-engineering and reconstructing the streambed material to be less permeable.	RISK: Relies on accurate estimates of future active channel widths, which relies on accurate estimates of future channel-forming flow rates. Underestimation of these values could result in blocking fish passage and structural damage.[3] ACTIONS TO CONSIDER: Ensure design meets current methodology described in this report for addressing future climate.	RISK: Risk of decreased minimum flow could include subsurface flow if simulated streambed is poorly designed/constructed and is too permeable. At low flows the shape of the channel bed could pose a threat for fish in the system. ACTIONS TO CONSIDER: For existing facility, consider re-engineering and reconstructing the streambed material to be less permeable. Build the bed with a distinct thalweg that will increase water depths during low flows, not a plane-bed morphology that could disperse flows.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces culvert flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance of culverts.[1]	RISK: Increased risk of blocking fish passage due to plugging of culverts with debris and sediment. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance of culverts.[1]

Table 8
Fish Element Risk Pathways
Element: Culverts

Wet/Dry Periods		Streamflows			Water Temperature	Wildfires	
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**	**Runoff Timing Shift**	**Increase**	**Effects**	**Sediment and Debris**
Stream Simulation Design Method[1,2]							
RISK: This method relies on accurate estimates of future BFWs, which relies on estimates of future channel-forming flow rates. Underestimation of these values could result in blocking fish passage and structural damage. ACTIONS TO CONSIDER:[4]	RISK: Risk of decreased minimum flow could include subsurface flow if simulated streambed is poorly designed/constructed and is too permeable. ACTIONS TO CONSIDER: For existing facility, consider re-engineering and reconstructing the streambed material to be less permeable.	RISK: This method relies on accurate estimates of future BFWs, which relies on estimates of future channel-forming flow rates. Underestimation of these values could result in blocking fish passage and structural damage. ACTIONS TO CONSIDER: [4]	RISK: Risk of decreased min flow could include subsurface flow if simulated streambed is poorly designed/constructed and is too permeable. At low flows the shape of the channel bed could pose a threat for fish in the system. ACTIONS TO CONSIDER: For existing facility, consider re-engineering and reconstructing the streambed material to be less permeable. Build the bed with a distinct thalweg that will increase water depths during low flows, not a plane-bed morphology that could disperse flows	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces culvert flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance of culverts. [1]	RISK: Increased risk of blocking fish passage due to plugging of culverts with debris and sediment. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance of culverts. [1]
Hydraulic Design Method[1]							
RISK: This method is based upon estimation of future high and low flow rates under climate change. Underestimation of these values could result in blocking fish passage and structural damage. ACTIONS TO CONSIDER: [4]	RISK: This method is based upon estimation of future high and low flow rates under climate change. Underestimation of these values could result in blocking fish passage and structural damage. ACTIONS TO CONSIDER: [4]	RISK: This method is based upon estimation of future high and low flow rates under climate change. Underestimation of these values could result in blocking fish passage and structural damage. ACTIONS TO CONSIDER: [4]	RISK: This method is based upon estimation of future high and low flow rates under climate change. Underestimation of these values could result in blocking fish passage and structural damage. At low flows the shape of the channel bed could pose a threat for fish in the system. ACTIONS TO CONSIDER: [4] Build the bed with a distinct thalweg that will increase water depths during low flows, not a plane-bed morphology that could disperse flows	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces culvert flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance of culverts. [1]	RISK: Increased risk of blocking fish passage due to plugging of culverts with debris and sediment. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance of culverts. [1]

Table 8
Fish Element Risk Pathways
Element: Culverts

Wet/Dry Periods		Streamflows			Water Temperature	Wildfires	
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**	**Runoff Timing Shift**	**Increase**	**Effects**	**Sediment and Debris**
Hydraulic Retrofit							
RISK: This method is based upon estimation of future high and low flow rates under climate change. Under- or overestimation of these values could result in blocking fish passage and structural damage. ACTIONS TO CONSIDER: [4]	RISK: This method is based upon estimation of future high and low flow rates under climate change. Under- or overestimation of these values could result in blocking fish passage and structural damage. ACTIONS TO CONSIDER: [4]	RISK: This method is based upon estimation of future high and low flow rates under climate change. Under- or overestimation of these values could result in blocking fish passage and structural damage. ACTIONS TO CONSIDER: [4]	RISK: This method is based upon estimation of future high and low flow rates under climate change. Under- or overestimation of these values could result in blocking fish passage and structural damage. At low flows the shape of the channel bed could pose a threat for fish in the system. ACTIONS TO CONSIDER: [4] Build the bed with a distinct thalweg that will increase water depths during low flows, not a plane-bed morphology that could disperse flows	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	RISK: Effects of wildfires are increased sediment and wood accumulation. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance of culverts. [1]	RISK: Increased risk of blocking fish passage due to plugging of culverts with debris and sediment. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance of culverts. [1]
Trash Racks and Livestock Fences							
RISK: Increased risk of blocking fish passage due to plugging of racks and fences with debris. ACTIONS TO CONSIDER: Enhance the inspection and maintenance requirements contained in the WCR guidance documents shown in Figure 1.	No additional risks due to climate change effects are identified at this time.	RISK: Increased risk of blocking fish passage due to plugging of racks and fences with debris. ACTIONS TO CONSIDER: Enhance the inspection and maintenance requirements contained in the WCR guidance documents shown in Figure 1.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces culvert flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance of culverts. [1]	RISK: Increased risk of blocking fish passage due to plugging of culverts with debris and sediment. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance of culverts. [1]

Notes:

1. Disturbance events like fires, high flows, or debris flows can reset stream systems and the complexity of these systems. Where sediment or woody debris removal is being considered, maintaining the delivery of the debris to locations downstream from the diversion should be discussed with NMFS and incorporated into the actions to support maintenance of fish habitat-forming processing below the diversion.
2. All stream crossings and grade control fishways to be designed to withstand 100-year peak flood flow without failure of the crossing. Estimate 100-year peak flood flow using techniques presented in this report. Include allowance for debris and sediment transport.
3. Minimum culvert width to be greater than or equal to 1.5 times the BFW for Stream Simulation and 1.5 times the active channel width for Embedded.
4. These design methods start with knowing the BFWs. At present, the designer can measure them and use those measurements in their designs. However, going forward, BFWs will be a moving target in those streams with changing wet and dry periods and changing streamflows (increased maximum flows and decreased minimum flows). So, in future culvert design projects, the hydrologists should use the products of climate change models to estimate the future channel-forming flows. The designers should use those flows along with the sediment and slope properties of the reach to estimate new BFWs. There are both fish passage and structural integrity risks. The worst case for a given project would be underestimating the magnitudes and frequencies of channel-forming flows and the widths of the BFWs.

Table 9
Fish Element Risk Pathways
Element: Grade Control Fishways

Wet/Dry Periods		**Streamflows**		**Runoff Timing Shift**	**Water Temperature**	**Wildfires**	**Sediment and Debris**
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**		**Increase**	**Effects**	
All Structure Types (Constructed Channel, Rigid Weirs, Boulder Weirs and Channel-Spanning Fish Ladders)							
RISK: Design of these structures relies on estimates of future BFWs and sediment transport rates. In turn, these values rely on estimates of future channel-forming flow rates and frequencies. Over- and underestimation of these values could result in flows bypassing around the ends of the structures, greater than planned-for scour and deposition, structural failure, and loss of fish passage. ACTIONS TO CONSIDER: Implement the climate change-based hydrologic processes and techniques presented in this document. Also see: *NMFS Guidelines for Salmonid Passage at Stream Crossings in Washington, Oregon, and Idaho.*	RISK: Design of these structures relies on estimates of future BFWs and sediment transport rates. In turn, these values rely on estimates of future channel-forming flow rates and frequencies. Over- and underestimation of these values could result in flows bypassing around the ends of the structures, greater than planned-for scour and deposition, structural failure, and loss of fish passage. ACTIONS TO CONSIDER: Implement the climate change-based hydrologic processes and techniques presented in this document. Also see: *NMFS Guidelines for Salmonid Passage at Stream Crossings in Washington, Oregon, and Idaho.*	RISK: Design of these structures relies on estimates of future BFWs and sediment transport rates. In turn, these values rely on estimates of future channel-forming flow rates and frequencies. Over- and underestimation of these values could result in flows bypassing around the ends of the structures, greater than planned-for scour and deposition, structural failure, and loss of fish passage. ACTIONS TO CONSIDER: Implement the climate change-based hydrologic processes and techniques presented in this document. Also see: *NMFS Guidelines for Salmonid Passage at Stream Crossings in Washington, Oregon, and Idaho.*	RISK: Design of these structures relies on estimates of future BFWs and sediment transport rates. In turn, these values rely on estimates of future channel-forming flow rates and frequencies. Over- and underestimation of these values could result in flows bypassing around the ends of the structures, greater than planned-for scour and deposition, structural failure, and loss of fish passage. ACTIONS TO CONSIDER: Implement the climate change-based hydrologic processes and techniques presented in this document. Also see: *NMFS Guidelines for Salmonid Passage at Stream Crossings in Washington, Oregon, and Idaho.*	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time.	No additional risks due to climate change effects are identified at this time. ACTIONS TO CONSIDER: For many systems, disturbance events like fires, high flows, debris flows, etc. reset the stream system and the complexity of these systems. Where debris removal is considered, continuity of debris (e.g., large wood, etc.) needs to be incorporated into the action.	RISK: Effects of wildfires are increased sediment and wood accumulation and increased risk of flash floods and debris flows. Debris accumulation reduces flow capacity and blocks fish passage. ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance of culverts. For many systems, disturbance events like fires, high flows, debris flows, etc. reset the stream system and the complexity of these systems. Where debris removal is considered, continuity of debris (e.g., large wood, etc.) needs to be incorporated into the action.

Table 10
Fish Element Risk Pathways
Element: Sea Level Rise and Tide Gates[1]

Wet/Dry Periods		Streamflows			Water Temperature	Wildfires	
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**	**Runoff Timing Shift**	**Increase**	**Effects**	**Sediment and Debris**
Element: Sea Level Rise and Tide Gates							
RISK: Higher downstream mean sea level elevations reduce the effectiveness of tide gates by impacting the hydraulics of the system. Sea level rise will reduce the tide gate effectiveness resulting in longer lasting and deeper flood events. (Walsh and Miskewitz (2013)) Effects of sea level rise will result in higher base water levels on both sides of the levees and higher frequency of flooding. The lower river basins may experience wetter, higher flow conditions. Higher elevations could be due to both river flow during wet periods and SLR. The result is that existing tide gates would have longer periods where they are not performing as designed.	RISK: The lower river subbasins may experience drier conditions.	RISK: Higher downstream mean sea level elevations reduce the effectiveness of tide gates by impacting the hydraulics of the system. sea level rise will reduce the tide gate effectiveness resulting in longer lasting and deeper flood events. (Walsh and Miskewitz (2013)) Effects of sea level rise will result in higher base water levels on both sides of the levees and higher frequency of flooding. The lower river basins may experience wetter, higher flow conditions. Higher elevations could be due to both river flow during wet periods and SLR. The result is that existing tide gates would have longer periods where they are not performing as designed.	RISK: The lower river subbasins may experience drier conditions.	Risk: Various life stages of fish will encounter different flows than historically, and there may not be enough water in the river as needed for that life stage. For example, adults migrating upstream to spawn juveniles migrating downstream. These changes in the hydrograph are already happening as increased temperatures are already leading to shifts in runoff timing (hydrograph) to earlier spring peak flows and then lower flows in the summer and fall. Also, a higher proportion of winter precipitation falling as rain vs snow, leads to higher winter flows.	RISK: Reduced fitness for adult and juvenile migration or spawning because increased water temperatures place metabolic demands on the fish. Water chemistry is also affected: higher water temperatures also result in lower dissolved oxygen (DO) and other aspects of water chemistry. Lower DO is a stress on fish across all life history stages. Lower river and estuary water temps being higher will occur under climate change, and fish will be more stressed, and under these conditions.	RISK: Increased sedimentation due to runoff over ground that is bare or reduced vegetation cover after a wildfire in a tidal estuary tributary. Adds to risk of increased water temperature because vegetation isn't shading affected reaches. (see: https://www.fs.usda.gov/rmrs/documents-and-media/wildfire-impacts-stream-sedimentation) .	RISK: increased sedimentation and debris due to higher precipitation and related high flows/flooding. this may be compounded in wildfire areas.

Table 10
Fish Element Risk Pathways
Element: Sea Level Rise and Tide Gates[1]

Wet/Dry Periods		Streamflows			Water Temperature	Wildfires	
Wet Extremes	**Dry Extremes**	**Increased Max Flow**	**Decreased Min Flow**	**Runoff Timing Shift**	**Increase**	**Effects**	**Sediment and Debris**
Element: Sea Level Rise and Tide Gates							
ACTIONS TO CONSIDER: Conditions that may be present in the future due to Sea Level Rise (Walsh and Miskewitz (2013)) Will likely require larger tide gates in order not to exceed the maximum allowable velocities required for fish passage and the tide gates remaining open a higher percentage of time to allow for fish passage compared to current conditions. The tide gates could remain open a higher percentage of time than under current conditions, leading to longer time periods available for fish passage. Tide gate could be out of criteria for longer period. Consider review tidal cycle and functionality of tide gate. Does it need to be modified. Review functionality of gate check document section	ACTIONS TO CONSIDER: Existing tide gates should be checked to determine if they meet fish passage criteria. New tide gates should be designed to meet fish passage criteria. The tide gates could remain closed a higher percentage of time than under current conditions, leading to shorter time periods for fish passage opportunities.	ACTIONS TO CONSIDER: Conditions that may be present in the future due to Sea Level Rise (Walsh and Miskewitz (2013)) Will likely require larger tide gates in order not to exceed the maximum allowable velocities required for fish passage and the tide gates remaining open a higher percentage of time to allow for fish passage compared to current conditions. . The tide gates could remain open a higher percentage of time than under current conditions, leading to longer time periods available for fish passage. Tide gate could be out of criteria for longer period. Consider review tidal cycle and functionality of tide gate. Does it need to be modified. Review functionality of gate check document section	ACTIONS TO CONSIDER: Implement the climate change-based hydrologic processes and techniques presented in this document. Also see: NMFS Guidelines for Salmonid Passage at Stream Crossings in Washington, Oregon, and Idaho.	ACTIONS TO CONSIDER: To have more water in the river consider actions to manage instream flows, for example changes in upstream reservoir releases or limiting diversions to maintain needed flows for the fish	ACTIONS TO CONSIDER: Consider actions to manage temperatures, such as reservoir releases of cold water or creating shade over warm sections of streams, including preserving or planting shade vegetation. Ensure tide gates perform as designed.	ACTIONS TO CONSIDER: For many systems, disturbance events like fires, high flows, debris flows, etc. reset the stream system and the complexity of these systems. Where debris removal is considered, continuity of debris (e.g., large wood, etc.) needs to be incorporated into the action.	ACTIONS TO CONSIDER: Additional monitoring, debris removal, and maintenance of culverts. For many systems, disturbance events like fires, high flows, debris flows, etc. reset the stream system and the complexity of these systems. Where debris removal is considered, continuity of debris (e.g., large wood, etc.) needs to be incorporated into the action.

Notes:

1. NMFS recognizes that in very large watersheds (e.g., Columbia River) climate change impacts can be different depending on location. For example, lower watershed areas near the ocean may receive more rain on average while upper watershed areas may receive less. While this table focuses on watershed areas near tide gates, what happens upstream in all watersheds can affect water surface elevations in estuarine areas.

2.5 Long-Term Project Case Studies

The case studies are presented as examples of the processes shown in Figures 3 and 5. These include a fishway project in an unregulated river and in a regulated river, and an example of culverts and water crossings.

2.5.1 New Fishway Project in an Unregulated River

For this example, a theoretical fishway project was developed above the reservoir impounded by the Skookumchuck Dam on the Skookumchuck River in the Chehalis River Basin, Washington. Because it is above the dam, the river is not considered regulated. The site was selected because there are hydrologic projections for climate change conditions available that were derived using both statistically downscaled and dynamically downscaled climate data and two different hydrologic models. In addition, a USGS stream gage (Station 12025700; Skookumchuck River near Vail, Washington) is nearby and data from that gage were used to represent current hydrologic conditions (USGS 2022a). The contributing drainage area is 40 square miles. The following example uses hydrologic projections obtained from statistically downscaled data. It then compares the data to projections obtained using dynamically downscaled data to illustrate differences that may result from the different modeling approaches. The steps shown in Figure 5 for a long-term project are described in the following sections.

2.5.1.1 Determine Life Expectancy

Step 1 in the process is to determine the project lifespan (Section 2.3.1). In this example the fishway is assumed to have a useful life of 25 years (it is planned to be replaced in about 2050). Therefore, the fishway is expected to operate under mid-century climate conditions.

2.5.1.2 Determine Importance Factors

Step 2 in the process is to determine the importance factors. For this example, discussions with NMFS staff were completed following the considerations identified in Section 2.3.2, and the project was judged to have a medium importance factor.

2.5.1.3 Identify Mechanical and Biological Risk Pathways

Step 3 in the process is to identify the risks associated with the project elements (Section 2.3.3 and Table 1 in Section 2.4). The primary risks associated with a new fishway at the site were identified as being changes in fish passage design flows and peak flows. For the purpose of brevity in this document, changes in sediment transport or stream temperature were not addressed for this example.

2.5.1.4 Assess Risk Tolerance

Step 4 in the process is to assess risk tolerance (Section 2.3.4). For this example, it was assumed that an assessment of risk was prepared by the applicant and NMFS, and the overall risk was judged to be medium.

2.5.1.5 Complete Project Screening Matrix

Step 5 in the process is to select climate projections data that reflect the risk and importance of the project. With a medium risk tolerance and medium importance factor, ensemble mean results should be used (Figure 6).

2.5.1.6 Examine Appropriateness of Available Climate Projections Products

Step 6 in the process is to assess the adequacy of the climate change data available at the site (Section 2.3.6). The CIG has performed modeling for the basin using two hydrologic models and two methods to downscale GCM data (statistical and dynamical). In addition, model outputs are available that are bias-corrected. Table 11 provides a summary of the model results (Mauger et al. 2016).

Table 11
Model Results Available for the Skookumchuck River near Vail, Washington

Hydrologic Model	Forecast Timeframe	Bias-Corrected	GCM Downscaling Method	
			MACA (Statistical)	WRF (Dynamical)
VIC	2050s	No	Yes	Yes
VIC	2080s	No	Yes	Not Available
VIC	2050s	Yes	Yes	Yes
VIC	2080s	Yes	Yes	Not Available
DHSVM	2050s	No	Yes	Yes
DHSVM	2080s	No	Yes	Not Available
DHSVM	2050s	Yes	Yes	Yes
DHSVM	2080s	Yes	Yes	Not Available

A description of the modeling process used by CIG is provided Mauger et al. (2016). The hydrologic models used by CIG are the VIC and DHSVM models. The downscaling methods used are the Multivariate Adaptive Constructed Analogs (MACA) and Weather Research and Forecasting (WRF) methods. The MACA projections used 10 GCMs (included in CMIP5) and included the RCP8.5 greenhouse gas (GHG) scenario. The WRF projections used two GCMs included in CMIP3 and are based on a moderate (A1B) GHG scenario which relates to RCP6.0.

For this analysis, the MACA downscaling method along with the bias-corrected DHSVM model results were used because a larger ensemble of model results is available and the RCP8.5 GHG scenario was used in the GCMs that were downscaled. Mid-century conditions were used as described in Section 2.5.1.1.

2.5.1.7 Existing Conditions Analysis Using U.S. Geological Survey Gage Records

To simplify the case study and reduce the amount of data to be analyzed, a single month of daily flows were used (September) for flow exceedance during the period when fish will be using the facility. The 100-year flow was also estimated for the project site.

Flow statistics for the Skookumchuck River near Vail gage were developed and are summarized in Table 12. The period of record available is 1968 to 2021. The past 25 years of record were used for determining 5% and 95% exceedance for daily flows, consistent with NMFS criteria for this geographic region (Design Manual) for the month of September. The full period of record was used for peak flows. The peak flow analysis was performed using the USGS flood frequency analysis program PeakFQ (USGS 2022b). It was assumed that the 100-year instantaneous peak flow would be required for the design.

