WATER STORAGE INVESTMENT PROGRAM

Technical Reference

California
WATER COMMISSION
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Acronyms and Abbreviations

Term	Definition
AACE	Association for the Advancement of Cost Engineering
AF	acre-feet; an acre-foot is about 325,851 gallons
ANN	artificial neural network
ASTM	ASTM International, formerly the American Society for Testing and Materials
BUVD	Beneficial Use Values Database
CADSWES	Center for Advanced Decision Support for Water and Environmental Systems
CALFED	CALFED Bay Delta Program
CalSim II	Planning model developed by the California Department of Water Resources and Bureau of Reclamation for simulating State Water Project areas, Central Valley Project areas, and areas tributary to the Sacramento-San Joaquin Delta
CASGEM	California Statewide Groundwater Elevation Monitoring
CCTAG	Climate Change Technical Advisory Group
CDFW	California Department of Fish and Wildlife
CEC	California Energy Commission
CEQA	California Environmental Quality Act (Public Resources Code Section 21000 et seq.)
CESA	California Endangered Species Act
cfs	cubic feet per second
cm	centimeter
CMIP5	Coupled Model Intercomparison Project Phase 5
COA	Coordinated Operations Agreement
Commission	California Water Commission
CPI-U	consumer price index for California
CVFED	Central Valley Floodplain Evaluation and Delineation Program
CVFPP	Central Valley Flood Protection Plan
CVHM	Central Valley Hydrologic Model
CVP	Central Valley Project
CWA	Clean Water Act
DOF	California Department of Finance
DPM	Delta Passage Model
DPR	California Department of Parks and Recreation

Term	**Definition**
DRERIP	Delta Regional Ecosystem Restoration Implementation Plan
DRMS	Delta Risk Management Strategy
DSM2	Delta Simulation Model II
DWR	California Department of Water Resources
EAD	expected annual damage
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ESHE	Emigrating Salmonid Habitat Estimation Model
ET	evapotranspiration
F	Fahrenheit
FERC	Federal Energy Regulatory Commission
FMP	denotes the farm process, a module within the Central Valley Hydrologic Model
GCM	global climate model
GHG	greenhouse gas
GIS	geographic information system
GSP	groundwater sustainability plan
H&H	hydrologic and hydraulic
HAV	Handbook for Assessing Value
HEC	Hydrologic Engineering Center
HEC-FDA	Hydrologic Engineering Center Flood Damage Reduction Analysis Model
HEC-FIA	Hydrologic Engineering Center Flood Impact Analysis Model
IEP	Interagency Ecological Program
IMPLAN	A modeling software used for economic impact assessment
I-O	input-output
IOS	interactive object-oriented salmon simulation
IPCC	Intergovernmental Panel on Climate Change
IWFM	Integrated Water Flow Model
kg	kilogram
km	kilometer
l	liter
LOCA	localized constructed analog
LTO	long-term operation

Term	**Definition**
M&I	municipal and industrial
mg	milligram
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
O&M	operations and maintenance
OBAN	Oncorhynchus Bayesian Analysis
OM&R	operations, maintenance and repair
OMP&R	operations, maintenance, power, and replacement
OMR	Old and Middle rivers
PFMC	Pacific Fisheries Management Council
PHABSIM	physical habitat simulation
ppb	parts per billion
ppt	parts per thousand
RAS	River Analysis System
RCP	representative concentration pathway
Reclamation	Bureau of Reclamation
REMI	A modeling software used for economic impact assessment
REV	relative environmental value
RHEM	Riparian Habitat Establishment Model
RPA	reasonable and prudent alternative
S&S	salmon and steelhead
SacEFT	Sacramento River Ecological Flows Tool
SCRB	separable cost-remaining benefits
SGMA	Sustainable Groundwater Management Act
SRH	sedimentation river hydraulics
State Water Board	State Water Resources Control Board
SWAT	Soil and Water Assessment Tool
SWP	State Water Project
TAF	thousand acre-feet
TMDL	total maximum daily load
URS	URS Corporation
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture

Term	Definition
USDI	U.S. Department of the Interior
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
USSD	U.S. Society on Dams
UWMP	Urban Water Management Plan
VIC	variable infiltration capacity
WARMF	Watershed Analysis Risk Management Framework
WEAP	Water Evaluation and Planning
WRIMS	Water Resource Integrated Modeling System
WSIP	Water Storage Investment Program
WUA	weighted usable area

SECTION 1

Introduction

This Technical Reference describes concepts and methods for quantifying benefits or adverse impacts that could result from water storage projects proposed for the Water Storage Investment Program (WSIP). The WSIP includes a competitive process by which the California Water Commission (Commission) will allocate state bond funds to pay for public benefits associated with water storage projects. According to the statute authorizing the bonds, which was passed by California voters in November 2014, each applicant must quantify the public benefits provided by their proposed project to support their request for bond funding. The statute directs the Commission to “adopt, by regulation, methods for quantification and management of public benefits” (California Water Code Section 79754).

At the time this document is being prepared, the Commission has proposed a regulation that includes quantification principles and performance standards that an applicant must follow for its project to compete for public funding under this program. Section 6004 of the proposed regulation describes the process by which without-project conditions, with-project conditions, and benefits must be quantified in physical values and in monetary values. The regulation requires that applicants use a provided set of data for future conditions with climate change and, for some applicants, it requires that they use specific water system and Delta operations models. Otherwise, the regulation does not require specific models or analytical methods that must be used by all applicants because in most cases a range of sound methods could be used, and the most appropriate method depends on the details of a proposed project (e.g., its location, size, operational rules, available information and models).

This Technical Reference provides more specific information to applicants about what a sound analysis of without-project and with-project conditions, benefits, and impacts should include, describes some models and methods that are appropriate for use with water storage projects, and provides data and model products that shall be used under specified conditions.

An acceptable quantification analysis must show how a proposed water storage project and its operation might affect the relevant physical resources and ultimately the benefits claimed or impacts that result. This document includes technical sections that, considered together, provide a range of analytical methods for quantifying benefits and impacts. This set of methods is intended to allow applicants to select the methods most appropriate for the location, size, and other parameters of their projects.

With the exception of the required datasets, an applicant may also select a method not included in this Technical Reference if the method is scientifically sound and adequately described and documented in the WSIP funding application. Criteria applicants can use to select methods, and that reviewers will use to evaluate selected methods, are detailed in Section 4, Calculating Physical Changes. The use of any method by an applicant, whether included in this Technical Reference or not, will be assessed for technical quality of analysis by subject-matter experts during the application review period.

1.1 Framework for Quantifying and Monetizing Project Benefits

Benefits are desirable changes resulting from a water storage project. They may fall into one of the five categories of public benefits defined for the WSIP in the Water Code, or they may be non-public benefits. Quantifying benefits requires estimating how physical conditions would change with the water storage project relative to the conditions without the project, and then assigning a monetary value to those changes where possible. This basic approach is consistent with analysis performed for environmental impact studies, feasibility studies, and other assessments of prospective projects or activities. Because the proposed water storage projects do not yet exist, their benefits cannot be measured at the time WSIP decisions are made – they must be assessed using analytical tools and models that incorporate best available science. A large number of analytical tools are described in this Technical Reference.

The framework for quantifying benefits is embodied in Section 6004 of the proposed regulation. It begins with a clear and quantitative description of conditions without the proposed water storage project (i.e., the without-project future conditions), covering the period of time (called the planning horizon) of project construction and operation. The two future conditions are 2030 and 2070. These two future conditions are required for quantification and they correspond to climate change projections provided to applicants. Then conditions with the project implemented (i.e., the with-project future conditions) are assessed. Analytical tools and models are used to develop both the without- and with-project future conditions in order to quantify the difference in the two conditions. Desirable changes are benefits and undesirable changes are impacts.

Expressing the benefits in monetary values is needed in order to calculate the expected return for public investment. Monetized benefits are also needed to calculate cost shares for benefit categories that are consistent with and do not exceed the benefits received by each category, and that meet the WSIP cost share requirements in the Water Code. This Technical Reference describes how costs must be estimated and displayed and provides methods for allocating costs among benefit categories. This document also shows how expected return for public investment is calculated using the quantified net benefit (monetary value of physical benefit less the unmitigated impact), allocated cost, and the WSIP funding request. Finally, uncertainty in future conditions, in particular uncertainty associated with climate change and uncertain hydrologic conditions, must be considered.