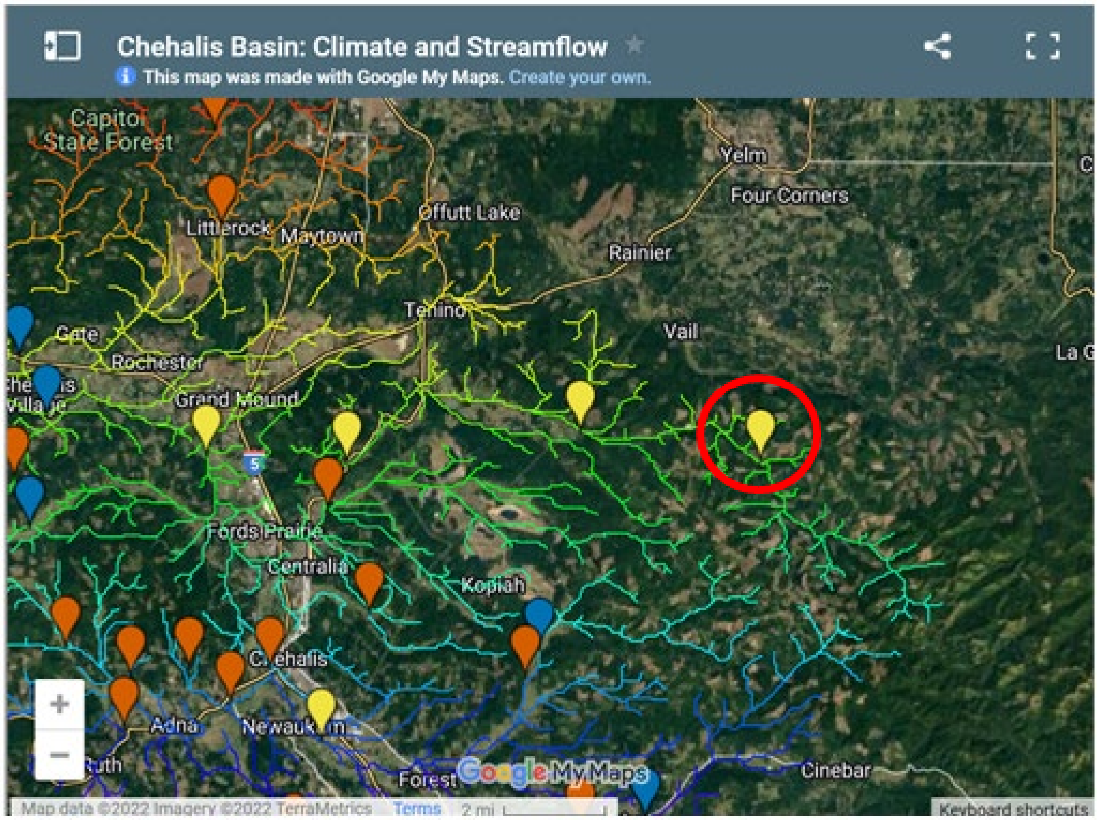
Table 12
Current Hydrologic Conditions for Skookumchuck River near Vail, Washington

Streamflow Statistic	Flow (cfs)
95% Exceedance for September	16
5% Exceedance for September	80
100-year Daily Peak	5,930
100-year Instantaneous Peak Flow	9,630

2.5.1.8 Estimate Future Hydrologic Conditions Using DHSVM and MACA Downscaling

The output from the DHSVM model was reviewed and analyzed for September streamflow and 100-year peak flows for historical and mid-century conditions and the RCP8.5 climate scenario. Table 13 presents the results of the DHSVM model using MACA statistical downscaling and bias correction. Ten GCMs were used in the analysis; Table 13 presents the ensemble mean and range (note that Table 19 in Section 2.5.1.10 lists the GCMs used in the analysis). The model results are available in the Data section of the University of Washington CIG Datasets web page (Mauger et al. 2016). In that section, the Skookumchuck River near Vail site should be selected from the interactive map and a listing of model results will appear. The link to "DHSVM BC" should be followed to a listing of data and graphs that present the data in various forms for download. A screenshot of the interactive map is shown in Figure 8.[10]

Figure 8
Interactive Map of Chehalis Basin Showing Location of Skookumchuck River near Vail Washington (red circle on map)



Note: Map accessed from the University of Washington CIG Datasets web page (Mauger et al. 2016).

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[10] University of Washington, College of the Environment, Climate Impacts Group web page: https://cig.uw.edu/datasets/hydrology-in-the-chehalis-basin/

Table 13
September Streamflow Statistics, Ensemble Results for DHSVM Model and MACA Statistical Downscaling for the Skookumchuck River near Vail, Washington, Mid-Century using RCP8.5, using 1996 – 2021 to determine the exceedance flows.

	Historic (DHSVM)			Ensemble (Mid-Century) (MACA)		
Exceedance	Mean (cfs)	High (cfs)	Low (cfs)	Mean (cfs)	High (cfs)	Low (cfs)
95%	14.0	14.9	13.2	10.7	14.1	7.9
5%	93.4	102.3	83.6	76.1	126.4	48.5

Table 14 provides projected peak daily flows for the DHSVM model using MACA statistical downscaling for 10 GCMs. The data was also obtained from the University of Washington CIG Datasets web page (Mauger et al. 2016). The DHSVM model output is on a daily time step, so the peak daily flows should be adjusted to estimate instantaneous peak flows. Section 2.5.1.9 presents a procedure for this adjustment by multiplying peak instantaneous flows obtained from the USGS gaging record by the ratio of the modeled future peak daily flows to modeled historical peak daily flows.

Table 14
100-year Peak Flows (Daily) for the Skookumchuck River near Vail, Washington from DHSVM Model and MACA Downscaling

Historic			Ensemble (Mid-Century)		
Mean (cfs)	High (cfs)	Low (cfs)	Mean (cfs)	High (cfs)	Low (cfs)
6,384	9,162	4,205	10,288	13,896	6,488

2.5.1.9 Apply Projected Changes in Environmental Conditions to Design Variables Identified in Climate Results to Risk Pathways

A recommendation in Section 2.3.6.1 is to observe the percent change (adjustment factor) between modeled future and modeled historical conditions and apply that change to stream gage records to estimate future flows if calibrated or bias-corrected models do not accurately represent historical conditions. As an example of why to use this process, the modeled historical flows are compared to historical gage flows in Table 15.

Table 15 shows that the differences between modeled historical flows and gage records are -12.5% and +17% for 95% and 5% exceedance flows respectively. The model-predicted 100-year daily peak is overpredicted by 8%, compared to USGS records. Note that if a large ensemble of GCMs was not available, the historical conditions may not have been as representative, as indicated by the range between high and low values shown in Tables 13 and 14. In addition, the model results are already bias-corrected and should match historical flow records. The differences between modeled historical flow records and historical USGS gage records show that even with bias-corrected model output, differences in flows exist that may affect the design of a fish passage structure. For that reason, the additional step of applying the percent change in modeled flows to historical stream gage records is recommended. This may not be necessary in every instance and will depend on the accuracy of modeled data compared to the observed historical conditions.

This technique of applying modeled changes to current flows is commonly used in hydrologic modeling studies. An example is work performed in the Chehalis Basin in Washington State by CIG (Mauger et. al. 2021) and Watershed Science and Engineering (WSE 2021). For that project, flow scalars (percent change) were computed from climate modeling and applied to current condition hydrographs that were used in a hydraulic model of the Chehalis River.

Table 15
Comparison of Modeled Historical Conditions for the Skookumchuck River near Vail, Washington to USGS Gage Records

Streamflow Statistic	Historical Flow from USGS Records (cfs)	Ensemble Mean of Modeled Historical Flows (cfs)	Percent Difference
95%	16	14.0	-12.5%
5%	80	93.4	17%
100-Year Daily Peak	5,930	6,384	8%

For this case study, the percent change between modeled future conditions and modeled historical conditions was applied to the historical flows calculated from the USGS record to estimate future flows. This procedure will ensure future flows are not under- or overpredicted. Table 16 provides the calculation of percent change between modeled future and historical conditions (Columns 3 to 5) and the calculation of future flows by multiplying the percent change by historical USGS flow records (Column 5 x Column 2). The percent change for September streamflow and peak flows were calculated using data summarized in Tables 13 and 14 (using the ensemble mean) and applied to data in Table 12. Table 16 summarizes the calculation for September streamflow and peak daily flows.

Table 16
Streamflow Statistics, Adjusted by Ratio of Modeled Future to Modeled Historical Conditions for the Skookumchuck River near Vail, Washington

Streamflow Statistic	Historical Flow from USGS Records (cfs)	Modeled Flow (Ensemble Mean)			Projected Flows (Mid-Century) (USGS Record Flows x % Change in Modeled Flow) (cfs)
		Historical (cfs)	Future Mid-Century (cfs)	% Change in Modeled Flow	
95%	16	14.0	10.7	-24%	12.2
5%	80	93.4	76.1	-19%	65.2
100-Year Daily Peak	5,930	6,384	10,288	61%	9,560

The fish passage design flows for mid-century conditions, using the ensemble average, are estimated to be about 12 cfs for 95% exceedance and 65 cfs for 5% exceedance, which is a decrease of 19% to 24% in flows. Peak flows are projected to increase substantially (over 60%) in that time period and the 100-year peak daily flow is projected to be 9,560 cfs. The instantaneous peak will be higher. Applying the 61% increase in peak daily flow to instantaneous peak flow shown in Table 12, the instantaneous peak flow could be 15,500 cfs.

2.5.1.10 Comparison of Different Model Results and Recommendations for Design

As an illustration of additional downscaling methods, a designer might encounter, note that climate change projections are also available from VIC model results and MACA downscaling and both VIC and DHSVM using WRF dynamical downscaling. However, hydrologic modeling results using the WRF model downscaling are available for only two GCMs using the CMIP3 A1B GHG scenario. For those reasons, the modeling using WRF is not compared to the modeling that used MACA downscaling. A comparison of the VIC model results to the DHSVM results using MACA downscaling is shown in Tables 17 and 18. Bias-corrected results are shown in Table 17. The VIC model results are obtained using the same procedure as described in Section 2.5.1.7 but by following the" VIC BC" link to data and graphs. The ensemble mean is presented as well as the high and low results from climate models used in the ensemble. The calculations for Table 18 compare the differences between the average of the ensemble, the high estimate of the ensemble and the low estimate of the ensemble. The value shown is not the "highest" difference, or "average" or "low" difference, just the difference between the highest estimate under climate change to the highest estimate for historical conditions, difference between average of ensemble under climate change to average of historical results, etc. The point of presenting this information is to show the potential range of results, which indicates the need to assemble and compare all the available data to inform judgments regarding how much to adjust flows.

Table 17
Percent Change in September Streamflow Statistics, Modeled Future to Modeled Historical Conditions Using Other Models and Downscaling Approaches for the Skookumchuck River near Vail, Washington

Model and Downscaling Method Used	Exceedance	Percent Change from Ensemble of Modeled Historical Conditions		
		Mean	High	Low
VIC, MACA	95%	-1%	-1%	-1%
	5%	-17%	9%	-39%
DHSVM, MACA	95%	-24%	-5%	-40%
	5%	-19%	24%	-42%

Table 18
Percent Change in 100-year Peak Flows (Daily) Modeled Future to Modeled Historical Conditions Using Other Models and Downscaling Approaches. The value shown is the difference between the highest estimate under climate change to highest estimate for historical conditions.

Model and Downscaling Method Used	Percent Change from Ensemble of Modeled Historical Conditions		
	Average	High	Low
VIC, MACA	66%	125%	9%
DHSVM, MACA	61%	52%	54%

The results using the ensemble mean show differing values of projected flow changes, with the VIC model predicting little change (-1%) in low fish passage flows, while the DHSVM model predicts a 24% decrease. The VIC and DHSVM results for high fish passage flows are about the same (17% vs 19% decrease), and projected changes in peak flows are about the same (66% vs 61% increase). In this case, NMFS would likely require the applicant to use the more conservative of the values estimated. That would be a 24% decrease in low fish passage flows, a 19% decrease in high fish passage flows, and a 66% increase in peak flows. The purpose of this comparison is to illustrate there will be differences in model results. An evaluation of all available model results is recommended to derive conservative values to use in fish passage design.

2.5.1.11 Flow Estimates if Project Has Low Risk Tolerance and High Importance Factor

An example of a calculation of extreme model outputs is provided if the fishway project has a high importance factor and low risk tolerance. To select the extreme case of an ensemble, a typical approach is to use the 90th percentile range of estimates (Section 2.3.6.1). Table 19 provides the 100-year flow estimates of each combination of GCM and the DHSVM model in the ensemble. The data can be found using the same procedure described in Section 2.5.1.7. The 90th percentile of the 100-year flows is 12,397 cfs. Consistent with calculations shown in Table 16, the percent change in modeled future conditions to modeled historic conditions was applied to the historical flows calculated from the USGS record to estimate the extreme case of an ensemble. The percent change is 94% (12,397/6,384) and the peak daily flow is 11,500 cfs (1.94 x 5,930). The instantaneous peak is estimated to be 18,680 cfs (1.94 x 9,630).

Table 19
100-Year Daily Peak Flow from All Ensemble Results for DHSVM Model and MACA Downscaling, Mid-Century for the Skookumchuck River near Vail, Washington

GCM Name	100-Year Peak Daily Flow (cfs)
bcc-csm1-1-m	9,159
CCSM4	9,075
CNRM-CM5	9,815
CanESM2	11,404
CSIRO-Mk3-6-0	12,397
HadGEM2-CC365	13,896
HadGEM2-ES365	6,488
IPSL-CM5A-MR	10,286
MIROC5	8,103
NorESM1-M	12,258
Mean of Ensemble	10,288
90th Percentile of Ensemble	12,397

In summary, calculating future exceedance flows in the early fish facility design stages gives the biologist, engineer, and applicant insight into how daily low, daily high, and instantaneous peak flows are estimated to change in the future due to climate. In this example, obtaining this information allows the new fishway to be designed and sited within the project location to operate and pass fish safely under the expected range of conditions.

2.5.2 New Fishway Project in a Regulated River

An example of a project in a regulated river system was prepared to illustrate the type of data that may be available for a new project in a regulated river and the effect of climate change on water supply, reservoir operations, and streamflow. The example provided is in the Yakima River Basin in Washington. The Yakima River Basin contains Reclamation's Yakima Project. The Yakima Project is comprised of 5 reservoirs with over one million acre-feet of storage and that supplies approximately 2 million acre-feet of water to irrigation districts. The Yakima Project currently depends on snowpack to meet summer water supply requirements. Climate change will reduce the amount of snowpack but increase winter runoff (U.S. Bureau of Reclamation 2019), which will reduce the reliability of water supply as current volumes of storage cannot meet the entire water supply. Reclamation has been engaged in modeling the Yakima Project to examine the effects of climate change and to test various alternatives to improving water supply. Reclamation uses the RiverWare[9] operations model for that work (Magee et al. 2011; Zagona et al. 2001).

The example project is at Nelson Dam located on the Naches River at River Mile 3.8, which diverts water for the City of Yakima. The dam is currently being removed by the City. For that reason, and because the authors had access to RiverWare model runs that simulate streamflow in the regulated Naches River, this site was selected as a project example. No new fishway is planned for Nelson Dam, rather, the site was selected because the information needed for an example project in a regulated river was made available for this location.

2.5.2.1 Identify Project Element Lifespan

The first step in the process is to determine the project element lifespan (Section 2.3.1). In this example, the theoretical fishway is assumed to have a useful life of about 20 years. Therefore, the fishway is expected to operate under mid-century climate conditions.

2.5.2.2 Determine Importance Factors

The second step is to determine the importance factors. Based on the importance of this population to recovery goals and the percentage of the listed population that encounter the project site, this project was judged in consultation with NMFS biologist staff to have a medium importance factor (Section 2.3.2).

2.5.2.3 Identify Risk Pathways

The next step is to identify the risks associated with the project elements (Section 2.3.3 and Table 1 in Section 2.4). The primary risks associated with a new fishway at the site were identified as being changes in fish passage design flows and peak flows. For this example, changes in sediment transport or stream temperature were not addressed.

2.5.2.4 Assess Risk Tolerance

The next step is to assess risk tolerance (Section 2.3.4). For this example, it was assumed that an assessment of risk was prepared by the applicant and NMFS, and the overall risk was judged to be medium. With a medium risk tolerance and medium importance factor, ensemble mean results should be used (Figure 6). However, in regulated river systems ensemble means are not always available because of the amount of modeling required to run operational models. Therefore, for this example, the climate scenario that would result in adverse impacts in the context of an Environmental Impact Statement (U.S. Bureau of Reclamation 2019) was used and was also available from Reclamation.

2.5.2.5 Examine the Available Climate Data

The next step is to examine the climate change data available at the site (Section 2.3.6). The inflow hydrographs used in the RiverWare model were developed by the RMJOC (RMJOC 2010). The B1 emissions pathway was used along with a single GCM, the Hadley Centre Coupled Model 3 (HadCM3), as input to a hydrologic model to develop unregulated flows used in RiverWare. The B1 emissions pathway was considered to be an “adverse” climate scenario at that time. It has a similar radiative forcing and projected global temperature increase as RCP4.5 in the mid-century time period (see Section 3.4.1 for a comparison of CMIP3 and CMIP5). This set of modeling results was readily available through work performed for the Yakima River Basin Integrated Water Resource Management Plan. Although the 2010 hydrologic modeling has been superseded by “RMJOC-II” modeling (RMJOC 2018), Reclamation tested the more recent climate data with RiverWare and found the modeling results to be within the range of conditions found with the earlier “adverse” climate scenario (U.S. Bureau of Reclamation, 2019).

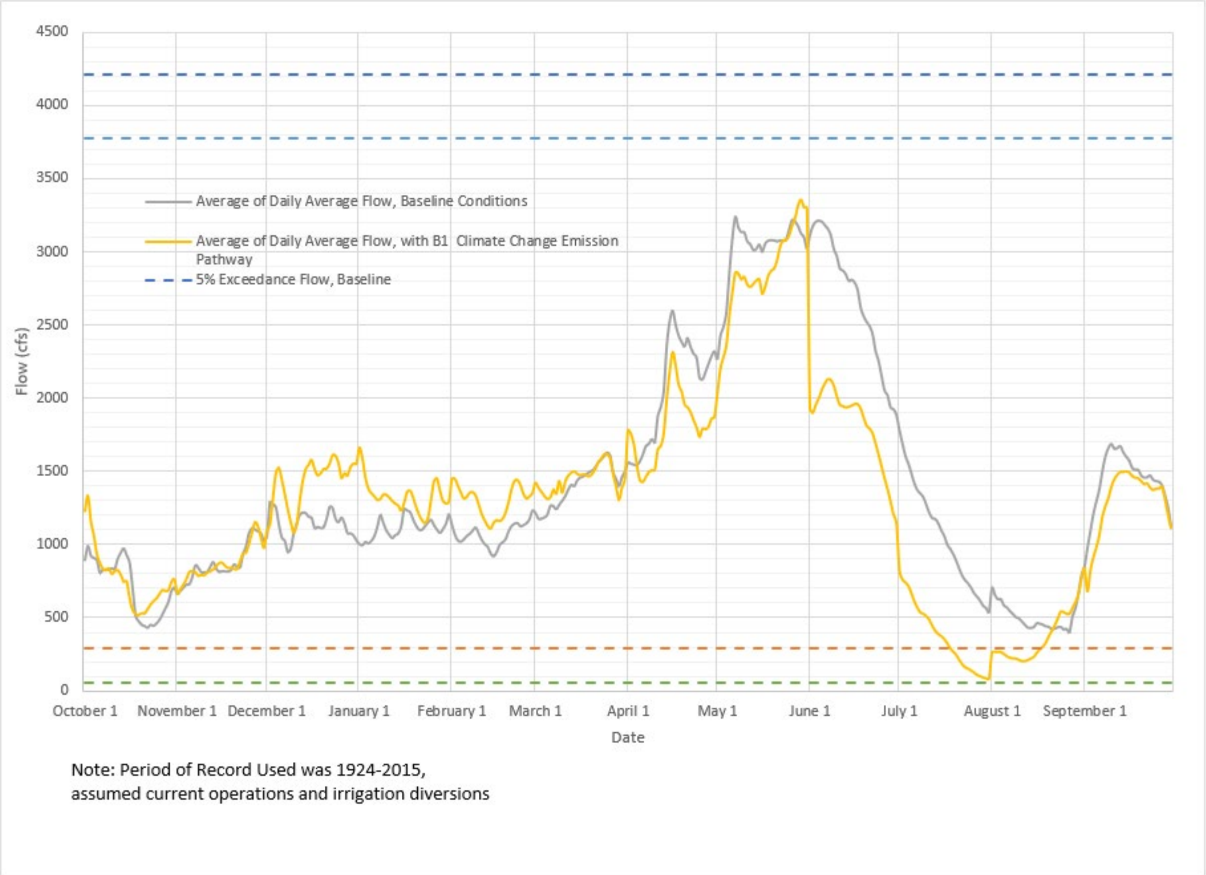
2.5.2.6 Daily Flow Exceedances Using Results of RiverWare Modeling

RiverWare model output was available for the period of 1924 to 2015 for a point 3.7 miles downstream of the site. Baseline conditions are considered to be historical runoff hydrographs into reservoirs with current operating policies and water demands. Climate change conditions also include current operating policies and water demands. A comparison of the modeling results is shown in Figure 9. The modeling results show higher flows in winter, and much lower flows in late spring and summer are predicted with climate change. However, the modeling results for summer need to be carefully reviewed by an applicant to ensure future operating policies are fully considered as the impact on instream flows are considerable. Applicants should consider a range of potential operating conditions for future management of a regulated river system. For these results the modeling shows the fish passage design flows (5% and 95%

exceedance values of daily average flows) are considerably reduced with the 5% exceedance flow changing from 290 cfs to 52 cfs (Table 20). This significant reduction in low fish passage flows under modeled future conditions will be a challenge to the design of a proposed structure. The applicant should consult with the agency that regulates the river (in this case Reclamation) to further evaluate potential future operations as recommended in Section 2.5.2.7. In some cases, the change in flows will render a proposed structure infeasible and the applicant should consider other project alternatives.

Figure 9

Daily Average Flow and Exceedances for Baseline Conditions with Climate Change in the Naches River, Washington (near the Mouth) for mid-century for one GCM.



Note: Period of Record Used was 1924-2015, assumed current operations and irrigation diversions

Note: Period of Record Used was 1924 to 2015 and assumed current operations and irrigations diversions. Future operations may change affecting fish passage design flows.

Table 20
Comparison of Daily Flow Exceedances for Baseline and with Climate Change in the Naches River, Washington, near the Mouth. Based on historical inflows to reservoirs 1924 – 2015. The greenhouse gas scenario used was B1.

5% Exceedance Flow Baseline (cfs)	5% Exceedance Flow – with Climate Change (cfs)	95% Exceedance Flow – Baseline (cfs)	95% Exceedance Flow – with Climate Change (cfs)
4,210	3,778	290	52

2.5.2.7 Estimate of Peak Flows

RiverWare provides daily average flows, not peak flows. The closest USGS gage, Naches River below the Tieton River, is located about 14 miles upstream from the proposed project site. The period of record is 1909 to 1979. Peak Flow statistics for that gage are listed in Table 21.

Table 21
Peak Instantaneous Flow for USGS Gage 12494000 Naches River (below the Tieton River)

Exceedance Probability	Event	12494000 Peak Flood Frequency Analysis (cfs)
0.5	2-year	6,903
0.2	5-year	11,050
0.1	10-year	14,090
0.04	25-year	18,190
0.02	50-year	21,430
0.01	100-year	24,810

The statistical analysis estimates that the 100-year peak instantaneous flow for the period of record to be 24,810 cfs. Output from the RiverWare model was reviewed to determine the highest daily average flows and the percent change in peak daily flows with climate change. That percent change would then be applied to the 100-year peak instantaneous flow to estimate future peak flows.

Table 22
Comparison of Peak Daily Flow from RiverWare Model for Baseline and with Climate Change. The percent change is the adjustment factor.