1.2 Limitations

Analytical methods (i.e., models, data sets, analytical assumptions) potentially suitable for the WSIP are described in this Technical Reference. The WSIP will only fund water storage projects that can provide public benefits enumerated in statute, which are ecosystem improvements, water quality improvements, flood control benefits, emergency response, and recreational purposes. However, statute requires that ecosystem improvements are at least 50 percent of the total public benefits funded under the WSIP (Water Code Section 79756(b)). Therefore it is crucial to accurately describe and quantify ecosystem benefits.

The methods described in this Technical Reference provide guidance for quantifying the benefits and impacts of eligible water storage projects. This Technical Reference is not intended to be a comprehensive guide to quantifying benefits or impacts of every potential water-related project or other resource allocation determination in the state.

This Technical Reference provides general concepts of analysis, plus some information on the features, advantages, and drawbacks of a set of methods. The following limitations apply to this document:

- It provides information on important concepts for quantification methods supporting public benefits of a water storage project potentially eligible for the WSIP. In addition, methods for some non-public benefits of water storage projects are provided.
- It is not a user’s manual for how to implement any particular method. With the exception of provided economic unit values and climate change-related information, applicants are responsible for determining how to implement the appropriate methods.
- It describes the concepts that an appropriate quantification method must or should include, and provides a summary of some specific models that could be useful. It does not list or describe all possible methods or models.

This Technical Reference describes methods as *required, recommended*, or *suitable*. For any method used, the applicant must describe how it implemented the method, including data, assumptions, calculations, and sources of information, and provide detail that allows technical reviewers to assess the overall quality of the analysis.

Required methods (models, data sets, parameter values, or assumptions) are designated in this document with the phrase “must use” or “shall use.” Relatively few required methods are included, and they are primarily presented as assumptions or data for use in the analysis to provide consistency across all applications. Examples of required datasets are the 2030 and 2070 future condition hydrology datasets provided. Examples of required parameter values are the discount rate and some cost or benefit escalation rates. Other requirements include consistency with analyses in an applicant’s environmental and feasibility analysis, unless justification of differences is provided.

Recommended methods are those that an applicant should use, to the extent the method is appropriate and applicable to its proposed project. Relatively few methods are recommended in all situations. The word “recommended” or the phrase “should use” indicates a recommended method, often followed by more information on the conditions under which it is recommended. The applicant may nevertheless use another method if, for example, the recommended method is not appropriate for its project (e.g., the method does not quantify the specific benefits produced by the project), or reliable data are not available to implement the recommended method (e.g., the detail and scope of data required for the method exceeds the data available). An applicant must justify why the recommended method is not used.

Other suitable methods are those that might be appropriate and acceptable to use for a particular project, but no clear preference exists. These types of methods are briefly described, along with some information on advantages and drawbacks, to help an applicant decide which method may be most appropriate for its project. An applicant must justify its use of a particular method.

Finally, this Technical Reference specifies in numerous instances that both benefits (desirable changes) and impacts (undesirable changes) must be quantified. Two clarifications are important:

- Impacts must be quantified if they are not fully mitigated. If an impact is fully mitigated, as demonstrated in the environmental documentation or other documentation, it need not be quantified for purposes of WSIP. If an impact is not or only partially mitigated, the unmitigated portion must be quantified.

- For brevity, descriptions of quantification methods often only mention benefits and not impacts. However, in all cases, impacts in each of the benefit categories must also be quantified.

SECTION 2

Defining the Without-Project Future Conditions

2.1 Background

Benefits or impacts of a proposed water storage project are prospective; they occur in the future as a result of the changes in water-related conditions brought about by the water storage project. Benefits and impacts are measured as changes by comparing conditions with the water storage project to conditions without the water storage project over a consistent future time period. Therefore, defining the water-related conditions (that is, the characteristics of the natural and human water environment that may be affected by the water storage project) is critical for establishing the baseline against which benefits or impacts are measured.

This section presents the conditions that all applicants must include in their descriptions and quantification of without-project future conditions. These include both specific conditions that all applicants must include, data products and model products that certain applicants must use, plus more general principles that applicants must apply to develop without-project future conditions for their specific project and location. First, this section describes how applicants determine the appropriate geographic and temporal scope of their analysis. Then it discusses consistency of an applicant’s analysis of benefits and impacts with the analysis presented in its environmental impact assessment. The section also includes a set of physical, regulatory, and socioeconomic conditions and assumptions that must be used or considered, including sources of information and references available to the applicant as it prepares its proposal. Finally, the section includes a discussion of how assumptions, data, and analysis are used to provide a complete picture of without-project future conditions.

Describing without-project future conditions using existing documents may be challenging if those documents’ future condition years do not align with the project’s planning horizon. Existing documentation may also only describe current conditions, so applicants must project how current conditions may change in the future or verify that current conditions persist into the future. Applicants may be able to describe future conditions in terms of general trends of condition, extrapolating and interpolating as appropriate. In most cases, models will be needed to forecast future conditions in a way that will ensure consistency between the without-project and with-project conditions.

Descriptions of current and future without-project conditions must provide objective and justifiable assessments of the water-related resources. Applicants must not understate or overstate current or future conditions to exaggerate or otherwise misrepresent claimed benefits.

2.2 Study Area

The applicant's analysis of without-project future conditions must include any watershed(s) or region(s) that affect or are affected by the proposed project. Applicants must use a study area that encompasses, at a minimum, the immediate vicinity of the project, including the boundary of the applicable sub-watershed or groundwater sub-basin.

Physical changes caused or created by a proposed project are likely to extend beyond the immediate vicinity of the project and beyond the local watershed. Physical changes caused by the project may have effects throughout the state water system via interaction with other facilities, water uses, regulatory requirements, and other environmental conditions.

Potential interactions may require an applicant to expand the study area to include:

- The watershed/region in which the proposed project is located or to which it is connected (including reaches/areas upstream)
- Neighboring watersheds/regions where changes could occur at or near existing or proposed interconnections
- Downstream watersheds/regions where changes could occur
- Watersheds/regions that are tributary to the watershed/region, where changes could occur

To document and justify benefits claimed outside of the immediate vicinity of the project, the analysis study area should be extended to encompass those areas that may be affected by the construction and operation of the proposed project. For example, if the re-operation of a reservoir affects flows to the Sacramento-San Joaquin Delta (Delta), the Delta shall be included in the analysis' study area. Potential changes in operations and management of the Delta or Delta facilities will require an applicant to expand the study area to include the Delta watershed/region. Similarly, potential changes in State Water Project (SWP) and Central Valley Project (CVP) operations, including those on the Trinity, Sacramento, Feather, American, Stanislaus, and San Joaquin rivers, will require an applicant to expand the study area for analysis to include these watersheds/regions.

2.3 Planning Horizon

The applicant's analysis must quantify public benefits and impacts over the expected future life of the project. Feasibility-level project analysis compares without-project and with-project conditions in the future, using forecasts or projections of future development and natural resource conditions. The analysis compares the physical and economic metrics between the with- and without-project future conditions over an entire planning horizon. The planning horizon defines the duration of this comparison period. Conceptually, the planning horizon includes the construction and operations period —

essentially the period over which costs are incurred and benefits and impacts are generated. The operations period is also called the expected life of the project.

For practical reasons, the planning horizon is normally limited to no more than 100 years. Beyond 100 years, benefits and costs are highly uncertain, and with discounting, the present value of monetized benefits becomes small. Therefore, the planning horizon may not exceed the expected life of the project facilities plus the construction period, or 100 years, whichever is less.

Analyses conducted for the WSIP must, at a minimum, include without- and with-project future conditions at 2030 and 2070, if the project planning horizon extends to 2070 or beyond. In addition, the relative environmental value for ecosystem and water quality improvements requires an assessment of current conditions for those resources (see sections 4.7 and 4.8). The analyses can also include projected conditions for any other year determined by the applicant where conditions in the study area are expected to change and may influence the proposed project's operations, facilities, or potential benefits.

2.4 California Environmental Quality Act (CEQA) Considerations

Water Code Section 79755(a)(5)(C) requires that environmental documentation associated with a proposed project approved for WSIP funding be completed prior to allocation of funds. In addition, a project is not eligible for funding unless draft environmental documentation is available for public review. All projects proposed for funding must comply with CEQA. Projects that require federal action may also have impact analysis that satisfies the National Environmental Policy Act (NEPA). However, NEPA considerations are not discussed here because they do not apply to all projects.