Baseline Conditions Peak Daily Flow (cfs)	Climate Change Conditions Peak Daily Flow (cfs)	Percent Increase
17,517	19,614	12%

The estimated percent change in flows with climate change (12%) is the adjustment factor applied to the 100-year peak flow from the USGS gage to obtain an estimate of future 100-year peak flows of 27,800 cfs. In summary, fish passage design flows for this site on the Naches River are projected to substantially decrease with mid-century climate conditions. Based upon existing operations of the Yakima Project, the low fish passage flow may be reduced from 290 cfs to 52 cfs. The high fish passage flow is projected to decrease from 4,210 cfs to 3,778 cfs. The Naches River is a regulated river, and the applicant should consider how future operations will occur with climate change as low flows predicted by modeling may not occur due to instream flow requirements and reductions in diversions. Discussions with Reclamation and other agencies should take place to assess how future operations may occur and how they would affect Naches River flow, both low flows and peak flows during flooding.

A potential change in operations provides another element of uncertainty in projections of climate change impacts. The results presented here may represent a high estimate of changes at low flows because the RiverWare modeling maintained the same level of diversions under a reduced water supply scenario. It is recommended that an applicant consider a wider range of potential fish passage flows in regulated river systems to accommodate a range of potential operating scenarios.

2.5.3 Culvert and Water Crossing Designs

Stream crossing projects such as culverts and bridges should follow the processes illustrated in the figures in this chapter, including the risk pathway matrix included in Table 8. Additional guidance related to incorporating climate resilience into stream crossing design has been developed by the State of Washington. That process is summarized included here for the benefit of applicants who may be interested in that process. Please see https://wdfw.wa.gov/species-habitats/habitat-recovery/fish-passage/climate-change for more complete details.

A standard practice for the design of culverts and water crossings for fish passage is to use the stream simulation design method. A stream simulation method crossing design seeks to maintain continuity of channel structure and composition by conveying water, sediment, and wood in the same way as the surrounding stream reach (Barnard et al. 2013; Cenderelli et al. 2011). NMFS guidelines for stream simulation designed culverts and water crossings in California include use of a minimum span width equal to the existing active channel width multiplied by 1.5 (NMFS Guidelines for Stream Crossings in California [NMFS 2022b]) and NMFS guidelines for stream simulation designed culverts and water crossings in Washington, Oregon, and Idaho use a minimum span width of the existing BFW multiplied by 1.5 (NMFS 2022c). Bankfull widths are typically related to 1- to 2-year recurrence interval peak flows (Simon et al. 2004).

Climate change is expected to increase peak flows at the 1- to 2-year recurrence intervals that are responsible for shaping BFWs. The higher flows will cause more sediment movement and may widen the channel, increasing BFW. An estimate of BFW under climate change is needed to design a new crossing while using the guidelines for stream crossings shown in Figure 1.

An approach to estimating increases in BFW due to climate change is presented in the Washington Department of Fish and Wildlife publication *Incorporating Climate Change into the Design of Water Crossing Structures* (Wilhere et al. 2016) and a journal article (Wilhere et. al. 2017). In those publications, hydraulic relationships between bankfull discharge and BFW were used to derive the potential increase in BFW with increases in bankfull discharge, which are expressed as percentages. Hydraulic geometry parameters are defined for three large ecoregions in Washington State: Pacific Maritime Mountains, Western Cordillera, and Western Interior Basin and Ranges. NMFS will use these relationships where they are shown to be applicable and, in other regions, will apply a simplified approach that is described in the following paragraphs.

The relationship between the change in BFW with change in bankfull discharge is expressed in the following equation:

Equation 1

$$\frac{BFW_2}{BFW_1} = \left(\frac{Q_{BF2}}{Q_{BF1}}\right)^b$$

Where Q_{BF} is bankfull discharge, and "b" is a coefficient defined for ecoregions as shown in Table 23. Subscript "2" represents BFW under future conditions, and subscript "1" represents BFW under current conditions. Table 23 lists the parameters used for estimating changes in BFW.

Table 23
Parameters Used for Estimating Change in Bankfull Width

Ecoregion Division	Q_{BF} Recurrence Interval	Equation Parameters	
		b	R-squared (percent)
Pacific Maritime Mountain	1.2	0.50	76.0
Western Cordillera	1.5	0.44	84.4
Western Interior Basin and Ranges (Columbia Basin in Washington State)	1.4	0.60	86.8

The process in a stream simulation design is to measure the BFW (or active channel width depending on location) at the project site and multiply that width by 1.5 to determine the required width of a stream simulation designed culvert or water crossing. With climate change, peak flows are expected to increase, and potentially debris and sediment transport will also increase. The capacity of the crossing to convey the 100-year flood flow with the accompanying debris and sediment should be verified to prevent catastrophic failure.

Within the ecoregions described in the Washington Department of Fish and Wildlife report (Wilhere et al. 2017), Equation 1 and the parameters in Table 23 can be used to estimate future BFWs. Outside of those ecoregions, similar hydraulic relationships may exist and can be used by the applicant after conferring with NMFS. If no similar relationships exist, NMFS may require projection of future 1.5-year recurrence events and use of Equation 1 with a "b" parameter of 0.5 to estimate future BFWs. The methodology described in Sections 2.2 and 2.3 for existing flows, and in Section 2.3.6.1 for future flows, should be used in the analysis.

2.6 Monitoring, Adaptive Management, Operations, and Maintenance

Climate change will likely increase the need for monitoring, adaptive management, and O&M requirements at fish passage facilities. NMFS may require that a M&AM plan be prepared during project design and implementation. The objective of the monitoring is to ensure the facility is performing as intended. For example, fish migration timing may shift through time due to changes in environmental conditions, and facility operations may need to be adjusted earlier or later to capture the new migration windows. Without monitoring, the need for such changes would go unnoticed.

NMFS will likely require that an M&AM plan be incorporated into the project for ESA Section 7 consultations and Section 10 permits covering long-term projects where climate change may exacerbate the adverse effects of an action. The M&AM plan would include adequate monitoring of environmental and biological variables, identification of triggers for additional protective measures, and the types of additional measures that could be completed. Changes in project performance relative to the variables monitored and additional protective measure triggers could result in a reinitiation of consultation.

In addition to increased monitoring of facility performance, daily operations of a facility may require increased effort under future climate conditions. For example, this may include a more frequent need to remove woody debris and sediment following peak flow events, or algal accumulations on bypass screens during summer; restricted adult trap operations due to warmer temperatures; and more frequent fish transport operations from traps due to shorter migration windows or restrictions in holding densities due to warmer temperatures. Chapter 9 of the Design Manual addresses O&M issues associated with fish passage facilities. It describes necessary components of an O&M plan that include facility operating criteria, operating procedures, and staffing requirements based on NMFS's current understanding of O&M for that type of project. However, given predicted changes in hydrology and environmental conditions due to climate change and increased uncertainty and risk associated with the predictions, project O&M activities may need to be adjusted through time, and additional O&M activities may be required to ensure the facility is operating properly.

3 Background

Section 3 covers background information on why building fish passage facilities and stream crossings resilient to climate changes is needed. This includes NMFS's policies regarding climate change, a discussion of climate models (including variability, uncertainty, and risk), biological considerations, and special situations (i.e., sea level rise and subsidence).

3.1 NMFS ESA Policy on Climate Change

NMFS has developed national guidance on the treatment of climate change in NMFS ESA decisions (NMFS 2016), which includes the following:

- Consideration of future climate condition uncertainty:
  - For ESA decisions involving species influenced by climate change, NMFS will use climate indicator values projected under the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP) 8.5 (RCP8.5) when data are available. When data specific to that pathway are not available, NMFS will use the best available science that is as consistent as possible with RCP8.5.
- Selection of a climate change projection timeframe:
  - When predicting the future status of species in decisions under ESA Sections 4, 7, and 10, NMFS will project climate change effects for the longest time period over which NMFS can reasonably foresee the effects of climate change on the species' status.
  - When evaluating effects of the action in ESA Sections 7 and 10 decisions, NMFS will use the time period corresponding to the duration of direct and indirect effects of the action.
- Consideration of future beneficial effects:
  - When NMFS is confident of the relative magnitude of both beneficial and adverse effects, the agency will treat them like any other effects. When less confident of the relative magnitude of effects, NMFS will give more weight to the negative effects to account for the consequences to the species of making a detrimental decision.
- Responsiveness and effectiveness of management actions in a changing climate:
  - Where appropriate, NMFS Section 7 consultations and Section 10 permits covering a long time period during which climate change is likely to exacerbate the adverse effects of an action, should incorporate an adaptive management approach that includes the following:
    - Adequate monitoring of climate and biological variables
    - Identification of appropriate triggers related to those variables
    - Identification of protective measures that can be implemented without reinitiating ESA consultation when triggers are reached or, alternatively,

        identification of triggers that inform the decision to reinitiate ESA consultation

- Incorporation of climate change into project designs:
  - NMFS will review its internal guidance and structural design criteria (e.g., the Design Manual) to ensure that the criteria are adequate for ESA-listed and non-listed species in light of anticipated future climate conditions.
  - NMFS will analyze how effects on anadromous species from project designs may change over the life of the project, considering reasonably foreseeable climate change effects. NMFS will consider how climate change can affect the degree to which projects NMFS evaluates under its statutory authorities may accommodate future as well as current needs of anadromous species. When structural criteria applied by other agencies are not sufficient, NMFS will engage with those agencies to attempt to find solutions (NMFS 2016).

Following issuance of NMFS (2016), standard practices within the WCR on incorporating climate change into project reviews typically include the following:

- The treatment of climate change in project design is done on a case-by-case basis.
- The following factors affect how NMFS analyzes an action:
  - The duration of an action's effects; for fish passage facilities this is typically the design life or license period of the facility but could extend further if it continues to be operated beyond the design life or license period.
  - How effects on anadromous fish from an action and climate change interact.
  - The resiliency of fish, fish populations, and species to the effects of the action and climate change and any amplification of the effects of the action by climate change.
- For actions that have effects lasting no longer than approximately 10 years:
  - NMFS expects that project applicants should begin with recent climate conditions to determine project hydrology (e.g., flood recurrence intervals, peak flows, and fish passage design flows [i.e., the design flows recommended in the guidance documents shown in Figure 1 for the project location, which are typically 5% and 95% for most areas of the WCR]) and environmental conditions including water temperature. As a starting point, NMFS will consider the previous 25 - 30 years of record.
  - Next, NMFS expects the applicant to use this information (the hydrology and environmental data) to evaluate conditions expected to occur in the relatively short (approximately 10-year) project period.
  - NMFS will also consider the potential impacts of a project beyond the historical hydrology and environmental data by focusing on effects the potential for extreme events associated with floods, droughts, and forest fires when assessing potential project impacts.

- For actions that have effects lasting for a period greater than 10 years, including FERC-licensed projects, the level of effort needed for the analysis typically depends on the following:
    - Whether the effects of the proposed action vary in response to environmental conditions that are expected to change through time (e.g., water temperature, streamflow, sea level height, prevalence of invasive species, etc.);
    - Whether the action includes measures to reduce its adverse effects (e.g., through an adaptive management plan) in response to changing environmental conditions.
- NMFS provides technical assistance and works with applicants on the following potential adjustments to a proposed project:
    - Modifying the scope and extent of a proposed action to reduce impacts;
    - Offsetting continuing adverse effects through compensatory mitigation and larger scale planning efforts like marine resource planning;
    - Development of an M&AM plan as described in Section 2.6 that identifies monitoring requirements, triggers, and additional actions if a trigger is reached.
- NMFS evaluates whether future conditions meet the needs of fish based on projections from currently available climate models and other pertinent information. NMFS errs on the side of being more conservative in its review and judgment of the potential effects of a project on anadromous fish populations, and alternative project scenarios will be examined. This could include factoring in precipitation patterns that indicate regions are drier or wetter than normal and a reduction in the productivity of large marine ecosystems on which anadromous fish species depend.

Given the increased risk to species due to climate change, it is critical that fish passage facility designers work closely with NMFS early in the design process. This is needed to ensure that facility designs are consistent and fully integrated with ESA consultation requirements and should save the applicant time and associated costs in the long run. Uncertainty, or the range of future uncertainty and risk, are discussed in more detail in Section 3.4.2.

3.2 Climate Change Requires a New Perspective

Projections of climate impacts on ecosystems are challenged by a limited understanding of physical controls on biological systems, uncertainty in future GHG emissions, climate sensitivity to changes in greenhouse gases, and ecological consequences. Management and conservation plans that explicitly account for changing climate are rare, and existing plans generally rely on retrospective analyses. These uncertainties in forecasting biological responses to changing climate highlight the need for resource management and conservation policies that are robust to unknowns and responsive to change (Schindler et al. 2008). Hydrologic trends in the historic record over the past 50 years or more have been attributed to climate change (Lall et. al. 2018). Trends observed broadly across the west coast region include observed declines in summer flows, advances in runoff timing, and enhanced flooding that are relevant to fish populations (Luce et al 2009, Hamlet et al 2007, Stewart et al 2005). Fish passage structures will often have to accommodate a wider range of flows than was historically the case as both the top and bottom flows move in opposite directions.

Effects of climate change on populations and species within NMFS' authority have already been observed. For example, Crozier et al. (2019) conducted a climate vulnerability assessment that included all anadromous Pacific salmon and steelhead population units listed under the ESA and concluded that major ecological realignments are already occurring in response to climate change. In their view, to be successful, conservation strategies need to account for geographical patterns in traits sensitive to climate change now, along with climate threats to species-level diversity.

To date, NMFS's approach in designing fish passage facilities has been to use the observed historical hydrologic record as a basis for design, based on the assumption this will result in the safe operation of a facility and effective fish passage into the future. For example, the Design Manual states that low flow and high flow ranges will be determined "by summarizing the previous 25 years of mean daily streamflow occurring during the fish passage season or by an appropriate artificial streamflow duration methodology (if streamflow records are not available). Shorter data sets of streamflow records may be usable if they encompass a broad range of flow conditions." However, as pointed out by Hamlet (2011), primary obstacles to climate change adaptation that need to be overcome include assumptions of stationarity as the fundamental basis of water resources system design and the entrenched use of historical records as the sole basis for planning.

Thus, climate change requires a new perspective and additional analyses when designing fish passage facilities, culverts, and stream crossings. *Improving Resilience* addresses this new perspective. It was developed to provide an approach that uses modeled assumptions of future conditions to estimate hydrology and other environmental variables, which are then used to assess the ecological and biological consequences of climate change and incorporate resiliency to climate change into the design of a fish passage facility.

NMFS understands that projecting future conditions involves modeling assumptions and value judgments. This results in increased biological risk and risk that a facility will not perform as expected, requiring redesign and modification. In addition, some biological responses due to climate change are unknown, variable, or are difficult to estimate and predict. Also, potential biological responses and shifts in how humans use available water and watersheds need to be considered and incorporated into the design process.

Following the process flowcharts described in Sections 2.1, 2.2, and 2.3, the applicant and NMFS should use the estimated future conditions and assessments of risks to anadromous species and key facility elements to these conditions to determine how well a proposed design addresses future projected environmental conditions. These changes will require increased coordination with NMFS during the design process and documentation of how resilience to climate change was incorporated into a proposed design. Additional modifications may be discussed and incorporated into the final design.

3.3 Non-Design Factors NMFS Will Assess

The factors discussed in this section are in addition to factors related to hydrology, hydraulics, and biological passage performance described in the guidance documents shown in Figure 1. NMFS will assess the following additional factors when considering how climate change will affect the design of a proposed project:

- Project Lifespan: As discussed in Section 2, the life expectancy of a project and the duration of its effects are major determinants of how the hydrologic and environmental data needed for project design will be sourced. This is because, as shown in Figure 9 and discussed in Section 3.4, uncertainty associated with climate projections increases with the projection period. Properly installed and sized culverts have an assumed life expectancy of 50 years. FERC-licensed projects are defined by the terms of the license. NMFS will evaluate the magnitude of estimated climate change effects over the life expectancy or license term of a project if it is likely to remain in place and continue to have effects on fish passage.
- Project cost: NMFS is interested in working with applicants to arrive at a design that is mindful of the cost of the project while addressing the biological and facility risks associated with climate change.
- NMFS Climate Change Policy: NMFS will review the policy on incorporating climate change into ESA consultations (Section 3.1) and incorporate the policy into their assessments.
- Biological Risk: NMFS will incorporate the relative importance of the proposed project, its location in a watershed, and the watershed’s importance to anadromous fish species populations (Section 3.5) into project assessments.
- Additional Risk: NMFS will review additional risks associated with designs that are not resilient to climate change, which could include the following:
  - The cost of redesigning and rebuilding a facility;
  - The biological impacts associated with a facility not providing fish passage as intended;
  - How fish may be affected by the facility if the region experiences a significant climate-related effect such as three or more drought years in a row.
- Alternatives to the design: For example, this might include assessing whether a nature-like fishway or trap-and-haul program is better for adult passage than a traditional fish ladder when climate change is considered.

3.4 Climate Models, Uncertainty, Variability, and Risk

3.4.1 Global Climate Models

GCMs are numerical models that represent the major climate system components (atmosphere, land surface, and sea ice) and their interactions. The globe is divided up into grid cells, each of which is described by both fixed properties and time-varying data (i.e., pressure, temperature, humidity, and wind velocity at several layers for the atmosphere). The model is run by solving a set of coupled fundamental mathematical equations that describe the physics and dynamics of the movements and processes taking place in each of the earth's systems, to advance the parameters for each grid cell by a time step that is typically around 10 minutes. The values for each parameter are saved or processed (to derive other quantities) for output at different time scales (e.g., hourly, 3-hourly, daily, monthly) (NW CSC 2021).

The CMIP is a suite of coordinated GCM experiments with participation from approximately 30 modeling groups around the globe, developed for a series of reports by the IPCC (IPCC 2007, 2013, 2021). Each modeling group provides output of its models to a central archive to facilitate an inter-model comparison and studies using the data developed by others. With each IPCC report there is a new generation of models that were improved upon based on research conducted in the intervening years. The most recent IPCC report (IPCC 2021) is the Sixth Assessment and is based on the CMIP6 generation of models. While the output of the latest generation of models is expected to be downscaled and used for future hydrologic modeling efforts, these products are not yet available. Currently available hydrologic models to project future streamflows use downscaled output from CMIP3 (IPCC 2007) and CMIP5 (IPCC 2013) modeling efforts.

GCMs have generally increased in their spatial representation and complexity, and their representation of the statistics of historical conditions including recent trends. Compared to CMIP3, there is a much larger archive of model output for the CMIP5 models, with daily output available for most runs and even 3-hour output for some variables. Downscaling methods have also advanced, so in general, products based on CMIP5 are preferred in most cases to those based on CMIP3. These advances are significant from a fish passage context because the daily data can be used directly in hydrologic modeling without first disaggregating the data from monthly data and the assumptions that entails. Daily model output also facilitates the computation of climatic indices based on daily data, such as extremes of daily temperature or precipitation instead of monthly averages, peak flows and low flows within a month, number of days with flows above or below thresholds, and hydrographs with daily detail. The improvements in CMIP5 do not invalidate the previous work. However, CMIP5-based products are preferred for new analyses over those based on CMIP3. Products appropriate for use in analysis for WCR fish passage design are used in several examples in Section 2.5 and are detailed in Section 6, including citations and sources for downloading the data.

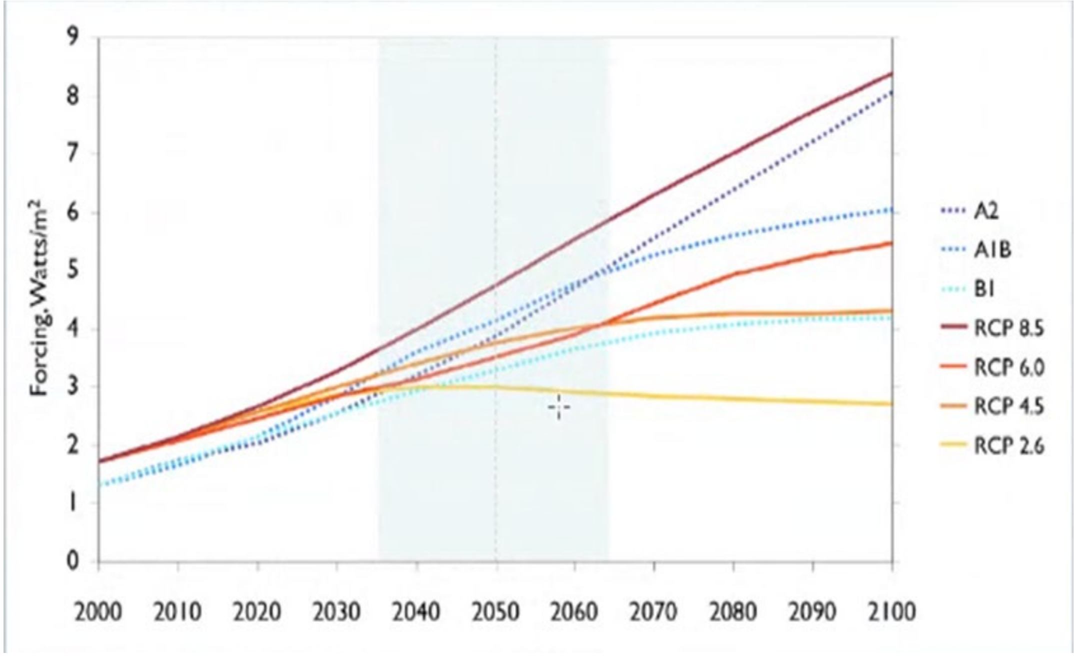
The CMIP5 climate projections were run for the 2006 to 2100 period. Unlike historical runs, the projections consider a range of potential socioeconomic scenarios that address changes in human population, energy consumption, land use, and globalization (RCPs). The RCPs translate the potential socioeconomic scenarios into projected changes in radiative forcing (i.e., the additional energy trapped by the earth-atmosphere system) measured in watts per square meter (W/m^2) by year 2100, which is quantified relative to 1850s climate. The four RCP experiments in CMIP5 are as follows:

1. RCP 2.6, +2.6 W/m^2 by 2100 with aggressive climate action,
2. RCP 4.5, +4.5 W/m^2 by 2100 with moderate climate action,
3. RCP 6.0, +6.0 W/ m^2 by 2100 with moderate climate action,
4. RCP 8.5, +8.5 W/m^2 by 2100 with no climate policy and business-as-usual emissions.