The without-project condition for the WSIP serves an analogous purpose to the No Project Alternative used for CEQA. It provides a reference set of conditions against which to measure changes resulting from a project. However, the potential variety of project types, stages of development, locations, and potential benefits make it unlikely that any one CEQA No Project Alternative will be consistently defined and evaluated across all projects. Further, CEQA analysis focuses on significant environmental effects of a proposed project [for more information, see the CEQA Guidelines in the California Code of Regulations, Title 14, Section 15126.2(a)]. Therefore, CEQA analyses include a much broader set of impact categories, such as air quality, traffic, or cultural resources, than are needed to quantify the water-related benefits or impacts in an application for the WSIP. CEQA No Project conditions therefore include descriptions and assumptions that allow analysis of this broad range of impact categories. The WSIP analysis need not include quantification of all changes and impacts identified in the CEQA analysis.

In contrast, water-related benefits provided by a project need not be analyzed in great detail for CEQA compliance, whereas they are the primary focus of the analysis and quantification for the WSIP. Water-related benefits include changes in any of the five defined public benefits and changes in non-public benefits provided by the project such as water supply and hydropower. A broader set of water-related, without-project conditions must be specified to quantify those benefits.

The CEQA Guidelines, as defined in Title 14 of the California Code of Regulations in Section 15125(a), require an environmental impact report to include a description of existing conditions, which are the physical environmental conditions in the vicinity of the project as they exist at the time the Notice of Preparation is published, or if no Notice of Preparation is published, at the time environmental analysis begins, from both a local and regional perspective. This demarcation date for the CEQA existing conditions is unlikely to be consistent across all applications.

The CEQA Guidelines, as defined in Title 14 of the California Code of Regulations Section 15126.6(e)(2), state that the No Project Alternative includes reasonably foreseeable changes in the existing conditions and changes that would be reasonably expected to occur in the foreseeable future if the proposed project were not implemented, based on current plans and consistent with available infrastructure and community services. The criteria for determining foreseeable changes used for CEQA are unlikely to be consistent across applications. Without-project conditions for purposes of WSIP benefits analysis must also include reasonably foreseeable future conditions.

CEQA requires that direct, indirect, and cumulative impacts of proposed projects be assessed against a baseline which normally consists of existing conditions – meaning those conditions existing at the time the Notice of Preparation is filed. CEQA also allows the use of a future hypothetical baseline. However, for purposes of WSIP, projections of future conditions that include climate change and sea level rise are required for purposes of applicant submission to allow comparisons of monetized values of public benefits among competing projects. The same climate change and sea level rise assumptions are required for all proposed projects to allow this comparison, and the resulting values allow for an approximation of how climate change and sea level rise may affect project benefits in the future.

Table 2-1 summarizes the similarities and differences between an applicant's CEQA analysis of environmental impacts of a proposed project and its analysis of the water-related benefits and impacts under the WSIP. Applicants must disclose any differences between their CEQA No Project Alternative and the without-project condition provided for the WSIP application when such differences exist.

Table 2-1. Comparison of CEQA Analysis to WSIP Benefits Analysis.

Subject	CEQA Impact Analysis	WSIP Benefits Analysis
Study area	Must include areas of potentially significant direct and indirect impacts	Must incorporate locations of water-related benefits or impacts
Project benefits	Analysis of benefits not required except if needed to determine environmental impacts and their significance	Quantification of water-related benefits over the planning horizon required to the extent possible
Project impacts	Consider all potential impacts on the physical environment	Quantify all impacts on water-related benefit categories, so that net benefits can be assessed
Demarcation date for existing or current conditions	Notice of Preparation date or when environmental analysis starts	Same as CEQA existing condition.
Future condition year(s)	Varies by project	2030 and 2070, at a minimum, if within planning horizon
No project/without-project conditions	Conditions reasonably expected to occur in the foreseeable future if the project were not approved, based on current plans and consistent with available infrastructure and community services.	Same as for CEQA, with any additional specific information or forecasts needed to quantify water-related benefits or impacts at the future condition years.

2.5 Feasibility Study Considerations

Water storage projects evaluated under federal guidelines must follow agency-specific guidelines, but no similar guidelines exist for water storage projects developed by local agencies that expect no federal participation.

A completed project feasibility study is required as part of the project eligibility requirement (Water Code Section 79757) of the WSIP. A feasibility study is an evaluation and analysis of the overall viability of a proposed project, but will contain information on the without-project future conditions used in the analysis. An applicant must identify and explain differences in assumptions, procedures, and results between its feasibility study and its application, and how those differences could affect project feasibility.

2.6 Water Resources System and Operations

Applicants must evaluate their water storage projects and quantify the benefits within the broader context of California’s water system conditions, facilities, and rules governing operations as they are expected to exist under future conditions. Without-project future conditions are the reference conditions against which changes (i.e., benefits and impacts) are measured. Therefore, applicants must carefully define the without-project future conditions.

Water resources system and operations conditions are characterized by information and assumptions about the water resources system, including:

- Facilities, including storage, conveyance, levees, other hydrographic features, and infrastructure

- Level of development, including population, land use, water demands, water rights, and water contracts at specific points in time (i.e., 2030 and 2070)
- Climate and sea-level conditions
- Standards, regulations, decisions, and permits (i.e., limits, thresholds, and priorities)
- Facilities operations criteria, operations agreements, and other laws, regulations, and policies governing operations

Where future conditions are not specified by required data products or model products, applicants shall use the current condition as the reference point for defining or projecting future conditions. Current condition is the existing condition for the CEQA environmental documentation, though applicants may need to include additional information to provide a basis for assessing benefits and impacts. Future condition years shall be 2030, 2070, and, if determined by the applicant, any other year prior to 2070 where conditions in the study area are expected to change and may influence the proposed project's operations, facilities, or potential benefits.

2.6.1 Watershed Operations

Applicants must demonstrate substantial knowledge of the facilities and operations in the watersheds influenced by the proposed project and incorporate that knowledge into their description of without-project future conditions. In addition, a detailed understanding is required of the criteria that govern diversion, storage, flow, and management of water for the local watershed and region.

Table 2-2 lists potential sources of information and references available to help applicants prepare their descriptions of without-project future conditions for the water resources system. Information derived from sources in the Table are supplemental to, and cannot replace, data provided in the 2030 and 2070 future condition data and model products. The list is not comprehensive, and applicants are responsible for identifying the most appropriate information to support their analysis. The sources of information listed are in the public domain and have been compiled and made accessible by agencies or other organizations as shown, possibly excepting some information held by local agencies.

Table 2-2. Example Sources of Information for Defining the Without-Project Future Conditions of the Water Resources System.

Source of Information	Reference Documents and Web Pages
Local and Regional Agencies	• Individual agencies may provide, via website or direct request, descriptions of facilities and operations and information on current and future demands. They may also provide useful information in water management plans, permitting and licensing studies, and environmental assessments. • Water Resources Collections and Archives at the University of California at Riverside: http://library.ucr.edu/wrca/grants/districts.html.

Table 2-2. Example Sources of Information for Defining the Without-Project Future Conditions of the Water Resources System.