Note that RCP4.5 and RCP6.0, as well as A2 and A1B from CMIP3, have similar climate change implications out to mid-century (around 2050), while RCP2.6 has lesser effects on climate and RCP8.5 has greater effects (see figures 10 and 11). The four RCPs increasingly diverge after mid-century in their effects on climate. Figure 10 presents the radiative forcing over the 21st century for the four RCPs in CMIP5. A comparison of emissions scenarios A2, A1B, and B1 for CMIP3 is included. The CMIP3 emissions scenarios are described in a special IPCC report on emissions scenarios (IPCC 2000). As stated in Section 1, climate change information is updated constantly. Figure 11 compares RCPs used in CMIP5 (dashed lines) with Shared Socioeconomic Pathways (SSPs) used in CMIP6 (shaded areas) indicating the range of outcomes associated with different models.

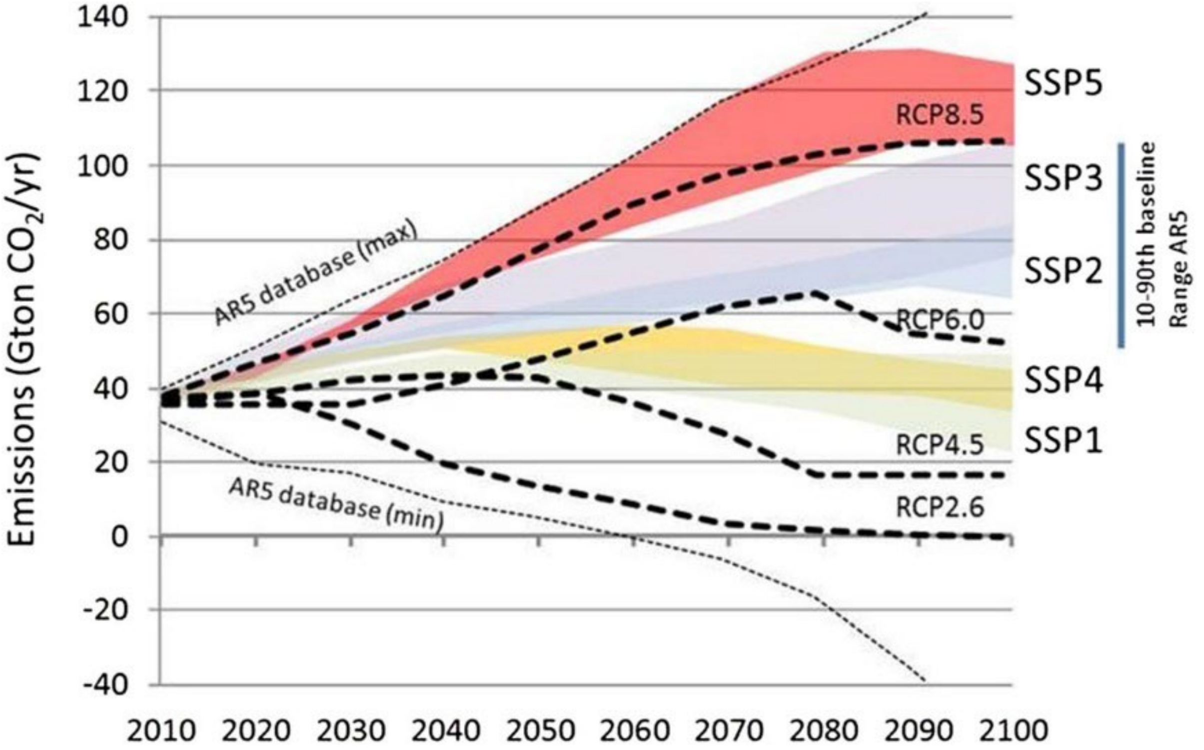
Figure 10

Projected Effects of Climate Change Vary by emission scenarios and Increase with Time



Note: Comparison of the radiative forcing of the Representative Concentration Pathways (RCPs) used to drive the CMIP5 climate models and the SRES emissions scenarios used for the CMIP3 climate models, from 2000–2100. Over the 2050-centered analysis period (2035-2064; blue shading) the three SRES scenarios and RCP 4.5 and RCP 6.0 have similar radiative forcing, and thus similar projected global temperature increases. RCP 8.5 is higher, and RCP 2.6 is lower. All of the RCPs and SRES scenarios diverge markedly after 2050. (Original Data source: SRES: IPCC 2000; RCP: IIASA RCP Database; http://tntcat.iiasa.ac.at:8787/RcpDb/) . From Lukas et al. 2014 Fig 3-3. The figure displays radiative forcing associated with CMIP3 (A2, A1B, and B1) and CMIP5 (RCPs) climate models from 2000 to 2100. The mid-century (2035 to 2064) period is depicted with blue shading. The CMIP3, RCP4.5, and RCP 6.0 have similar radiative forcing and projected global temperature increases, whereas RCP8.5 is higher and RCP2.6 is lower.

Figure 11
Comparison of RCPs (dashed lines) Used in CMIP5 and SSPs (shaded areas) used in CMIP6



Note: Graph acquired from Ho et al. 2019, This graph is similar to Figure 10, but compares the radiative forcing (warming) associated with the CMIP5 (RCPs) and CMIP6 (SSPs) climate models from 2010 to 2100. The shaded areas for the SSPs indicate the range of outcomes of different models as captured by Riahi et al. (2017). This graphic does not imply the likelihood of one future over another.

The GCMs provide the primary scientific basis for understanding climate dynamics into the future. However, output data from GCMs are at macroscales (i.e., 50- to 300-kilometer grid cells), making direct application of such data intractable for streamflows and environmental conditions relevant for fish passage. To overcome these limitations, coarse-scale GCM output must be translated (or downscaled) to local scales for modeling and value-added decision making (NW CSC 2021). The GCM's that are the basis for most downscaled climate and hydrology products are updated every few years based on new generations of GCMs released as part of the CMIP. Recent generations of GCMS have been updated for the IPCC reports released in 2007, 2013, and 2021 (IPCC 2007, 2013, 2021). Techniques for downscaling are often developed to address specific needs, such as hydrologic extremes, and typically evolve between the IPCC reports. Thus, there are multiple downscaled climate and hydrology products available. Downscaled products based on the 2021 GCMs are expected to become available in the next year or two. Section 6 provides information and links to products appropriate for design of fish passage.

There are two general approaches to downscaling methods: statistical and dynamical. In statistical downscaling, the GCM outputs are calibrated to historical observations and formulated by applying statistical relationships between large-scale observations and place-based-scale observations from the historical record to the GCM projections. A primary limitation of statistical downscaling methods stems from the built-in stationarity constraint of historical observations, which may unjustly constrain relationships in a changing climate. For example, changes in snow cover extent in a warming scenario may result in local climate feedbacks that may not be resolved using historical observations. Another limitation is that statistical downscaling is less accurate in areas where there are few observations available (e.g., in mountains or remote rural areas). Most observations tend to be at lower elevations and near cities, so projections tend to be more uncertain and less accurate as you move away from these locations. On the other hand, dynamical downscaling is limited by the fidelity of the regional models, which may not perfectly represent the physics of the system.

Recently, some downscaling methods have been designed to better represent future extremes, including those in the products considered appropriate in Section 6. In this context better represent means that when runs are made to compare to historical conditions, the method does a good job of simulating the statistics of past extremes, so they’re assumed to be a better projection of future extremes than other methods. This includes the statistical downscaling product called Localized Analogs (LOCA; Pierce et al, 2104, 2015, Vano et al. 2020). Dynamical downscaling generally does better at extremes (particularly for precipitation), because it better represents topographic variations and thus local weather and climate processes, and thus can project changes that go beyond the range of what was seen in the past. In dynamical downscaling, regional atmospheric models are run over just a particular region of the earth utilizing the GCM outputs as boundary conditions on the simulation. A regional climate or weather model is used to simulate finer scale physical processes that are consistent with the larger scale GCM output used as boundary conditions. Dynamical downscaling may overcome some of the limitations of statistical downscaling. Specifically, it has the benefit of not relying on historical climate patterns to project future change. However, dynamical downscaling is computationally expensive and the current availability for CMIP5 models is limited, although more are expected over the next several years. However, dynamical downscaling introduces additional uncertainties, such as how processes are represented in the regional models, and may require additional statistical downscaling to remove introduced biases (NW CSC 2021, WHCWG 2013).

Where dynamically downscaled products are available, applicants may wish to discuss with NMFS and climate experts whether these should be used in lieu of, or in addition to, statistically downscaled models. A comparison of the two might involve comparing observed and modeled historical flows and reviewing the methods used to develop the projections, including the resolution of the regional climate model, and approach to hydrologic model calibration. Such an analysis may be in publications for a region or river basin. However, we acknowledge that this may be beyond the capacity of most project designers. This level of discussion may be needed for high importance or low risk tolerance projects, especially those which will be costly to build.

3.4.2 Uncertainty or the Range of Possible Futures

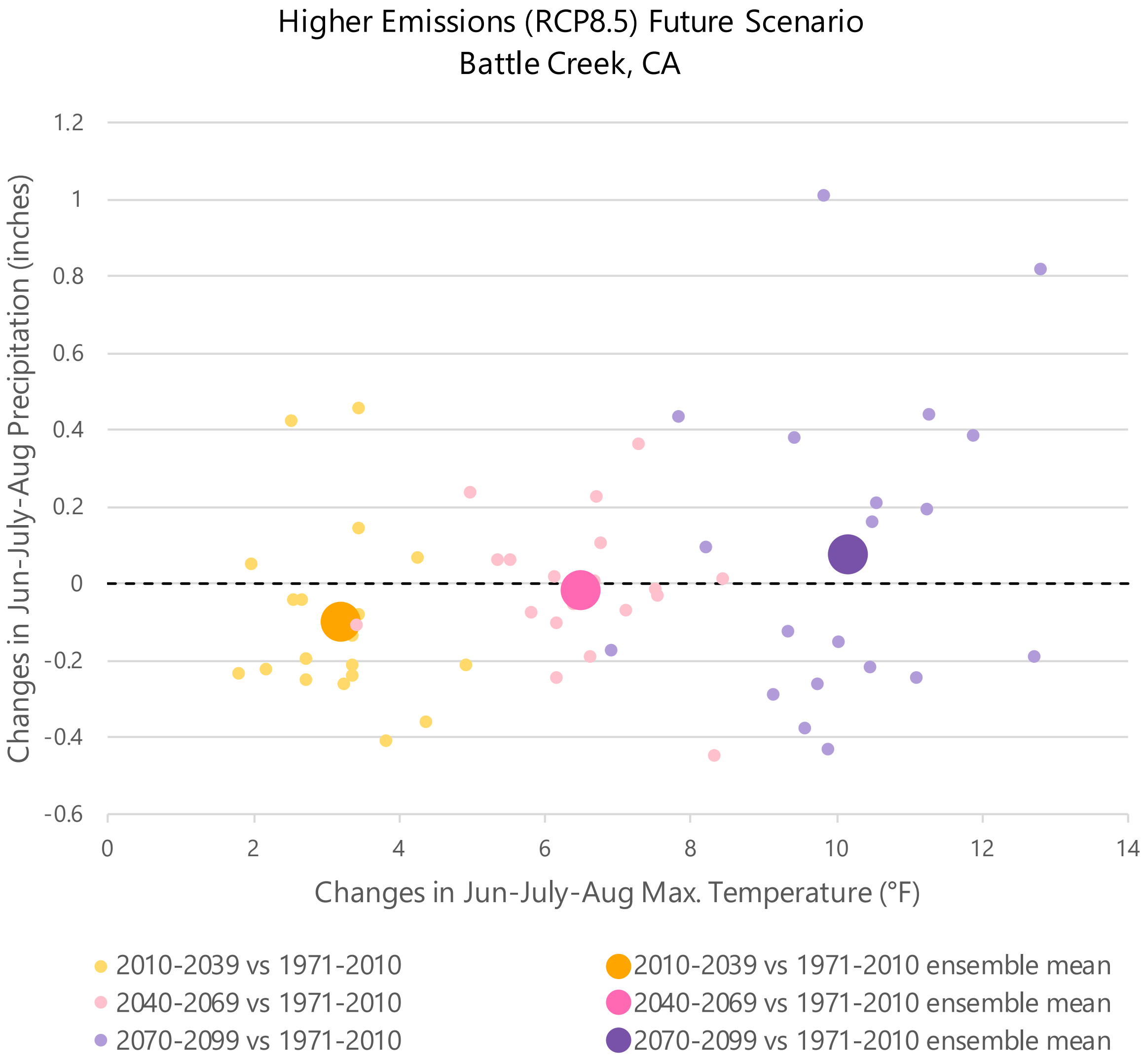
Climate projections offer a range of plausible futures, often described as uncertainty. Future climate change will depend upon the amount of global greenhouse gases emitted and the response of the earth system. Projecting emissions into the future is difficult because it is not known how the global human society will change during that time in terms of population growth, economic growth, energy use, technology, and human response to changing climate. The longer the projection period, the greater the spread in the projections because of uncertainties in human behavior and uncertainties about how the Earth's climate will respond.

Simulations of future climate for a given region, including the temperature and precipitation outputs, differ. This is because of differing assumptions of human behavior among climate models, natural variability, and uncertainty regarding some key climate processes, GCM configuration, and future emissions. However, we note that all GCMs project increases in global average temperatures, with the main differences among GCMs being the magnitude of the increases. Conversely, projections of average precipitation can show increases or decreases, depending on the particular GCM and location. The tendencies vary geographically, with parts of the Pacific Northwest likely to get more precipitation and parts of the southwest likely receiving less, and variation across the WCR is also related to elevation and terrain (May et. al. 2018; Gonzalez et. al., 2018; NCA 2018). Another source of uncertainty is the availability and accuracy of observational data available to test or calibrate the climate models, especially when downscaled to local scales. The predominant source of projection uncertainty changes with the length of time modeled. Initially, natural variability is the main source of uncertainty. This is followed by uncertainty associated with GCM configuration by mid-century and human behavior by late century.

These uncertainties result in a wide range of projections or potential outcomes. While a wide range of results makes interpretations and use of model outputs challenging, it provides useful information for project planning. To be conservative and precautionary in project design, NMFS (2016) requires the use of emissions scenario RCP8.5 (i.e., high emissions, business as usual, or continued emissions at current trajectories).

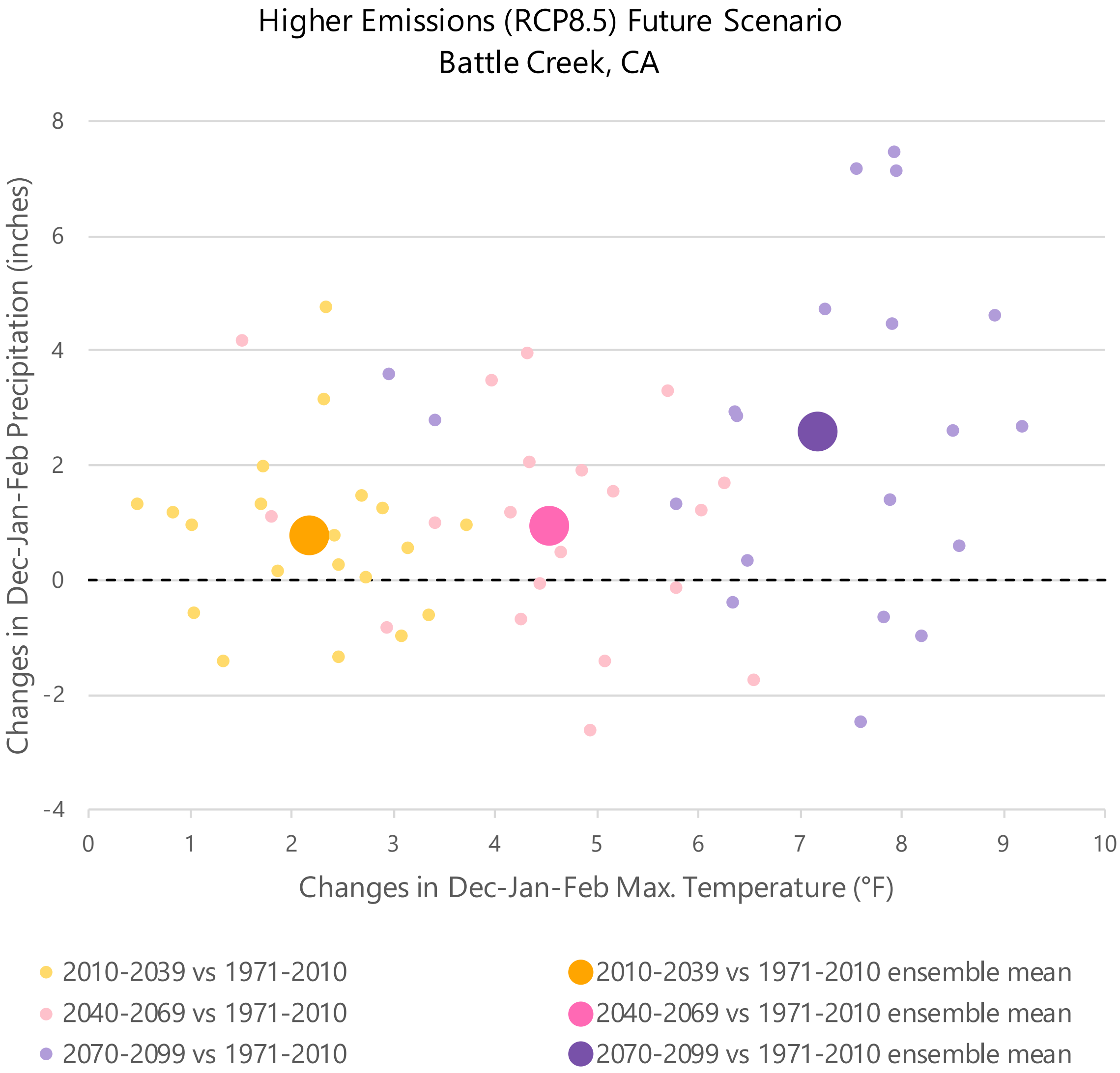
As described earlier and in Figure 10, there is a range of possible futures or GCM projections for each time period. Figures 12a and 12b show the ranges in outputs from single GCMs (small dots) and ensemble means (large dots) for changes in precipitation and air temperature near Battle Creek, in northern California. All the models represented in figures 12a and 12b show increasing temperatures for June and July. For precipitation, these figures show that some models project precipitation decreases, while others project precipitation increases from June through August. Two strategies to address uncertainty in climate change projections are commonly used. The first is to use a multi-model ensemble of CMIP models, from which the ensemble mean and range of projections from several GCMs is evaluated (IPCC 2010; Parker 2013). Another approach is to use individual model projections in a scenario planning exercise. This has become common in natural resource planning (Fren and Morrison, 2020, Borggaard et al. 2019; Rowland et. al. 2014), and can consider multiple possible futures, and in particular futures that are challenging for a system such as high or low flows or high stream temperatures that may stress a system. While using the ensemble mean is appropriate for many projects, using a range of futures (Section 2.5.1.7) is an appropriate way to bracket the uncertainty in modeling, in particular for high importance factor or low risk tolerance situations.

Figure 12a
Change in Summer Mean Air Temperature vs. Mean Summer Precipitation for Battle Creek, California (Showing the Ensemble Average and Spread of all GCM for CMIP5 Based on RCP8.5 for Three Current or Future Time Periods Compared to 1971–2010)



Note: The range of projections for summer (June-July-August) near Battle Creek in northern California for changes in precipitation and air temperature. Three future time periods are shown. Small dots indicate twenty individual GCM and large dots indicate the ensemble means for each time period. Graphic generated at The Climate Toolbox Future Climate Scatter Tool (Climate Toolbox 2022) where other areas and locations and variables may be selected.

Figure 12b
Change in Winter Mean Air Temperature vs. Mean Precipitation for Battle Creek, California (Showing the Ensemble Average and Spread of all GCM for CMIP5, RCP8.5 for Three Current or Future Time Periods Compared to 1971–2010)



Note: The range of projections for Winter (December-January-February) near Battle Creek in northern California for changes in precipitation and air temperature. Three future time periods are shown. Small dots indicate twenty individual GCM and large dots indicate the ensemble means for each time period. Graphic generated at The Climate Toolbox Future Climate Scatter Tool (Climate Toolbox 2022), where other areas and locations and variables may be selected.

3.4.3 Climate Change Across the West Coast Region

Average temperatures are projected to increase across the Western United States out to mid-century. Precipitation changes are generally small compared to year-to-year variability, but models tend to project increases in annual precipitation for the Northwest, particularly in the Columbia and Missouri River Basins, and decline in the Southwest (USGCRP 2018, May et al. 2018; Gonzalez et al. 2018; NCA 2018). In most river basins, snowpack is projected to decline as more winter precipitation falls as rain and warmer temperatures melt snow sooner. In some high-elevation regions, snowpack may increase due to a slight projected increase in winter precipitation. Throughout the Western United States, seasonal changes in streamflow are projected to occur earlier in the year (U.S. Bureau of Reclamation 2021a, 2021b). In the Columbia River, Klamath River and Sacramento-San Joaquin River basins, the predicted patterns through year 2100 include 1) mean annual temperature (air temperature) increasing and a widening ensemble spread, implying there is some increase in the range of mean annual temperature values over time; 2) April 1 snow water equivalent (median value) decreases over time; and 3) the April through July runoff also decreases during the projection period (U.S. Bureau of Reclamation 2021b). Observed stream temperatures are increasing (e.g., 0.14°C to 0.27°C per decade in summer and early fall from 1976 to 2015, Isaak et al. (2018)) and will likely continue.

Projections of climate and hydrologic conditions in the Western United States are based on the GCMs discussed in Section 3.4.1. The available resources include climate and hydrologic modeling results using CMIP3 and CMIP5, using one of several statistical downscaling techniques including the Bias-Corrected Statistically Downscaled (U.S. Bureau of Reclamation 2013), MACA (Abatzoglou and Brown 2011), and Localized Constructed Analogs (LOCA; Pierce et al. 2014, 2015; Vano et al. 2020) as input to hydrologic models such as VIC (Gao et al. 2010; Liang et al. 1994). Ensembles of GCMs are also available that can provide a range of uncertainty in climate projections.

3.4.4 Risk

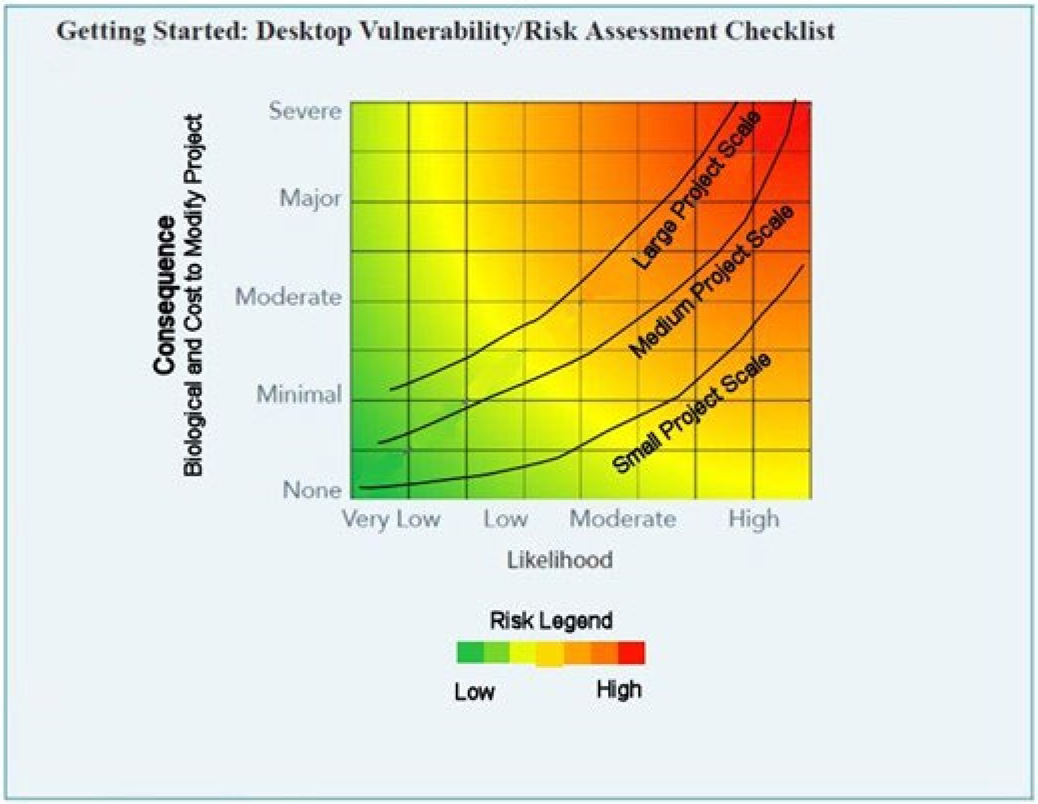
Climate change over the 21st century is projected to modify the rate and timing of streamflow in the Western United States and increase stream temperatures (NCA 2018). The biological risks associated with proposed actions increase with climate change because the project may not function as intended or produce the desired outcomes.

Risk is a measure of the chance and the consequence of an uncertain future event (Yoe 2012). Risk consists of two parts: an undesirable outcome (such as a reduction in fish passage) and the probability of that outcome occurring. The probability of that outcome occurring is related to the range in potential climate outcomes (related to uncertainty as discussed in Section 3.4.2) and whether the design of the facility can accommodate those outcomes.

Risk to a fish population is not uniform across life stages and periods. For example, errors in underestimating low flow during summer are likely more biologically meaningful than overestimating peak flows during flood events. This is because low flow during summer is often associated with warmer temperatures, can occur for weeks or months, and limits habitat capacity and productivity. Peak flows are typically short in their duration, water temperatures are not a factor, and fish occupy favorable micro-habitats until the flows recede. An exception to this could occur in highly erosive geologies where the risks of underestimating peak flows may become comparable to the risks of underestimating low flows (e.g., higher peak flows combined with highly erosive geologies and increased wildfires on top of that could lead to catastrophic debris flows) and also in areas where human activities have simplified large portions of stream channels, leaving fish few refuges from high flows.

NMFS will judge the level of risk and potential consequence to individual fish, populations, and species associated with a proposed action and provide guidance to an applicant on the level of acceptable risk. Figure 13 provides a general framework for thinking about risk and depicts how risk and consequences increase with larger projects. However, each project is unique and will be assessed individually. Small projects have the potential to produce very large biological responses, such as the removal of a small diversion dam that provides access to excellent spawning and rearing habitat. In this example, the cost benefit associated with the project is likely less risky than a large project because of lower cost, but the biological risk is large if the project is not designed properly and causes passage issues.

Figure 13
How Consequences Increase with the Likelihood of Effects Occurring from Climate Change and Project Scale



Note: Graphic adapted from FHWA (2015).

Section 2.4 provides tables describing risks for different fish passage facility elements such as fish ladders, fish screens, bypass systems, barriers, trap and transport, and culverts. An applicant should consider the risk pathways in the design of their project and incorporate an appropriate range of hydrologic model outcomes in the design.

3.5 Biological Responses to Climate Change

This section provides background information for applicants on biological factors NMFS may consider when reviewing facility designs as well as examples from research. The biological responses described in Section 3.5 are the basis for the risks listed in Section 2.4 (Tables 1 to 10) and the potential actions listed to address them. Section 3.5.1 outlines the three main effects of climate change on anadromous species. It presents an expanded discussion of potential effects from warmer temperatures given the importance of including these effects when assessing overall risk to cold-blooded organisms. Section 3.5.2 provides additional information on specific factors to consider.

3.5.1 Main Effects

The three main effects of climate change on anadromous fish species are associated with changes in water temperature, low flow, and peak flow. The effects of low and peak flow on fish passage facility performance and temperature are described in Tables 1 to 10 (Section 2.4). Additional information on temperature effects is discussed in Section 3.5.1.1. In addition, Section 3.5.1.2 discusses flow variability, gender differences, and interacting effects to point out these important but perhaps subtle factors when assessing the biological risks associated with a proposed project.

A key concept to keep in mind is spatial variability. This is the impetus behind accessing climate projections that are downscaled for the specific location of a proposed project (Section 2). Climate effects vary spatially and are projected to be widespread in the WCR. For example, Wade et al. (2013) estimated that steelhead exposure to increases in temperature will be most widespread in the southern Pacific Northwest, whereas exposure to substantial flow changes will be most widespread in the interior and northern Pacific Northwest. They also noted few locations with low exposure and low sensitivity to climate change.

Anadromous fish species can respond to effects of climate change at two levels. First, individual fish will respond to environmental conditions within fixed tolerance limits. For example, Armstrong et al. (2013) observed behavioral thermoregulation enabled juvenile Coho Salmon to mitigate trade-offs between trophic and thermal resources by exploiting thermal heterogeneity. Fish that exploited thermal heterogeneity grew at substantially faster rates than did individuals that assumed other behaviors. If a fish cannot mitigate the effects of environmental conditions through behavioral adjustments, they may die. Second, there can be population-level responses that reflect the ability of a population to respond or adapt to the environmental variability to which the population is exposed (Crozier et al. 2008). McClure et al. (2013) identify the following characteristics of populations and species that influence their resilience and vulnerability to climate change:

- The dispersal potential of the species (this confers resilience by reversing local extinction)
- Population- and species-level diversity (this provides adaptive capacity by promoting evolutionary adaptation);
- Phenotypic plasticity (the ability of one genotype to produce more than one observable trait; this confers resilience by allowing phenotypic response to environmental changes);
- Generation time (long generation times limit the rate of demographic response to changing conditions but may also buffer a population during extreme events);
- Small geographic range (this increases vulnerability through greater proportional loss of current habitat, but species may gain new habitat elsewhere).

Timpane-Padgham et al. (2017) reviewed the published literature on ecological resilience to identify biological, chemical, and physical attributes that confer resilience to climate change to inform habitat restoration. It is important to recognize that individual and population-level responses to the effects of climate change are the result of changes in habitat access, quality, and capacity. Numerous studies on the effects of climate change on habitat provide a useful framework for assessing effects of climate change. . To inform habitat restoration activities, Timpane-Padgham et al. (2017) reviewed the literature to identify biological, chemical, and physical attributes of ecosystems that confer resilience to climate change. A total of 45 attributes were identified and classified as individual (9), population (6), community (7), ecosystem (7), or process-level (16). The authors point out that certain ecological attributes such as diversity and connectivity are commonly considered to confer resilience to climate change because they apply to a wide variety of species and ecosystems. Connectivity (i.e., fish passage) supports diversity and, therefore, ecosystem resilience to climate change. When reviewing proposed project designs,

NMFS will consider the population- and species-level characteristics identified by McClure et al. (2013), ecosystem and ecological attributes that confer resilience to climate change identified by Timpane-Padgham et al. (2017), and specific biological responses to conditions from climate change. For example, migration delays under future climate change due to a poorly performing passage facility at a barrier will be a key consideration of NMFS when reviewing proposed projects because of the potential effects on individual fish survival and overall population productivity.

3.5.1.1 Water Temperature

The Columbia River has been warming, high temperatures last longer, and stressful temperatures begin earlier and persist longer. For example, Quinn and Adams (1996) reported that adult sockeye salmon migrated approximately 6 days earlier and experienced temperatures roughly 2.5°C warmer at the time of their analysis compared to the 1950s. In this situation, individual fish adjusted their migration timing and behavior to an environmental condition, but the shift may also influence the population. In a recent study of the Western United States, Fitzgerald et al. (2021a) developed a 465,775-river kilometer (km) spatial stream network and applied plausible future stream temperature change scenarios to predict thermal impacts on migratory riverine populations of 26 ecotypes of Chinook salmon. They reported that thermal stress, assessed for each life stage and ecotype based on federal criteria, was influenced by migration timing rather than latitude, elevation, or migration distance, and early-migration phenotypes were especially vulnerable due to prolonged residency in inland streams.

Shifts in migration timing might be advantageous to a population (e.g., adults are able to reach the spawning grounds by migrating earlier). It could also be detrimental if it results in lowered passage and spawning success, egg survival, and shifts in emergence timing that affect juvenile migration timing and survival. Therefore, changing environmental conditions can result in individual fish responses that may have population-level effects through time. Both immediate and delayed effects on the different life stages need to be considered.

The following reports demonstrate that environmental conditions from climate change, including higher summer water temperatures and lower instream flow, and may create lethal passage conditions for fish or have indirect effects on population survival:

- Bowerman et al (2021) modelled adult pre-spawn mortality rates and found a strong positive association with mean summer temperatures, suggesting that populations that spawn in the warmest portions of the range are at highest risk.
- Israel et al. (2015) reported that the average estimated egg-to-fry survival rate for brood year (BY) 2013 winter-run Chinook salmon in the Sacramento River was 15.1% in 2014, compared to 30.8% for the comparative period (BYs 2007 through 2012 and Water Years 2008 15 through 2013). They concluded the winter-run Chinook salmon monitoring data suggested that the abundance of juveniles surviving to the Sacramento-San Joaquin Delta was likely reduced by the drought conditions experienced in WY 2014.
- Murauskas et al. (2021) reported that more than 90% of sockeye salmon that entered the Columbia River and were destined for the Okanagan River in 2015 did not survive to the spawning grounds during record high water temperatures observed that year.
- LeMoine et al. (2020) found that landscape resistance mediates native fish species distribution shifts and vulnerability to climate change in riverscapes. They observed distribution shifts in four native species (bull trout, cutthroat trout, longnose dace, and slimy sculpin) across hundreds of sites in a large river network over a 20-year period and how these shifts are impeded by natural and anthropogenic stream barriers.
- Rubenson et al. (2020) documented current and expanding distributions of smallmouth bass in rivers throughout the northwestern U.S., and the degree to which bass distributions may overlap with natal areas of anadromous and resident salmonid species. The invasion front of bass populations appears to be strongly controlled by stream temperature and reach gradient.
- Naughton et al. (2005) reported reach survival estimates for sockeye salmon in 1997 (a high flow year) exceeded 90% through all sampled reaches in the Columbia River hydrosystem, except for the reach between Bonneville and The Dalles dams (survival was 87.4%). However, adults that entered later in the migration season and encountered lower flows and higher temperatures were less successful.
- Caudill et al. (2007) monitored the migration behavior of Chinook salmon and steelhead at eight Columbia and Snake River dams and observed that individual fish that did not reach the spawning grounds had longer passage times at nearly all dams than fish that eventually reached tributaries. They suggested that repeated exposure to elevated temperatures or lack of lower temperature conditions that would allow for recovery may compound the impact of temperature exceedances by causing energy depletion across several days or weeks and may cause delayed mortality.

- In the Fraser River, Crossin et al. (2008) reported that 68% of acoustically tagged sockeye salmon held for 24 days at 10° C reached the spawning grounds, compared to 35% of similarly tagged fish held at 18° C.
- Hinch and Martins (2011) conducted an extensive literature review of potential climate change effects on survival of Fraser River sockeye salmon to inform management decisions. Mortality to adults during freshwater migration based on telemetry studies was substantial in many stocks across all run timing groups in recent years and in years when migration temperatures exceeded 18 °C. They concluded that en route loss may be a critical contributing factor to decreasing trends in abundance for some Fraser River sockeye salmon stocks, especially those that do not cope well with warming rivers.
- In 2002, more than 34,000 adult salmon were estimated to have died in the lower Klamath River due to low flow and an apparent lack of migration cues to proceed upriver that resulted in migration delays, crowded conditions, warm water temperatures, and parasitic and bacterial disease outbreaks (Belchik et al. 2004). The frequency of these migration mortality events is variable, and the events tend to occur in years with anomalously high water temperatures or affect a subset of a returning cohort that entered the river during a period of peaking water temperatures (Cooke et al. 2004; Crozier et al. 2011).

Risks associated with elevated water temperature will expand to more watersheds as conditions are projected to continue to warm with climate change (Wade et al. 2013; Mantua et al. 2010). The most pronounced effects of climate change will occur at the southern margins of species' distributions (Crozier et al. 2008; Mantua et al. 2015; Herbold et al. 2018). Vulnerable life stages include adults that enter freshwater several months prior to spawning or undergo long adult migrations in freshwater (spring-run Chinook salmon, summer-run steelhead, sockeye salmon, winter-run Chinook salmon, and sturgeon species) and juvenile anadromous fishes that rear in freshwater one or more years prior to migrating to sea. While species have adapted behaviors to find refuge from the most extreme temperatures, the upper thermal limit of approximately 23°C (McCullough 1999) observed across regions and species points to an ultimate upper physiological limit to heat tolerance (Crozier et al. 2008).

Oftentimes effects on individual fish will be sublethal. In Pacific salmon, temperature affects maximum oxygen consumption rate and cardiac performance, stress, and disease. Sublethal exceedances of optimal temperatures for aerobic capacity typically occur during short periods of upstream migration that initially may not appear to cause migration delays or mortality. However, aerobic metabolism can remain elevated during a recovery period after exposure to higher than optimal temperatures (Farrell et al. 2008).

Fish that migrate prior to spawning (e.g., spring-run Chinook salmon and summer-run steelhead) evolved to migrate during favorable conditions prior to reaching a holding area or avoid poor conditions during the migration route. However, those fish are also susceptible to conditions during the holding period that may last months, including elevated temperatures that can affect embryo development. Berman (1990) found that adult spring Chinook salmon exposed to higher temperatures had embryos with higher levels of pre-hatch mortalities and developmental abnormalities and produced smaller eggs and alevins.

Chronic stress is energetically costly and may divert energetic stores away from aerobic capacity and migration success (Whitney et al. 2016). Future climate conditions may expose more salmon populations to temperature conditions that exceed their adapted aerobic scope for short-term cardiac performance, or for which they lack sufficient energy stores to meet the demands of upstream migration (Whitney et al. 2016). Increasing water temperature also exacerbates disease conditions in fish because parasitic and bacterial diseases become more virulent with increasing temperature (McCullough 1999). Sublethal behavioral responses include adults experiencing migration delays while seeking thermal refugia during summer (High et al. 2006; Goniea et al. 2006; Hyatt et al. 2003).

Adult fish can also experience direct mortality prior to spawning. Kock et al. (2020) present a review of trap-and-haul programs used to manage Pacific salmonids in impounded river systems. They point out that pre-spawn mortality can be exacerbated by trap-and-haul programs due to stress during collection and transport and the fact that fish are released into an environment they did not volitionally enter.

In summary, temperature has a large effect on fish metabolism and health and can influence fish passage success, both directly and indirectly, and during en route migrations to spawning grounds and holding prior to spawning. As mean and peak summer water temperatures rise in the future, migration delays and mortality events may occur more often. NMFS will be especially focused on potential effects of temperature and the interplay between the design of a fish facility and temperature on anadromous fish migrations, passage success, and holding prior to spawning under future climate conditions.

In general, these types of effects are not easily observed and require specific monitoring studies. Designing fish passage facilities that simply prevent exposure to upper critical temperature thresholds may not be sufficient to ensure successful passage of summer-migrating species. Minimizing stress and disease exposure to adult anadromous fishes during ladder passage, collection, holding, and transportation will take on greater importance as water temperatures increase. Artificial temperature modulation at fishways and ladders may be necessary (Caudill et al. 2013). For example, at Lower Granite Dam on the Snake River in Washington, modifications were made to supply the adult fish ladder with cooler water by pumping it from 60 feet deep to the reservoir surface and using a spray system to create a plume of cooler water on the surface where auxiliary flow enters the ladder (Figure 14) or plumbing it directly into the upper portion of the ladder (Figure 15). Modifications were installed at Lower Granite Dam in 2016; measurements taken in June and September 2019 indicated the modifications reduced ladder temperatures by 2.0 °C to an average temperature of 66.2°F. Similar modifications were installed at Little Goose Dam in 2018; measurements taken in June through September 2019 indicated the modifications reduced ladder temperatures by 1.7°C to an average temperature of 66.0°F (NPCC 2020).

Figure 14
Spray System to Supply Cooler Water to the Adult Fishway at Lower Granite Dam, Washington

Note: Photograph courtesy of Walla Walla District, U.S. Army Corps of Engineers (USACE 2016).

Figure 15
A Supplemental Water Intake Chimney Installed at Lower Granite Dam, Washington, to Deliver Cooler Forebay Water Directly to the Uppermost Water Supply Diffuser in the Adult Fish Ladder

Note: Photograph curtesy of Walla Walla District, U.S. Army Corps of Engineers (USACE 2016).

Increasing access to cold-water habitat historically available to species may also be important in the future to overcome effects of climate change. For example, Fitzgerald et al. (2021ba) assessed steelhead and Chinook salmon in California's Eel River and reported that a historically-occupied, high-elevation subbasin upstream of an impassable dam has substantial salmonid capacity relative to the rest of the watershed. They point out that the high-elevation subbasin could provide an important refuge during warm years for salmonids that prefer cooler water and a refuge from

Sacramento pikeminnow that would likely be distributed lower in the system due to their preference for warm habitat conditions. Providing access to cold-water habitat serves the dual purpose of expanding habitat capacity and supporting population productivity for the target species (salmonids), while reducing losses of the target species due to predation from native or non-native predator species that occupy warmer habitats lower in a system. Boughton et al. (2021) used a high-resolution approach based on remote sensing and dynamic habitat modeling to estimate capacity above dams in the Tuolumne and Merced rivers in California. Their results indicated that that steelhead reintroduction could succeed in either system and Chinook salmon reintroduction could succeed in the Tuolumne River if passage strategies account for large numbers of migrant fry and juveniles driven downstream by winter storms and snowmelt.

3.5.1.2 Flow Variability, Gender Differences, and Interacting Effects

Throughout this document, effects of low and peak flows are discussed. However, it is important to keep in mind that variability in flow regimes is also changing and the changes can affect populations. For example, Ward et al. (2015) analyzed 21 Chinook salmon populations from the Pacific Northwest with respect to the effects of changes in river flows and flow variability on population growth. More than half of the rivers analyzed experienced significant increases in flow variability over the last 60 years, and increased variability in freshwater flows had a more negative effect on population growth than other climate signals modeled.

It is also important to consider how environmental conditions have different effects on males and females. Female adult salmon can be disproportionately affected by environmental conditions, which can affect population productivity. For example, Hinch et al. (2021) reported that mortality of female coho, Chinook, and sockeye salmon averaged 2.1 times greater than males and was highest when migration conditions were challenging due to interacting effects of high or turbulent flows, high temperatures, confinement, or handling. Mortality was highest toward the end of freshwater migrations, indicating the tails of the spawning distribution were being disproportionately affected, which may have long-term effects on population diversity, structure, and persistence. The authors suggest that mortality may become more pronounced in coming years as riverine conditions change.

3.5.2 Specific Considerations

Specific biological responses to climate change that NMFS may consider during design reviews include the following:

- A species' life stage transition timing (e.g., juvenile parr to juvenile smolt) may shift due to changes in environmental conditions such as temperature and flow.
    - Warmer winters will accelerate egg development and lead to earlier emergence (Crozier et al. 2008). This may require earlier operation of juvenile bypass facilities.

  - Fluctuations in flow, flow timing, and temperature can result in migration delays or stranding events when sturgeon access managed floodplains, which may cause adult sturgeon to abort their spawning run and return to the ocean.
- Pre-spawn mortality of adult salmon may increase, underscoring the need to eliminate or reduce passage delays at project facilities.
  - In Lake Washington, Washington, pre-spawn mortality appeared to be higher in later migrating sockeye salmon (Newell et al. 2007).
  - In the Sacramento River, California, prolonged exposures to high temperatures caused later returning spring-run Chinook salmon to completely cease upstream migration, with mortality likely (Mosser et al. 2013).
  - Adult migration delays have been observed with reservoir temperature stratification resulting in increased water temperatures in fish ladders (Caudill et al. 2013) potentially affecting post-passage survival (Caudill et al. 2007).
- Juvenile survival and emigration timing are a function of several factors including size at emigration, which is influenced by emergence timing and growth, that are in part driven by temperature.
  - High temperatures during juvenile rearing can reduce lipid stores and growth (Kammerer and Heppell 2013), resulting in poorer fish condition at the time of emigration. This may require adjustments to screen criteria, debris cleaning schedules, and monitoring at juvenile bypass facilities.
- If the rate of change in water temperatures exceeds the ability for some species to adapt, shifts in species distributions will occur. In freshwater, the shifts will likely result in contractions in spatial distributions. For example, Eby et al. (2014) reported range contraction of bull trout in Montana in association with warmer water temperatures. New structures may be required to provide connectivity to previously inaccessible areas to provide species undergoing range shifts access to diverse habitats.
- Recent research has shown that juvenile salmon survival in the first few months after leaving freshwater is one of the largest determinants of cohort size (Burke et al. 2013). In marine ecosystems, large-scale climate forcings influence local and regional ecosystem structure. For example, Keister et al. (2011) reported ecosystem conditions, and the trophic structure and productivity of food sources juvenile salmon rely on, vary according to Pacific Decadal Oscillation phases. These and other ecosystem changes affect juvenile Pacific salmon survival in the California Current Marine Ecosystem off Washington, Oregon, and California and are monitored by NMFS due to their influence on cohort size, harvest allocations, and adult returns. Trends in adult abundance, and future trends under climate change, are factors NMFS considers when reviewing fish passage facility designs.
- Interacting factors such as sedimentation, wildfires, and contaminant transport are likely to affect fish habitats and health.