Source of Information	Reference Documents and Web Pages
California Department of Water Resources (DWR)	• California Data Exchange Center. Current reservoir and riverine conditions, and future scheduled releases in California: http://cdec.water.ca.gov/ • Database of SWP contracts and maximum allocations: DWR Bulletin 132: http://www.water.ca.gov/swpao/bulletin_home.cfm • State Water Project Analysis Office webpage (contract amounts): http://www.water.ca.gov/swpao • Listing of dams, including capacity, area, drainage area, crest elevation and length, and dam height: http://www.water.ca.gov/damsafety/damlisting/index.cfm • 2015 State Water Project Delivery Capability Report: https://msb.water.ca.gov/documents/86800/293731/Appendices2015DCR_20150427.pdf?version=1.0 • Listing of groundwater basins and approximate capacities: http://www.water.ca.gov/groundwater/bulletin118/index.cfm • Existing flood management systems and practices
Bureau of Reclamation (Reclamation)	• Projects and facilities database of Reclamation facilities. Provides dam characteristics and hydraulic and hydrologic information for the reservoir. Also includes Reclamation projects like the Central Valley Project: http://www.usbr.gov/projects • Central Valley Project Improvement Act provisions affecting the operation of the Central Valley Project: http://www.usbr.gov/mp/cvpia/ • Operations Criteria and Plan Biological Assessment: http://www.usbr.gov/mp/cvo/ocap_page.html • Coordinated Long-Term Operation of the CVP and SWP, Final Environmental Impact Statement: http://www.usbr.gov/mp/BayDeltaOffice/coordinated-long-term.html
U.S. Army Corps of Engineers (USACE)	• Monthly, daily, and hourly reservoir conditions for Central Valley reservoirs; flood storage rule curves; existing levee systems, other data: http://www.spk-wc.usace.army.mil/
State Water Resources Control Board (State Water Board)	• Adopted water rights decisions: http://www.swrcb.ca.gov/waterrights/board_decisions/adopted_orders/decisions/ • Adopted orders: http://www.swrcb.ca.gov/waterrights/board_decisions/adopted_orders/orders/ • Surface Water Ambient Monitoring Program: http://www.waterboards.ca.gov/water_issues/programs/swamp/ • Groundwater Ambient Monitoring Program: http://www.waterboards.ca.gov/gama/ • 2012 California Integrated Report: http://www.waterboards.ca.gov/water_issues/programs/tmdl/integrated2012.shtml
Federal Energy Regulatory Commission (FERC)	• Search engine for documents, testimony, and other information related to FERC hydroelectric licenses or other activities: http://elibrary.ferc.gov/idmws/search/fercgensearch.asp

The Commission will provide 2030 and 2070 climate and sea-level conditions for applicants to use in their water operations analysis of future conditions. In addition, the WSIP will provide without-project CalSim II modeling runs incorporating 2030 and 2070 climate and sea-level conditions to support the applicants’ analysis of future water operations. Applicants must use these conditions for their project analyses.

2.6.2 Delta Operations

Water operations in the Delta are governed by required actions and policies related to water quality criteria identified by the State Water Resources Control Board (State Water Board), federal Endangered Species Act (ESA) reasonable and prudent alternative (RPA) actions identified in the December 2008 U.S. Fish and Wildlife Service (USFWS) Biological Opinion and the June 2009 National Marine Fisheries Service (NMFS) Biological Opinion, and California Endangered Species Act (CESA) authorizations. Any analysis of a proposed water storage project that includes Delta operations (e.g., to demonstrate measurable ecosystem improvements to the Delta) must consider these required actions.

Applicants are required to include, if applicable to the analysis of a proposed water storage project, all required operations related to the Delta, the Biological Opinions, and the CVP and SWP as summarized below and in Table 2-3. If an applicant determines that the required operations do not apply to the analysis of a proposed project, it must explain why. Key water quality and water rights decisions and Biological Opinions affecting Delta operations include:

- State Water Board, Water Rights Decision 1641 (State Water Board, 1999)
    - San Joaquin River at Vernalis – Minimum flow
    - San Joaquin River at Vernalis – Maximum salinity
    - Lower Sacramento River at Rio Vista – Minimum flow
    - Delta Outflow Index – Minimum flow
    - Delta Outflow Index – Maximum salinity – Emmaton, Jersey Point, Rock Slough, Collinsville, and Chipps Island
    - Delta Outflow Index – Spring X2 position
    - Delta Cross Channel – Gate operation
    - South Delta Intakes – Maximum Delta exports
- USFWS Biological Opinion (USFWS, 2008) RPA actions:
    - Combined flow in Old and Middle rivers – Minimum flow (Actions 1 through 3)
    - Delta Outflow Index – Fall X2 position (Action 4)
    - Head of Old River – Barrier operation (Action 5)