- Increased winter scour of redds due to more frequent flooding is likely to reduce productivity of salmon and steelhead (May et al. 2009; Goode et al. 2013; Nicol et al. 2021).
- Warmer water temperatures are likely to affect fish community composition (Lynch et al. 2016) and exacerbate predation by warm-adapted species that prey upon salmonid species (Mantua et al. 2010). This may require additional actions that improve salmonid fish passage by reducing delay and prevent the passage of predatory species into upstream habitats to reduce their range expansion.
- Lynch et al. (2016) provide a summary of potential interacting effects and point out that multiple adverse effects of climatic shifts may exceed the compensatory processes of fish populations and result in population declines.
- Estimated survival of juvenile Chinook salmon and habitat carrying capacity were projected to be reduced by water diversions and reduced further by climate change, indicating that climate change will impose an additional stressor on salmon populations (Walters et al. 2013).
- Humans will also adapt to climate change. This could result in increased water diversion and reduced instream flows and connectivity to habitats required by fish.

3.6 Sea Level Rise

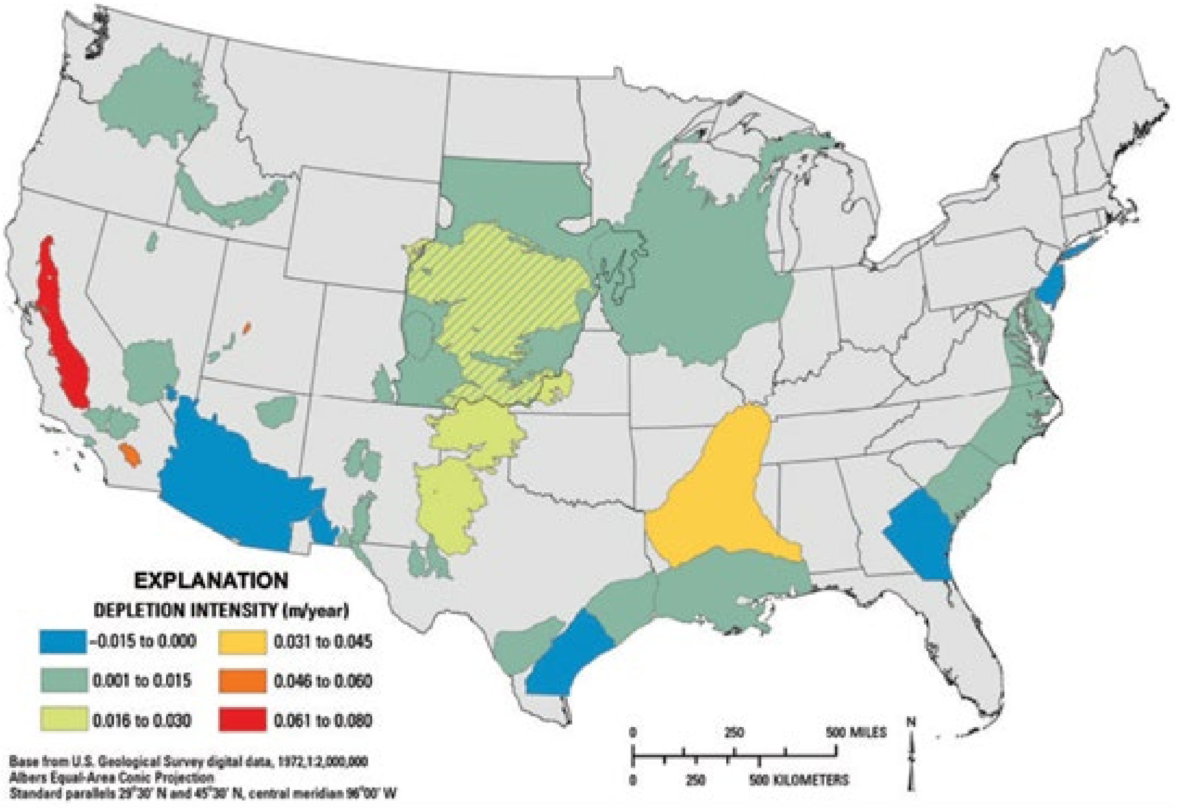
Sea level rise due to climate change may affect the function of existing tide gates in estuaries, requiring a re-evaluation of the functionality of existing gates. In addition, landowners may raise levees and upgrade or install new tide gates to accommodate changes in water elevation. Appendix A of the Design Manual provides a framework for analyzing hydraulic impediments to anadromous fish passage at tide gates. The approach outlined in the appendix addresses how to estimate the relative fish passage effectiveness and resilience of alternate tide gate designs.

NMFS will work with applicants to establish criteria for water velocities through open tide gates and the percent of time fish can pass through a tide gate in each tidal cycle for each age class (adults, fry, subyearlings, and smolts). NMFS may also evaluate the habitat and restoration potential of habitat upstream of a tide gate.

3.7 Subsidence

Land subsidence may be considered a secondary effect of climate change caused by the overdrafting of groundwater due to a lack of surface water supply (Hanson et al 2010). The overdrafting of aquifers extends through large areas of the Western United States (Figure 16). Depletion intensities changed markedly after 2000 and the greatest depletion intensity occurs in the Central Valley of California, where the aquifer-wide depletion intensity averaged 0.075 meter/year (Konikow 2015). The effect is a gradual settling or sudden sinking of the earth’s surface due to the subsurface movement of earth materials (Galloway et al. 1999). The settlement compacts clay layers in aquifers, reducing or eliminating water storage. The settling has the potential to affect the flow capacity of channels, flow control structures, sediment transport behavior, and the ability of fish passage facilities in river systems to perform as designed (California Department of Water Resources 2019).

Figure 16
Aquifer Depletion Map of the United States Showing the Intensity of Depletion from 2001 to 2008



Note: Map acquired from Konikow 2015.

Areas like the San Joaquin Valley in California have experienced as much as one foot of subsidence per year, requiring that project designs account for projected subsidence (San Joaquin River Restoration Program 2014) (Figure 17). Subsidence occurs at different rates within a channel reach, resulting in steeper and flatter slopes among channel segments. This can result in freeboard heights varying along the channel, which is a consideration for fish passage structures like fish screens and fishways (California Department of Water Resources 2019), and freeboard under bridges being reduced (Figure 18). Freeboard is a measure from the water surface elevation to the part of the structure in consideration (i.e., lowest part of a bridge structure, top of a fishway wall, or the area above the top of a fish screen).

Figure 17
Land Subsidence Near El Nido, California, from 1965 to 2016

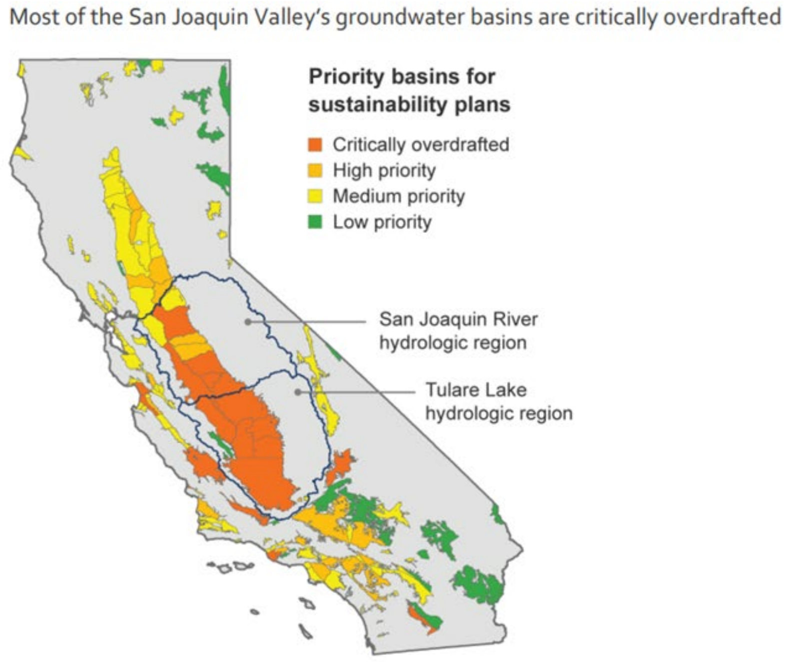
Note: Photograph taken by Justin Brandt, USGS (public domain).

Figure 18
Reduced Freeboard Under Bridge Near Firebaugh, California

Note: Photograph acquired from Florence Low/California Department of Water Resources via Alley (2017).

The Central Valley in California is known for ground settlement but, up until the last decade, the amount and rate of subsidence was not well understood. Many areas are currently over-drafted (Figure 19).

Figure 19
Map of Regions of California where Groundwater has been Over-Drafted



Notes: Map acquired from California Department of Water Resources (2019). Most of the groundwater basins in the San Joaquin Valley are over-drafted relative to compliance with the State of California's Groundwater Management Act by 2020.

Central Valley farmers knew there was a problem when their canals were not conveying the capacity they once had. Diversions located in areas influenced by groundwater pumping were subjected to the effect of subsidence, which created a depression on the surface of the land. Due to this effect, some diversions located in this zone of influence that once delivered water downstream in a canal via gravity now had to raise the diversion dam to create enough head to push the water uphill in the depression zone. Over time, water in the bypasses rode higher as levees sank.

For example, at Sack Dam on the San Joaquin River, subsidence created from surrounding groundwater pumping affected the Central California Irrigation District's diversion by reducing canal capacity by more than half (Healy 2015). Subsidence will likely continue until the aquifers are stabilized through regulatory actions under the State Groundwater Management Act, which has a projected stabilization date target of 2040.

To address subsidence, options considered for Sack Dam included raising the dam structure to achieve the required head to drive flow diversion down the canal or installing a pumping plant. However, raising the dam height to account for future subsidence until 2040 would trigger state dam safety regulations and add additional complexity to the project. Along with dam safety, the fishway and screen design should consider future subsistence rates at the site, including the maximum subsidence level that ensures the facility performs as intended (U.S. Bureau of Reclamation 2021c). Adaptive design elements being considered at Sack Dam include increased freeboard of the fish bypass screens, improved access for maintenance, additional pools in the fish ladder, and relocating the juvenile fish bypass outfall pipe (U.S. Bureau of Reclamation 2021c).

Subsidence will also affect sediment transport within the groundwater pumping zone of influence. Water velocity increases as the channel slope increases in the downstream direction heading into the apex of the cone, mobilizing sediment and creating scour along the banks of the channel. Once past the apex of the cone, water in the channel is forced uphill and velocity is reduced, resulting in sediment deposition.

In summary, subsidence is occurring throughout regions of the Western United States. Applicants should evaluate the status of subsidence and potential for additional subsidence to occur within a project area in the early stages of design. This is needed to ensure the facility functions properly over its design life and to save the applicant cost over the life of the project.

3.8 Post-Wildfire Considerations

As the Western United States continues to experience climate change that leads to longer periods of drought and wildfires, project proponents should consider post-burn effects on hydrology, sediment transport, and stream temperatures within 5 years of a wildfire event. The following reports demonstrate the intersection of climate change, wildfire, sedimentation and road infrastructures:

- Touma et al. (2022) described enhanced risk of debris flows and channel altering events in the western U.S. The northwestern U.S., in particular, is highlighted as a region with particularly high future risks and predicted numbers of incidents.
- Goode et al. (2012) reviewed the rate of sediment yields from basins in Idaho to understand the effects that increasing wildfires could have on channel form and rates of reservoir sedimentation.
- Luce et al. (2012) is large compendium of work and case studies focused primarily on headwater areas that addresses topics at the interface of climate change, road infrastructure, fish passage, wildfires and channel sedimentation.
- Mahlum et al. (2011) describe the effects of wildfire on stream temperatures.

In some cases, changes over longer periods may have to be considered, such as increased sediment transport potential or increased water temperatures due to a lack of riparian tree recruitment and growth.

In addition to changes in physical habitat, wildfires can generate thermal heterogeneity in aquatic ecosystems due to increased light flux and drive short-term increases in stream temperature, exacerbating bioenergetically stressful seasons for cold-water fishes such as salmonids (Beakes et al. 2014). The fire itself results in a short-term increase in temperature, and the removal of riparian vegetation apparently leads to increases in stream temperature that can last for a year or longer (Beakes et al. 2014). Beakes et al. (2014) suggest that temperature is linked to light flux controlled by riparian vegetation, and that stream temperatures will likely return to their pre-perturbed state as streamside vegetation regenerates.

Basins with high burn severity, especially those with steep and previously forested terrain, have flashier hydrographs that can produce peak flow orders of magnitude greater than pre-fire conditions due to fundamental changes in the hydrology of burnt watersheds, especially in the short term (1 to 3 years) (Neary et al. 2011).

These changes promote increases in runoff and sediment transport that increase the likelihood of runoff-generated debris flows (McGuirea et. al. 2019). Debris flows in southern California following fires have been so catastrophic that channels and outlet structures in some basins require large-scale improvements to protect against future debris flow events. These large, catastrophic debris and mass wasting events will require that special attention be paid to fish passage facilities, especially given the potential for these events to occur more frequently in the future. Sediment and debris flows have the potential to clog openings in their path such as culverts, trash racks, and other fish passage structures located within the channel. When designing a new fish passage facility (e.g., culverts), removing a dam or decommissioning roads in an area that has experienced a wildfire event, consider performing debris flow risk modeling to determine if the facility will perform as intended. McGuire et. al. (2019) found that numerical modeling result suggest that these changes lead to a roughly 40% increase in the 15-minute rainfall intensity-duration threshold associated with debris-flow initiation as well as more than a three-fold decrease in debris-flow volume from post-fire year 1 to post-fire year 2.

Post-burn sediment and debris flow events are not specific to California and have occurred across the Western United States as wildfires increase in frequency and intensity. On June 20, 2018, a runoff-initiated debris flow occurred in the Western Cascades in Oregon, in a region that had burned in 2017, as part of the 24,000-acre Milli Fire. As the effects of climate change result in more extreme wildfire events, areas like the Pacific Northwest and other regions with similar basin characteristics could become more susceptible to runoff-initiated debris flows (Wall et al. 2020).

The U.S. Department of Agriculture Burned Area Emergency Response Treatments Catalog provides useful tools for land and channel treatments after a fire that can be applied to areas where migratory fish are present or fish passage facilities are being considered (Napper 2006). A discussion of debris racks and deflectors is included in the Burned Area Emergency Response Treatments Catalog section on Road and Trail Treatments, along with various alternatives for modifying or replacing culverts damaged by fire.

Typical effects on hydrology the first years following a fire include increased peak flows, faster flow arrival times, and more frequent runoff. Table 24 describes the types of changes expected and the effects that may occur from changes in hydrologic processes following fires.

Tools have been developed by the U.S. Forest Service to assess post-burn conditions, determine post-fire flow rates, and make risk assessments (USDA 2014). In addition, Parsons et al. (2010) present a guide for mapping burn severity following fires.

Table 24
Hydrologic Process Changes Following Wildfires

Hydrologic Processes	Type of Change	Specific Effects
Rainfall	No change	• No change
Initial Abstraction	Reduced	• Less water stored • Overland flow increased
Infiltration	Reduced	• Overland flow increased • Streamflow increased • Soil sealing[1] • Hydrophobicity[1]
Routing	Faster	• Decreased roughness/vegetation
Vegetation	Reduced	• Less reduction of raindrop impact • Less interception • Reduced soil support • Woody debris
Erosion	Increased	• Water quality • Bulking

Notes:
Source: Atkins North America, Inc. (2021).

1. Soils that repel water are considered hydrophobic. After intense heating from a fire a thin layer of soil at or below the mineral soil surface can become hydrophobic due to a waxy substance derived from plant material burned during a hot fire penetrating into the soil. Hydrophobic soils repel water, reducing the amount of water infiltration and increasing flows in stream channels (USDA 2000). For additional information see Kalendovsky and Cannon (1997).

Tables 1 to 10 in Section 2.4 (Fish Element Risk Pathways) address risks associated with wildfires, sediment, and debris for the various project elements and possible actions to address the risks. In addition to the information in Table 8 (Culverts), NMFS may want designers to consider the following when designing road crossings in post-burn situations:

- Precipitation does not change after a fire, but climate change may increase the frequency of rain events or their magnitude and, in burned areas, this may exacerbate hydrologic effects.
- Changes in hydrology following a fire may occur (less water is stored due to changes in vegetation and soil properties, resulting in increased overland flow).
- Flow routing will increase due to decreased roughness and vegetation, so lag time should be adjusted.
- The hydrologic curve number (a factor used in hydrologic modeling to predict runoff) will change as soils are less permeable. The amount of post-burn runoff for an area can be determined using tools like the Soil Conservation Service Curve Number Method.
- The fire may result in changes in impervious area.
- Infiltration may be reduced due to soil sealing (requiring an adjustment in infiltration rate).
- Soil scorching increases the hydrophobicity of soils.
- Consider applying a bulking factor to account for sediment picked up in flood flows.
- Assess whether the model used accurately reflects the soil-water mixture experienced post-burn; most hydraulic modeling software assumes clear water for the simulations.
- In the short term, instream debris retention structures may be required (Figure 20).

Figure 20
Debris Catch System Installed Upstream of a Culvert on Vance Creek, Oregon Following a Wildfire

Note: Photography acquired from Oregon Department of Fish and Wildlife.

4 Definitions

Active Channel Width: Active channel width and BFW are broad topics, and their application may vary in different situations. For this document, active channel width is defined as follows:

The active channel width is measured perpendicular to streamflow. It is narrower than the BFW and is typically defined as the width of the stream channel bed between toes of banks or edge of permanent vegetation.

Applicant: A person or entity that proposes to design, modify, or construct a fish passage facility at an existing or new barrier, water diversion, or water conveyance that NMFS will review under its authorities identified in Chapter 1 of the Design Manual.

Anadromous: A category of fish migratory life history patterns where individuals in the species migrate between breeding grounds in freshwater and feeding grounds in marine environments.

Bankfull Flow and Bankfull Width: Bankfull flow and BFW are broad topics, and their application may vary in different situations. For this document, bankfull flow and bankfull width are defined as follows:

Bankfull flow is a peak flow at which water just begins to leave a stream channel and overtop its banks. The BFW is the width of the top of the water surface at the bankfull flow.

Bias-corrected Model Results: Bias correction is the process of scaling climate model outputs to account for systematic errors and improve how model results fit observed data.

Bulking Factor: Bulking is defined as increasing the clear-water discharge to account for high concentrations of sediment in flow. Mud and debris flows, which can significantly increase the volume of flow transported from a watershed, most often occur in mountainous areas subject to wildfires with subsequent soil erosion and in arid regions near alluvial fans and other zones of geomorphic and geologic activity. In areas prone to high sediment and debris concentrations, the use of a bulking factor can help provide for adequately sized facilities. Bulking factors can also be used in modeling to approximate sediment load in water for post-burn situations and increases in discharge to account for sediment (and debris) and add a safety factor to a design.

Climate: The weather conditions prevailing in an area in general or over a long period of time.

Climate Change: A change in global or regional climate patterns, and in particular a change apparent from the mid to late 20th century onwards and attributed largely to increased levels of atmospheric carbon dioxide produced by the use of fossil fuels.

Climate Variability: Climate variability refers to the climatic parameter of a region varying from its long-term mean.

CMIP3, CMIP5: CMIP stands for the Climate Model Intercomparison Project, and it represents a standard experimental framework for studying the output of coupled atmosphere-ocean GCMs to facilitate assessment of the strengths and weaknesses of climate models and enhance the development of future models. The number refers to a phase designation (3, 5, etc.) so that users can identify and use the latest phase of the framework that has been issued (National Center for Atmospheric Research Staff 2106).

Curve Number: The runoff curve number is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess.

Distinct Population Segment (DPS): Under the ESA (1976), a DPS is a vertebrate population or group of populations that is discrete from other populations of the species and significant in relation to the entire species.

Distributed Hydrology Soil Vegetation Model (DHSVM): A high-resolution, physics-based, open-source community model developed by the University of Washington to show the environmental and human effects on hydrologic processes. It has been applied both operationally, for streamflow prediction, and in a research capacity, to examine effects on peak streamflow and snow accumulation and melt, among other things.

Dynamically Downscaled: Dynamical downscaling refers to the use of high-resolution regional simulations to dynamically extrapolate the effects of large-scale climate processes to regional or local scales of interest.

Ensemble Mean: An ensemble is a group of items that are viewed as a whole rather than individually. In the context of climate modeling, many climate models are available for use that are based on numerous input assumptions. The ensemble mean is the average of the individual model results incorporated into the ensemble being used or evaluated.

ESA Status: ESA refers to the Endangered Species Act of 1976. Status refers to whether a species is listed as needing federal protection. Under the ESA, a species is considered to be in the endangered status if it is in danger of extinction throughout all or a significant portion of its range and in the threatened status if it is likely to become endangered in the foreseeable future.

Evolutionarily Significant Unit (ESU): A population of organisms that is considered distinct for purposes of conservation.

Fish Passage Facility: Structures that provide safe, timely and effective upstream and downstream passage of ESA-listed species including fish screens and ladders, nature-like fishways, grade control structures, culverts, bridges, and stream crossings.

General Circulation Models (GCM): GCMs are numerical models representing physical processes in the atmosphere, ocean, cryosphere, and land surface that are used to depict the climate using a three-dimensional grid over the globe. The term "general circulation model" is used interchangeably with "global climate model."

Genotype: The genetic constitution of an individual organism; an individual organism's collection of genes.

Intergovernmental Panel on Climate Change (IPCC): The IPCC is the United Nations body for assessing the science related to climate change. The IPCC prepares comprehensive Assessment Reports about the state of scientific, technical, and socioeconomic knowledge on climate change and its impacts and future risks, and options for reducing the rate at which climate change is taking place. It also produces Special Reports on topics agreed to by its member governments, as well as Methodology Reports that provide guidelines for the preparation of GHG inventories.

Life History Characteristics: Life history characteristics refer to different phenotypic expressions (i.e., observable traits) in organisms. The characteristics result from the organism's genotype (i.e., its genetic constitution), the environment, and interactions between the genotype and environment. These factors result in variations in morphology, age, and size at key life stages. Examples include stream-type versus ocean-type Chinook salmon; resident steelhead versus anadromous steelhead; and juvenile anadromous fishes that are categorized as fry, parr, or smolts based on their size and smoltification status. The variation in life history characteristics within a population contributes to population abundance and productivity and the resilience of the population to environmental variability.

Lifespan: The lifespan of a project is the length of time a project was designed for and expected to perform as designed. The effects of a project on anadromous fish species can extend beyond its lifespan.

Multivariate Adaptive Constructed Analogs (MACA): MACA is a statistical downscaling method that utilizes a training dataset (i.e., a meteorological observation dataset) to remove historical biases and match spatial patterns in climate model output.

Phenotype: The set of observable characteristics of an individual resulting from the interaction of its genotype with the environment.

Population trends: Changes in population abundance through time.

Population Viability: A viable salmonid population is an independent population of any Pacific salmonid that has a negligible risk of extinction due to threats from demographic variation (random or directional), local environmental variation, and genetic diversity changes (random or directional) over a 100-year time frame (McElhany et al. 2000).

Productivity: There are many definitions of productivity in fisheries management, including intrinsic productivity, life-stage productivity, and population productivity. This document uses the term in the context of overall population productivity (i.e., the productivity over the entire life cycle that results in the growth rate of a population), and as a factor that affects population growth rate, and provides information on how well a population is "performing" in the habitats it occupies.

Project Element: A discrete component of a fish protection or passage project that may or may not be combined with other elements. Each element has a unique set of risk exposure pathways to different environmental changes.

Representative Concentration Pathway (RCP) 8.5: An RCP is a GHG concentration trajectory adopted by the IPCC. Each pathway assumes a different climate future. The pathways cover a wide range of possible changes in future anthropogenic (i.e., human) GHG emissions and strive to represent the atmospheric concentrations of GHGs associated with each trajectory. In RCP8.5, emissions continue to rise throughout the 21st century, possibly representing a worst-case climate change scenario.

Shared Socioeconomic Pathway (SSP): SSPs are scenarios of projected socioeconomic global changes up to 2100 that are used to derive GHG emissions scenarios associated with different climate policies.

Stationarity: In mathematics and statistics, a stationary process is a stochastic process whose unconditional joint probability distribution does not change when shifted in time. In the context used here to improve the resilience of fish passage facilities to climate change, it refers to using a time series of data that is flat in appearance, has no trend, and has constant variance over time. In other words, stationarity implies that future hydrologic conditions will be like the past; and, therefore, the historical record can be used to estimate future conditions. Climate change information is indicating the opposite is true.

Statistically Downscaled: Statistical downscaling uses various statistics-based techniques to determine relationships between large-scale climate patterns resolved by GCMs and observed local climate responses.

Uncertainty: Uncertainty is defined as a situation in which something is not known, or something that is not known or certain. In the context of modeling, uncertainty can be caused by an imperfect knowledge of the system being modeled and can be estimated or characterized to determine how likely certain outcomes are if some aspects of the system are not exactly known.

Variable Infiltration Capacity (VIC) Model: VIC (Liang et al. 1994) is a macroscale hydrologic model that solves full water and energy balances, originally developed by Xu Liang at the University of Washington.

Weather Research and Forecasting (WRF) Model: The WRF model is a mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting applications.

5 Resources Described in Long-Term Project Case Studies and Culvert Section

5.1 Additional Resources for Section 2

This section provides suggested reading materials, in addition to the information presented in Section 2, on climate change modeling and links to information websites. These documents provide additional background information on regional climate change and impacts and other topics related to the information presented in *Improving Resilience*. This information is organized according to specific sections within the document. NMFS believes the resources will help applicants and their consultants incorporate resilience to climate change into fish passage facility designs. *Improving Resilience*Resources Described in Long-Term Project Case Studies

Resources used for Section 2.5.1, New Fishway Project in an Unregulated River

The resources used to develop this case study were obtained from the CIG website from a report that summarized climate change modeling in the Chehalis River Basin in Washington State titled *Effect of Climate Change on the Hydrology of the Chehalis Basin* (Mauger et al. 2016); Appendix A of the report contains links to data and mapping tools. On that web page is a map with additional links to data used in the case study along with additional locations within the Chehalis River Basin.

The example provided used MACA (Abatzoglou and Brown 2011) statistically downscaled projections. Projections are based on 10 GCMs included in the CMIP5 experiment. The 10 GCMs were selected from the larger set of CMIP5 simulations based on their ability to accurately represent the climate of the Pacific Northwest. Projections span from 1950 to 2099 and include both a low (RCP4.5) and a high (RCP8.5) GHG scenario. Only the RCP8.5 scenario was used in the example.

The main sources for Section 2.5.1 (New Fishway Project in an Unregulated River) include the following:

- University of Washington Climate Impacts Group, 2022. Climate Impacts Group (CIG) Website. “Increase Climate Resilience.” Available at: https://cig.uw.edu/.
- Mauger, G.S., S.-Y. Lee, C. Bandaragoda, Y. Serra, J.S. Won, 2016. *Effect of Climate Change on the Hydrology of the Chehalis Basin*. Report prepared for Anchor QEA, LLC. Climate Impacts Group, University of Washington, Seattle. July 8, 2016. Available at: https://cig.uw.edu/wp-content/uploads/sites/2/2014/11/Final_Report_Chehalis_2016-07-08.compressed.pdf. Appendix A data and mapping tools available at: https://cig.uw.edu/datasets/hydrology-in-the-chehalis-basin/.

- DHSVM Model: Skookumchuck River Near Bucoda Data. *Index of /picea/mauger/2016_04_ChehalisFlooding/pub/streamflow_summaries/DHSVM/BCday/SkookumchuckR-nrVail*. Available at: https://data.cig.uw.edu/picea/mauger/2016_04_ChehalisFlooding/pub/streamflow_summaries/DHSVM/BCday/SkookumchuckR-nrVail/.
- MACA (Multivariate Adaptive Constructed Analogs), 2022. MACA Website. "Datasets." Available at: http://maca.northwestknowledge.net.

Resources used for Section 2.5.2, Project in a Regulated River

The publications referenced for Section 2.5.2 (Project in a Regulated River), which describe data available from Reclamation for eight Reclamation basins in the West, include the following:

- Summary Publications: Available at: https://www.usbr.gov/climate/secure/.
- Individual Basin Reports: An example for the Sacramento and San Joaquin Basins is U.S. Bureau of Reclamation, 2021. *Sacramento and San Joaquin River Basins SECURE Water Act Section 9503(c) Report to Congress*. March 2021. Available at: https://www.usbr.gov/climate/secure/docs/2021secure/basinreports/Sacramento-SanJoaquinBasin.pdf.
- U.S. Bureau of Reclamation, 2021. *Water Reliability in the West: 2021 Secure Water Act Report*. Prepared by U.S. Department of the Interior. January 2021. Available at: https://www.usbr.gov/climate/secure/docs/2021secure/2021SECUREReport.pdf.
- U.S. Bureau of Reclamation, 2021. *Technical Memorandum No. ENV-2021-001 West-Wide Climate and Hydrology Assessment*. March 2021. Version 1.2. Available at: https://www.usbr.gov/climate/secure/docs/2021secure/westwidesecurereport1-2.pdf.

Within the publications listed are references to other studies that provide climate change modeling detail. It appears that hydrologic products that contain reservoir routing will need to be requested from Reclamation's Research and Development Office or Water Operations.[11]

Resources used for Section 2.5.3, Culvert and Water Crossing Designs

The primary document used in Section 2.5.3 (Culvert and Water Crossing Designs) is the following:

- Wilhere, G., J. Atha, T. Quinn, L. Helbrecht, and I. Tohver, 2017. "Incorporating climate change into culvert design in Washington State, U.S.A." *Ecological Engineering* 104 (2017) 67–79. Available at: https://wdfw.wa.gov/publications/01867.

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[11] U.S. Bureau of Reclamation Research and Development Office: https://www.usbr.gov/research/
U.S. Bureau of Reclamation Water Operations: https://www.usbr.gov/main/water/

- Wilhere, G, Atha, J. Quinn T., and Helbrecht, L., 2016. Incorporating Climate Change into the Design of Water Crossing Structures. Final Project Report of the Washington Department of Fish and Wildlife Habitat Program – Science Division. September 2016. 48pp https://wdfw.wa.gov/sites/default/files/publications/01867/wdfw01867_0.pdf

6 Downscaled Climate and Hydrology Products with Characteristics Needed for Fish Passage Analysis and Design

This section provides a list of downscaled hydrology and climate products and other data sources with monthly flow projections, available at the time of publication of this document, that can be considered for use for fish passage facility design after discussions with NMFS on the appropriateness of the selection. Over time, NMFS anticipates that additional climate and hydrologic modeling will become available that will be used to update Section 6 periodically. There is no "one size fits all" or single product available as of 2022 that meets the needs for all subregions and types of projects in the WCR. For example, some products only cover specific basins or states. Applicants may wish to choose a product developed for their state or basin of interest, with consideration of practical choices such as which product has existing data that most closely matches their needs or is available in a report with similar analysis to their project.

Note that while the focus is on precipitation and hydrologic variables, downscaled climate products generally include temperature.

The preferred climate and hydrologic projection data will have been prepared using CMIP5 RCP8.5 and provide at least daily data usable for analysis of migratory design flows and expected peak flows. Monthly flows are not suitable for use in design of fish passage facilities. Engineering judgment will also be required in the estimate of instantaneous peak flows under climate change as most climate and hydrologic modeling is performed at a daily time step. Note that monthly projections are useful for exploring the effects of climate change, but daily data will be needed for design.

6.1 Products with Hydrologic Modeling Results in the West Coast Region

The following sections list additional hydrology modeling products and projections.

6.1.1 U.S. Forest Service, Department of Agriculture, Western Flow Metrics

Daily runoff and baseflow from the VIC macroscale hydrologic model were used to estimate historical and projected future stream flow metrics for stream segments in the Western United States This product is based on the CMIP3 A1B emissions scenario, which is a middle-of-the-road emissions scenario similar to RCP6.0, according to GlobalChange.gov, the U.S. Global Change Research Program.[12]

The dataset has information for 11 flow metrics at a reach scale in the NHD-Plus 1:100,000-scale hydrography network as ArcGIS shapefile table attributes. This allows the information to be spatially

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[12] U.S. Global Change Research Program – Emissions, Concentrations, and Temperature Projections web page: https://www.globalchange.gov/browse/multimedia/emissions-concentrations-and-temperature-projections

displayed, queried, and cross-referenced with potential fish passage project sites and used with other information sources in a GIS environment. This dataset encompasses all reaches of unregulated streams and rivers so all areas should have some level of baseline and future hydrologic information. However, the information this dataset provides may be more limited than what is needed in some cases, and in these situations supplemental analyses may be required.

Furthermore, along with providing output based on RCP8.5, it also provides streamflow metrics that may be useful information to use in analyses.

The following are links to flow metrics data:

- Western U.S. Stream Flow Metric Dataset User Guide: https://www.fs.fed.us/rm/boise/AWAE/projects/VIC_streamflowmetrics/downloads/WUS_VIC_Metrics_UserGuide.pdf;
- Western U.S. Stream Flow Metrics Dataset: https://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml;
- Download National Datasets: https://data.fs.usda.gov/geodata/edw/datasets.php?xmlKeyword=hydro+flow+metrics+west.

6.1.1.1 Available Data

Output from 10 CMIP3 GCMs (using the A1B scenario), with the lowest bias in simulating observed climate for the region across the region of interest, were calculated using a spatially explicit delta method (Littell et al. 2011). Three time periods are available: historical (1977 to 2006), mid-century (2030 to 2059), and end-of-century (2070 to 2099). The GCM output was used in hydrologic modeling performed with the VIC model. The VIC model produced streamflow on a daily time step.

Data published by the U.S. Forest Service includes the following:

- Flow Metrics: mean annual flow, mean summer flow, and winter and August flows;
- Flood Metrics: 1.5-year to 25-year flood flows based on mean daily flows and maximum daily flow.

Note that the flood metrics use mean daily flows. To estimate instantaneous peak flows that are used in the design of fish passage facilities, the flood flows provided by the U.S. Forest Service would need to be increased. Section 2.5.1 provides an example of adjusting mean daily flows to instantaneous peak flows used in project design. Citations for these topics include Wenger et al. (2010a, 2010b), Littell et al. (2011), and Elsner et al. (2010).

6.1.2 NorWest Stream Temperature Projections

The NorWest webpage hosts stream temperature data and climate scenarios in a variety of user-friendly digital formats for streams and rivers across the western U.S. The temperature database was compiled from information collected by biologists and hydrologists working for more than 00 resource agencies and contains more than 200,000,000 hourly temperature recordings at more than 20,000 unique stream sites. Those temperature data were used with spatial statistical network models to develop 36 historical and future climate scenarios at 1-kilometer resolution for more than1,000,000 kilometers of stream. This resource is managed by the USDA Rocky Mountain Research Station and is an interagency collaboration.

While NorWest stream temperature predictions are only available for monthly timesteps, in the absence of tools with daily timesteps this may still be a useful tool for assessing future stream temperature.

6.1.3 Columbia River Climate Change Hydrology

This section describes data from a modeling project performed by the CIG for use in planning water management in the Columbia River Basin. A description of the modeling process and data is available at the University of Washington Hydro – Columbia River Climate Change website.[13]

The modeling project used CMIP5 RCP4.5 and RCP8.5 emissions scenarios. Output from 10 GCMs were statistically downscaled using MACA and bias-correction spatial-disaggregation (BCSD) techniques while dynamical downscaling was used for 3 GCMs. Hydrologic modeling was performed using VIC and PRMS to develop streamflow projections at 396 sites throughout the Pacific Northwest. Most of the sites are located within the Columbia River Basin, but the dataset also includes selected sites within the coastal drainages in Washington and Oregon. The hydrological models were implemented at a spatial resolution of 1/16º (~6 km or 3.5 miles square). At 190 sites, model output was adjusted to remove systematic biases using reference streamflows provided by the RMJOC. The reference streamflows were a No Regulation-No Irrigation dataset, meaning the data represents streamflow conditions prior to construction of reservoirs and diversion of water for irrigation. Background documents for this work include Chegwidden et al. (2017) and RMJOC (2018).

6.1.4 Regulated River Systems Flow Projections

This section describes climate and flow projections available on regulated river systems in the Western United States The climate and flow projections were developed by Reclamation, USGS, USACE, and several universities. Reclamation prepared flow projections on eight major river basins in the Western United States for the 2021 Secure Water Act Report (U.S. Bureau of Reclamation 2021a). The river basins are shown in Figure 7 in Section 2.3.6.

For the Reclamation study, the LOCA method of downscaling was applied on output from 32 GCMs and for CMIP5 RCP4.5 and RCP8.5 emissions scenarios. Hydrologic projections were prepared using

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[13] University of Washington Hydro-Columbia River Climate Change website: https://www.hydro.washington.edu/CRCC/

the VIC model. Model output is on a daily time step with 1/16° gridded resolution. A description of the flow projections and summaries of results for each basin can be accessed at the Reclamation Climate Change web page.[14] More detailed climate projection data can be accessed at the Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections data archive.[15]

The BPA, USACE, and Reclamation, agencies that comprise the RMJOC, commissioned a climate change research project in 2013 with the University of Washington and Oregon State University. A description of the research project and links to monthly regulated streamflow data can be accessed at BPA's Climate Change and Federal Columbia River Power System web page.[16] Daily regulated streamflow data will need to be requested from BPA.

Part I (RMJOC 2018) of the research project focused on hydroclimate variables such as projected temperature, precipitation, snowpack, and streamflow changes in the Columbia River Basin, and for many river basins in Western Oregon and Washington, through the rest of the 21st century.

The Part I (RMJOC 2018) studies used 10 GCMs downscaled using BCSD and MACA and CMIP5 RCP4.5 and RCP8.5 emissions scenarios to develop climate projections used in hydrologic modeling. The VIC and PRMS hydrologic models were used to develop streamflow projections.

Part II (RMJOC 2020) followed the Part I studies with a focus on current reservoir regulation. The response of regulated streamflow to climate change under existing Columbia River hydro-regulation procedures were evaluated and summarized. Interrelated reservoir modeling was conducted by BPA, Reclamation, and USACE. Reservoir routing analyses were performed using existing reservoir operations models used by each agency.

6.1.5 Dynamically Downscaled Hydroclimate Projections for the Pacific Northwest

The Washington CIG has prepared dynamically downscaled climate projections for the Pacific Northwest using the WRF regional climate model (see Section 6.2.3). These climate projections have also been used to produce hydrologic change projections at a spatial resolution of 1/16° (~30 km^2) over Washington State. The projections are for the period 1970 to 2099. Currently, this is the only dynamically downscaled product with more than 3 GCMs downscaled; however, it is only available

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[14] Reclamation Climate Change web page: https://www.usbr.gov/climate/

[15] Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections data archive: https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html#About

[16] BPA's Climate Change and Federal Columbia River Power System web page: https://www.bpa.gov/energy-and-services/power/climate-change-fcrps

for the Columbia Basin and Washington State. A description of the data and directions on how to access the data is found at the University of Washington, Climate Impacts Group web page.[17]

To develop future streamflows at a project site, the climate projections would need to be used in a hydrologic model of a basin. Some hydrologic modeling is available for parts of Washington State using models such as VIC and DHSVM. The Washington State Department of Fish and Wildlife maintains a web portal used to obtain future streamflow data that is used in the design of new culverts. For that work, the VIC model was used to project future streamflows in Puget Sound and along the Washington Coast. A description of the modeling and data available, is contained in Mauger (2021). Examples of work performed using this WRF ensemble are projects on climate change and flooding in Snohomish County, Washington (Mauger et. al. 2021), changes in streamflow and water temperature in Chico Creek, Kitsap County, Washington (Mauger et. al. 2021, and high flows in rivers in King County, Washington (Mauger and Won, 2020). There are several new studies that are underway across the region by multiple research groups including Western Washington University, and CIG. For the larger basins or more widespread coverage from VIC modeling, initial model development has been undertaken but that additional work would be needed to develop dynamically-downscaled WRF projections for the entire region.

6.1.6 California Climate Assessment Products (Cal-Adapt)

Cal-Adapt hosts climate change projections and related data, much of which was generated for California's Fourth Climate Change Assessment. Data can be accessed at the Cal-Adapt website.[18]

Available data includes daily 1/16° (6 km) spatial resolution projections of precipitation, minimum and maximum temperature, specific and relative humidity, wind speed, and surface solar radiation for CMIP5 GCMs using LOCA statistical downscaling for RCP8.5 and RCP4.5.

The ensembles or subsets of 10 and 4 models used do a good job simulating important aspects of California's climate. Time periods simulated are Historical Baseline (1961 to 1990), Mid-Century (2035 to 2064) centered on the year 2050, and End-of-Century (2070 to 2099).

Hydrologic projections were prepared using the downscaled climate model in VIC models to produce gridded estimates of runoff. Streamflow projections were prepared using VIC to route runoff through stream channel networks (Pierce et al. 2018).

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[17] University of Washington, College of the Environment, Climate Impacts Group web page: https://cig.uw.edu/datasets/dynamically-downscaled-hydroclimate-projections-wrf-model/

[18] Cal-Adapt website: https://cal-adapt.org

6.2 Downscaled Climate Products for Use in the Applicant's Own Hydrologic Modeling

This section describes climate modeling products that are available for applicants to use in cases where hydrologic projections do not currently exist or are not adequate. Products include temperature and precipitation and often other hydrologic variables (e.g. soil moisture). Note that all downscaling techniques (statistical and dynamic) improve the detail provided in the GCMs, which have a large scale. All statistical methods capture observed patterns of near-surface meteorology and simulated changes computed in the GCMs. All the products described here are appropriate for basin-scale hydrologic modeling. A hydrologic model may be required in conjunction with a reservoir operations model in a regulated river system to project future streamflows considering other operations for hydropower, water storage, and releases for instream and out-of-stream uses (Sections 2.5.2 and 6.1.3).

6.2.1 Localized Constructed Analogs Statistical Downscaling

LOCA is a statistical downscaling technique that was applied to 32 CMIP5 GCMs at a 1/16th degree spatial resolution, covering North America from Central Mexico through Southern Canada. The historical period is 1950 to 2005, and there are two future scenarios available: RCP8.5 and RCP4.5 over the period 2006 to 2100. LOCA data has been used in the following:

- Fourth California Climate Assessment (Pierce et al. 2018)
- U.S. Climate Resilience Toolkit and Climate Explorer (Lipschultz et al. 2020)
- U.S. Fourth National Climate Assessment (USGCRP 2017)

LOCA data was used in VIC hydrologic modeling performed for Cal-Adapt in Nevada and California. Other hydrologic modeling results using LOCA data were not available in late 2021.

A description of LOCA data is at the LOCA Statistical Downscaling website.[19] LOCA data are available for download from the following agencies and organizations:

- Lawrence Livermore National Laboratory Green Data Oasis: This includes the original set of files in netcdf format. Available at https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html.
- NASA OpenNEX: The LOCA downscaling was done on NASA supercomputers. Data from the NASA Earth Exchange is available at: https://www.nasa.gov/nex.
- U.S. Geological Survey Geo Data Portal: This portal provides Thematic Real-time Environmental Distributed Data Services (THREDDS) access to the data. Available at: https://cida.usgs.gov/gdp/.
- Cal-Adapt: This site provides access to data for California and provides value-added abilities to visualize and analyze the data. Available at: https://cal-adapt.org/.

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[19] LOCA website: http://loca.ucsd.edu/

- Desert Research Institute (DRI) SCENIC (Southwest Climate and Environmental Information Collaborative): This site provides climate data and analysis tools to natural resources and environmental scientists. Available at: https://wrcc.dri.edu/csc/scenic/.

6.2.2 Multivariate Adaptive Constructed Analogs Statistical Downscaling

MACA is a statistical method for downscaling climate data from 20 CMIP5 GCMs, for RCP8.5 and RCP4.5, downscaled to 4-km or ~6-km scenarios for the period 2006 to 2100, are available at the Climatology Lab website.[20]

All MACA datasets are available on the Northwest Knowledge Network (University of Idaho). A tutorial of how to use OPENDAP with code snippets for various programming languages is available at the MACA website.[21] Data are available for two different resolutions used in simulation of historic conditions (called "training data"). One dataset uses the 6-km (1/16th degree) daily product of Livneh et al. (2013) from 1950 to 2011 that also incorporates the Canadian portion of the Columbia River Basin. The other uses the gridMet daily dataset at a ~4-km grid (1/24th degree) from the 1979 to 2012 period.

The following links provide access to the MACA datasets:

- The gridded 1/16-deg(~6km) MACAv2-LIVNEH dataset is available on North Carolina Climate Office's Thematic Real-time Environmental Distributed Data Services (THREDDS) server. Available at: http://convection.meas.ncsu.edu:8080/thredds/catalog.html.
- The gridded 1/24-deg(4km) MACAv2-METDATA dataset is available on the Geo Data Portal. Available at: https://cida.usgs.gov/gdp/client/#!catalog/gdp/dataset/5752f2d9e4b053f0edd15628.
- A tutorial developed for extracting data from the Geo Data Portal is available on the MACA website. Available at: https://climate.northwestknowledge.net/MACA/GDP.php.
- The gridded 1/24-deg(4km) MACAv2-METDATA dataset is available on the Google Cloud through Google Earth Engine. Available at: https://explorer.earthengine.google.com/#search/maca.

6.2.3 Weather Research and Forecasting (WRF) model Dynamical Downscaling for the Pacific Northwest

The Washington CIG has prepared dynamically downscaled climate projections for the Pacific Northwest using the WRF regional climate model. The data has an hourly temporal resolution and a spatial resolution of 12 km. The projections use 12 GCMs with the CMIP5 and RCP8.5 emissions scenario for the period 1970 to 2099. Currently, this is the only dynamically downscaled product with

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[20] Climatology Lab website: https://www.climatologylab.org/maca.html

[21] MACA website: https://climate.northwestknowledge.net/MACA/data_catalogs.php.

more than 3 GCMs downscaled; however, it is only available for the Pacific Northwest. A description of the data and directions on how to access the data is found at the University of Washington, Climate Impacts Group web page.22

6.3 Other Data Sources with Monthly Flow Projections

Other climate projections are available that do not supply daily data used for fish passage design; however, they are useful for visualization of climate change effects and comparison or can be used for other projects by an applicant.

6.3.1 The Climate Toolbox

The Climate Toolbox[23] is a collection of web tools for visualizing past and projected climate and hydrology of the contiguous United States.

Future climate projections were obtained using 20 climate models and CMIP5 with two emission scenarios. The projections were downscaled using MACA to a ~4-km resolution across the United States.

Future hydrologic projections used the VIC model to produce gridded hydrologic outputs which were routed through stream channels using the VIC model to produce streamflow projections.

A feature of The Climate Toolbox site is their future Climate Scatter Tool[24] that allows the user to explore the data and visualize the scatter, or range, of climate models for several variables at a chosen point or selected area. Another useful feature for the Western United States is the Streamflow Futures Tool.[25]

6.3.2 U.S Army Corps of Engineers Climate Hydrology Assessment Tool (CHAT)

The U.S. Army Corps of Engineers Climate Hydrology Assessment Tool[26] provides the annual maximum of average monthly streamflow it does not provide submonthly data, so it is not appropriate for fish passage analysis. The inter-model range across 64 CMIP-5 models (i.e., 32 GCMs and 2 RCPs) is displayed with this tool down to a Hydrologic Unit Code 8 level. It is a useful tool for comparing the range of projections among many models and 2 RCPs.

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[22] University of Washington, College of the Environment, Climate Impacts Group web page: https://cig.uw.edu/datasets/dynamically-downscaled-hydroclimate-projections-wrf-model/

[23] The Climate Toolbox website: https://climatetoolbox.org

[24] The Climate Toolbox Scatter Tool web page: https://climatetoolbox.org/tool/Future-Climate-Scatter

[25] The Climate Toolbox Streamflow Futures Tool web page: https://climatetoolbox.org/tool/Future-Streamflows

[26] U.S. Army Corps of Engineers Climate Hydrology Assessment Tool: https://climate.sec.usace.army.mil/chat/

7 Additional Resources and Reading

This section provides additional resources and suggested reading materials on climate change modeling and information websites. These documents provide additional background information on regional climate change and impacts and other topics related to the information presented in *Improving Resilience*. NMFS believes this information will help applicants and their consultants incorporate resilience to climate change into fish passage facility designs. This section is organized according to specific *Improving Resilience* sections, or regions and states within the WCR.

7.1 West Coast Region-Wide and Regional Climate Change, Hydrology, and Sea Level Rise

The following sections list additional resources and suggested reading materials.

7.1.1 U.S. Fourth National Climate Assessment (NCA4)

In the U.S. Fourth National Climate Assessment, Chapter 24 (Northwest) and Chapter 25 (Southwest) are excellent resources for general information relevant to regional hydrologic, and ecosystem changes, sea level rise, and reducing risks through taking steps to be more resilient (adaptation), although the information is not specific to fish passage. Appendix 5 (Frequently Asked Questions) is an excellent resource for learning more about the science of climate change. Citations for these resources:

- May C., C. Luce, J. Casola, M. Chang, J. Cuhaciyan, M. Dalton, S. Lowe, G. Morishima, P. Mote, A. Petersen, G. Roesch-McNally, and E. York, 2018. “Chapter 24: Northwest.” In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart, eds. U.S. Global Change Research Program, Washington, DC, U.S.A, pp. 1036–1100. DOI: 10.7930/NCA4.2018.CH24. Available at: https://nca2018.globalchange.gov/chapter/northwest.
- Gonzalez, P., G.M. Garfin, D.D. Breshears, K.M. Brooks, H.E. Brown, E.H. Elias, A. Gunasekara, N. Huntly, J.K.Maldonado, N.J. Mantua, H.G. Margolis, S. McAfee, B.R. Middleton, and B.H. Udall, 2018. “Chapter 25: Southwest.” In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart, eds. U.S. Global Change Research Program, Washington, DC, U.S.A, pp. 1101–1184. DOI: 10.7930/NCA4.2018.CH25. Available at: https://nca2018.globalchange.gov/chapter/southwest.
- Reidmiller, D., Dzaugis, M., Avery, C.W., Crimmins, A., Dahlman, L., Easterling, D.R., Gall, R., Greenhalgh, E., Herring, D., Kunkel, K., Lindsey, R., Maycock, T., Molar, R., Stewart, B.C., and R. S. Vose, 2018. “Appendix 5: Frequently Asked Questions.” In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. U.S. Global Change

Research Program, Washington, DC, U.S.A. Available at: https://nca2018.globalchange.gov/chapter/appendix-5/.

- Lall, U., T. Johnson, P. Colohan, A. Aghakouchak, C. Brown, G. McCabe, R. Pulwarty, and A. Sankarasubramanian, 2018. Water. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 145–173. doi: 10.7930/NCA4.2018.CH3.
- Lipton, D., M. A. Rubenstein, S.R. Weiskopf, S. Carter, J. Peterson, L. Crozier, M. Fogarty, S. Gaichas, K.J.W. Hyde, T.L. Morelli, J. Morisette, H. Moustahfid, R. Muñoz, R. Poudel, M.D. Staudinger, C. Stock, L. Thompson, R. Waples, and J.F. Weltzin, 2018. Ecosystems, Ecosystem Services, and Biodiversity. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change ResearchProgram, Washington, DC, USA, pp. 268–321. doi: 10.7930/NCA4.2018.CH7
- Lempert, R., J. Arnold, R. Pulwarty, K. Gordon, K. Greig, C. Hawkins Hoffman, D. Sands, and C. Werrell, 2018. Reducing Risks Through Adaptation Actions. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1309–1345. doi: 10.7930/NCA4.2018.CH28
- Jantarasami, L.C., R. Novak, R. Delgado, E. Marino, S. McNeeley, C. Narducci, J. Raymond-Yakoubian, L. Singletary, and K. Powys Whyte, 2018. Tribes and Indigenous Peoples. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 572–603. doi: 10.7930/NCA4.2018.CH15

7.1.2 U.S. Fifth National Climate Assessment (NCA5)

The Fifth National Climate Assessment (NCA5, https://www.globalchange.gov/nca5) is expected to be available in late 2023 and will include analyses from CMIP6. The NCA5 is expected to include chapters on the Northwest and Southwest U.S. regions, water, and ecosystems and biodiversity. Technical reports supporting NCA5 are becoming available, including a released set of state summaries developed by NOAA, available here: https://statesummaries.ncics.org/.

7.1.3 2017 Climate Science Special Report

The 2017 Climate Science Special Report is the climate science behind the U.S. Fourth National Climate Assessment. It includes chapters on topics such as precipitation as well as references that are nationwide and can be searched for by state or region of interest. The following is an example of a chapter on precipitation:

- Easterling, D.R., K.E. Kunkel, J.R. Arnold, T. Knutson, A.N. LeGrande, L.R. Leung, R.S. Vose, D.E. Waliser, and M.F. Wehner, 2017. "Chapter 7: Precipitation Change in the United States." In *Climate Science Special Report: Fourth National Climate Assessment, Volume I*. Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock, eds. U.S. Global Change Research Program, 207-230. Available at: http://dx.doi.org/10.7930/J0H993CC.

7.1.4 Interagency Sea level Rise Technical Report

This technical report is a synthesis of the most recent science related to sea level rise, and serves as a key technical input for the NCA5. It provides global mean sea level rise scenarios are regionalized for the U.S. coastline. It does not provide guidance or design specifications for a specific project, but is intended to help inform federal agencies, tribes, state and local governments, and stakeholders in coastal communities about current and future sea level rise. The executive summary provides key messages, and the body of the report provides detailed, technical information about the data, modeling, and analysis behind the report's findings.

Data from the report are being incorporated into current and planned agency tools and services, and are immediately available in NOAA's Sea Level Rise Viewer (https://coast.noaa.gov/digitalcoast/tools/slr.html)

- Sweet, W.V., B.D. Hamlington, R.E. Kopp, C.P. Weaver, P.L. Barnard, D. Bekaert, W. Brooks, M. Craghan, G. Dusek, T. Frederikse, G. Garner, A.S. Genz, J.P. Krasting, E. Larour, D. Marcy, J.J. Marra, J. Obeysekera, M. Osler, M. Pendleton, D. Roman, L. Schmied, W. Veatch, K.D. White, and C. Zuzak, 2022. Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 111 pp. https://oceanservice.noaa.gov/hazards/sealevelrise/noaa-nostechrpt01-global-regional-SLR-scenarios-US.pdf

7.2 Columbia River Basin and Pacific Northwest

7.2.1 CMIP5-Based Climate Projections for the Columbia Basin and the Third Oregon Climate Assessment

The CMIP5-based projections for the Columbia Basin and the Third Oregon Climate Assessment address knowledge gaps in regional climate projections for the Columbia River Basin. These should be of practical interest for water resources, energy, and land management planning activities that need information on 1) factors that contribute to seasonal differences, 2) whether interannual variability is projected to change, 3) factors that contribute to the large spread in projections across GCM simulations, and 4) whether the fidelity of simulations compared to historical conditions relates to the magnitude of projected change. Both resources are included in the following:

- Rupp, D.E., J.T. Abatzoglou, and P.W. Mote, 2016. "Projections of 21st Century Climate of the Columbia River Basin." *Climate Dynamics* 1–17. DOI: 10.1007/s00382-016-3418-7.
- Dalton, M.M., K.D. Dello, L. Hawkins, P.W. Mote, and D.E. Rupp, 2017. *The Third Oregon Climate Assessment Report*. Oregon Climate Change Research Institute, College of Earth, Ocean and Atmospheric Sciences, Oregon State University, Corvallis, Oregon.

7.3 California

7.3.1 California's Fourth Climate Assessment

California's Fourth Climate Assessment[27] includes key findings, e.g., daily extreme precipitation values are projected to increase 5-15% (RCP 4.5) to 15-20% (RCP 8.5), presenting challenges for storm drainage and flood control. It also includes technical information and the following regional reports:

- He, Minxue, Andrew Schwarz, Elissa Lynn, and Michael Anderson, 2018. "Projected Changes in Precipitation, Temperature, and Drought across California's Hydrologic Regions in the 21st Century**.**" California's Fourth Climate Change Assessment. *Climate Variability and Change in the 21st Century*. Publication number: CCCA4-EXT-2018-002. Available at: https://www.mdpi.com/2225-1154/6/2/31/htm.
- AghaKouchak, Amir, Elisa Ragno, Charlotte Love, and Hamed Moftakhari, 2018. *Projected Changes in California's Precipitation Intensity-Duration-Frequency Curves*. Prepared for California's Fourth Climate Change Assessment, State of California Energy Commission.
- Publication Number: CCCA4-CEC-2018-005. https://www.energy.ca.gov/sites/default/files/2019-11/CCCA4-CEC-2018-005_ADA.pdf.
- Pierce, D.W., J.F. Kalansky, and D.R. Cayan, 2018. *Climate, Drought, and Sea Level Rise Scenarios for California's Fourth Climate Change Assessment*. Prepared for California's Fourth Climate Change Assessment, State of California Energy Commission. Publication Number: CNRA-CEC-2018-006. https://www.energy.ca.gov/sites/default/files/2019-11/Projections_CCCA4-CEC-2018-006_ADA.pdf.
- Franco, Guido, Daniel R. Cayan, David W. Pierce, Anthony L. Westerling, and James H. Thorne, 2018. *Cumulative Global CO_2 Emissions and their Climate Impact from Local Through Regional Scales*. Prepared for California's Fourth Climate Change Assessment. Publication number:

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[27] California's Fourth Climate Assessment Website: http://www.climateassessment.ca.gov

CCCA4-EXT-2018-007. https://www.energy.ca.gov/sites/default/files/2019-11/Projections_CCCA4-EXT-2018-007_ADA.pdf.

Additional Resources

Additional journal articles or technical reports for California include the following:

- Baker, Z., J. Ekstrom, and L. Bedsworth, 2018. "Climate Information? Embedding Climate Futures within Temporalities of California Water Management." *Environmental Sociology* 1-15. doi:10.1080/23251042.2018.1455123.
- Benjamin Z. Houlton et al., 2018. *Sacramento Valley Region Report. California's Fourth Climate Change Assessment*. August 2018. Available at: https://www.energy.ca.gov/sites/default/files/2019-11/Reg_Report-SUM-CCCA4-2018-002_SacramentoValley_ADA.pdf.
- California State Summary from the National Climate Assessment: https://statesummaries.ncics.org/chapter/ca/

Sacramento and San Joaquin Basins Climate Impact Assessment

This resource includes the following:

- U.S. Bureau of Reclamation, 2016. *Sacramento and San Joaquin Basins Study*. Report to Congress 2015. Prepared for: U.S. Department of the Interior, Bureau of Reclamation, Mid-Pacific Region. Prepared By: CH2M Hill under Contract No. R12PD80946. Available at: https://www.usbr.gov/watersmart/bsp/docs/finalreport/sacramento-sj/Sacramento_SanJoaquin_SUMMARY.pdf.

7.4 Washington

Washington State Water Temperature Projections

The Washington State Water Temperature Projections are available from 10 CMIP3 climate models, under two emissions scenarios (A1B and B1), for three future time periods (2020s, 2040s, and 2080s).

Graphics show the non-linear relationship between air and water temperatures at a stream temperature site near Bonneville Dam on the Columbia River. Various data from the temperature projections are available from the following resources:

- Data from the Washington State Water Temperature Projections available at: https://data.cig.uw.edu/picea/mauger/Mantua2010_Stream_Temp/
- University of Washington Climate Impacts Group, 2010. "Climate Impacts Group (CIG) Datasets – Washington State Water Temperature Projections." Available at: https://cig.uw.edu/datasets/washington-state-water-temperature-projections/.

- Mantua, N.J., I. Tohver, and A.F. Hamlet. 2010. "Climate Change Impacts on Streamflow Extremes and Summertime Stream Temperature and Their Possible Consequences for Freshwater Salmon Habitat in Washington State." *Climatic Change* 102(1-2): 187-223, doi: 10.1007/s10584-010-9845-2.

Puget Sound and Its Watershed

The following is a comprehensive report summarizing the likely effects of climate change on the Puget Sound region of Washington State. It provides observed and projected changes for Puget Sound's climate, water resources, forests, species and ecosystems, coasts and ocean, infrastructure, agriculture, and human health, and describes local climate change risk reduction activities and highlights data resources available to support local climate adaptation efforts:

- Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch0Isaksen, L. Whitely-Binder, M.B. Krosby, and A.K. Snover, 2015. *State of Knowledge: Climate Change in Puget Sound*. Report prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle. doi:10.7915/CIG93777D.

Shifting Snowlines and Shorelines

This following Shifting Snowlines and Shorelines brief is intended to provide an accessible overview of changing sea level and cryosphere in Washington for regional planners, land managers, scientists, and members of the public:

- Roop, H.A., G.S. Mauger, H. Morgan, A.K. Snover, and M. Krosby, 2020. "Shifting Snowlines and Shorelines: The Intergovernmental Panel on Climate Change's Special Report on the Ocean and Cryosphere and Implications for Washington State." Briefing paper prepared by the Climate Impacts Group, University of Washington, Seattle, Washington. DOI: doi.org/10.6069/KTVN-WY66. Updated January 2020. Available at: https://cig.uw.edu/resources/special-reports/shifting-snowlines-shorelines/.

Sea Level Rise in Washington State

The following reports address sea level rise in Washington State and provide a general overview on choosing sea level rise projections:

- Miller, I.M., H. Morgan, G. Mauger, T. Newton, R. Weldon, D. Schmidt, M. Welch, and E. Grossman, 2018. *Projected Sea Level Rise for Washington State–A 2018 Assessment*. A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, Oregon State University, University of Washington, and U.S. Geological Survey. Prepared for the Washington Coastal Resilience Project. Updated July 2019. Available at https://cig.uw.edu/wp-content/uploads/sites/2/2019/07/SLR-Report-Miller-et-al-2018-updated-07_2019.pdf.

- Raymond, C.L, N. Faghin, H. Morgan, and H. Roop, 2020. *How to Choose: A Primer for Selecting Sea Level Rise Projections for Washington State*. A collaboration of Washington Sea Grant and University of Washington Climate Impacts Group. Prepared for the Washington Coastal Resilience Project.

2009 Washington Climate Change Impacts Assessment

The following Washington Climate Change Impacts Assessment was the most comprehensive assessment of climate change impacts on Washington State at the time it was published. It still provides relevant information. It involved developing updated climate change scenarios to assess the impacts of climate change to the following sectors: agriculture, coasts, energy, forests, human health, urban stormwater infrastructure, salmon, and hydrology and water resources. Adaptation in each of these sectors was also discussed. While published in 2009, the information is still valid, and the assessment discusses various topics associated with the sectors:

- Littell, J.S., M.M. Elsner, L.C. Whitely-Binder, A.K. Snover, 2009. "Evaluating Washington's Future in a Changing Climate – Executive Summary." In *The Washington Climate Change Impacts Assessment*. Climate Impacts Group, University of Washington, Seattle, Washington. Available at https://cig.uw.edu/wp-content/uploads/sites/2/2020/12/wacciaexecsummary638_compressed.pdf.

Additional Resources

Additional journal articles or technical reports for Washington include the following:

- Washington State Summary from the National Climate Assessment (2022): https://statesummaries.ncics.org/chapter/wa/
- Chehalis Basin studies by CIG (Mauger et al. 2016, 2021) and Watershed Science and Engineering (WSE 2019, 2021), which uses the DHSVM model to project future streamflow.

Washington Wildlife Habitat Connectivity Working Group (WHCWG). 2013. An evaluation of the utility of fine-scale, downscaled climate projections for connectivity conservation

- planning in Washington State. Washington Departments of Fish and Wildlife, and Transportation, Olympia, WA. Available online at http://www.waconnected.org

7.5 Oregon

The Oregon Climate Change Research Institute conducts a biennial assessment of the state of climate change science, including biological, physical, and social science, as it relates to Oregon and the likely effects of climate change on Oregon. Assessments were conducted starting in 2010. The following Fifth Oregon Climate Assessment conducted in 2021 evaluates past and projected future changes in Oregon's climate and hydrology. It is a resource for the state's mitigation planning for natural hazards and implementation of the 2021 Oregon Climate Change Adaptation Framework:

- Dalton, M., and E. Fleishman (eds.), 2021. *Fifth Oregon Climate Assessment*. Oregon Climate Change Research Institute, Oregon State University, Corvallis, Oregon. Uses the most up-to-date downscaled CMIP5 (5th IPCC) projections; CMIP6 not yet available. Available at: https://oregonstate.app.box.com/s/7mynjzhda9vunbzqib6mn1dcpd6q5jka.
- Additional journal articles or technical reports for Oregon include the following:
  - Oregon 2022 State Summary from the National Climate Assessment: https://statesummaries.ncics.org/chapter/or/

7.6 Idaho

There is less information on Idaho relative to the coastal states. However, most of Idaho is in the Columbia Basin and is included in most Western United States projection products, so data are available from those sources described above. Additional journal articles or technical reports for Washington include the following:

- Idaho 2022 State Summary from the National Climate Assessment: https://statesummaries.ncics.org/downloads/Idaho-StateClimateSummary2022.pdf

- Idaho Climate-Economy Impacts Assessment, 2021: https://www.uidaho.edu/president/direct-reports/mcclure-center/iceia

  - Includes chapter: Abatzoglou, J. T., Marshall, A. M., Harley, G. L. 2021. Observed and Projected Changes in Idaho's Climate. Idaho Climate-Economy Impacts Assessment. James A. & Louise McClure Center for Public Policy Research, University of Idaho.

  - Boise, ID. https://www.uidaho.edu/-/media/UIdaho-Responsive/Files/president/direct-reports/mcclure-center/iceia/iceia-climate-report-2021.pdf?la=en&hash=D242CB9198EF3FB2A775F85E7DA37C2E6EF21B28

- May, C., C. Luce, J. Casola, M. Chang, J. Cuhaciyan, M. Dalton, S. Lowe, G. Morishima, P. Mote, A. Petersen, G. Roesch-McNally, and E. York, 2018. "Chapter 24: Northwest." In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II (Report)*. Editors, D.R. Reidmiller, C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart. Washington, DC, USA: U.S. Global Change Research Program. pp. 1036–1100. doi:10.7930/NCA4.2018.CH24.

- What Climate Change Means for Idaho from the EPA: https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-id.pdf

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