- NMFS Biological Opinion (NMFS, 2009) RPA actions:
    - Clear Creek below Whiskeytown Dam – Minimum flow (Action I.1.1)
    - Red Bluff Diversion Dam – Operated with gates out all year (Action I.3.1)
    - Shasta Lake – Minimum end-of-September storage (Action I.2.1)
    - Sacramento River Below Keswick Dam – Minimum flow (Action I.2.2)
    - Sacramento River at Wilkins Slough – Flow objective for navigation (Action I.4)
    - American River Below Nimbus Dam – Minimum flow – American River Flow Management proposal (Action II.1)
    - Stanislaus River Below Goodwin Dam – Minimum flow (Actions III.1.2 and III.1.3)
    - Delta Cross Channel – Gate operation – additional days closed from Oct 1 – Jan 31 (Action IV.1.2)
    - South Delta Intakes – Maximum Delta exports Apr 1 – May 31 (Action IV.2.1)
    - Combined Flow in Old and Middle rivers – Minimum flow (Action IV.2.3)

These requirements are reflected in the without-project CalSim II modeling runs incorporating 2030 and 2070 climate and sea-level conditions provided in section 2.12 and Appendix A.

Applicants must use the data and model products described in section 2.12 and Appendix A for their project analyses, except that

1. Flood control benefits using hydrologic and hydraulic modeling of future flood events may utilize modeling provided in their feasibility studies, or modeling using historical flood events or historical hydrology with a comparison to future climate and sea level conditions.
2. Applicants not proposing CALFED surface storage projects, as defined in section 6001(a)(10) or not requesting funding for quantified benefits within the Delta or resulting from Delta improvements are not required to use the Appendix A model products for their project analyses.
3. If the model products provided do not adequately describe the without-project future conditions relevant to the project, applicants may also use other tools or models to complete the description of the without-project future conditions.

It should be noted that inclusion of the RPA actions in the without-project condition does not imply that the objectives of the RPA are fully met under all hydrologic and operational conditions. The water resources system is currently operated to achieve the objectives of the RPA to the extent possible with the facilities and operational policies in place based on an assessment of resource conditions, subject to the discretion of SWP and CVP operators in consultation with the regulatory agencies and stakeholders.

2.6.3 SWP and CVP Operations

The SWP has facilities in the Feather River watershed and the Delta. The CVP has facilities in the Trinity, Sacramento, American, Stanislaus, and San Joaquin River watersheds and the Delta. SWP and CVP facilities operate under the requirements of State Water Board Water Right Decision 1641 (State Water Board, 1999), the USFWS Biological Opinion (USFWS, 2008), the NMFS Biological Opinion (NMFS, 2009), State Water Board Water Rights Orders 90-05 and 91-01 (State Water Board, 1990, 1991), and the February 2009 Longfin Smelt Incidental Take Permit for operations of the SWP in the Delta (California Department of Fish and Wildlife [CDFW], 2009), among other standards, regulations, decisions, permits, agreements, and policies. The SWP and CVP Trinity, Sacramento, Feather and American River and Delta facilities operations are coordinated under the 1986 Coordinated Operations Agreement (COA) (Reclamation and DWR, 1986).

If applicable to the analysis of a proposed project, operations related to the Delta, Biological Opinions and CESA authorizations, and SWP and CVP contracts and agreements must be incorporated in the analyses provided by applicants. Table 2-3 summarizes operational requirements and criteria of the SWP and CVP. Some of these derive directly from water rights decisions and Biological Opinions described above. Others implement water rights agreements, contract terms, and other agreements governing operation of the SWP and CVP. If an applicant determines that the required operations are not applicable to the analysis of a proposed project, it must explain why.

These operational requirements and criteria are reflected in the without-project CalSim II model products incorporating 2030 and 2070 climate and sea-level conditions provided in section 2.12 and Appendix A. Any technical adjustments to the CalSim II model code for the 2030 without-project and 2070 without-project future conditions due to project-specific complexities or unique conditions must be documented and justified. Technical adjustments to the CalSim II model code shall be limited to modifications needed to complete the description of the proposed project and depiction of public and non-public benefits. Adjustments made to the without-project future conditions must also be included in the with-project future conditions and must be justified as requirements for the analysis of the proposed project. Regulatory requirements, agreements, and operations criteria of the SWP and CVP in the CalSim II model code for the 2030 without-project and 2070 without-project future conditions shall not be modified.

It is recognized that under future climate conditions, in some of the dry and critical years, CalSim II results may show water levels in the SWP/CVP system reservoirs below the lowest release outlets, making the system vulnerable to operational interruptions where regulatory requirements may not be met. It is recognized that these operational conditions may be unrealistic since uncertainty grows as conditions are estimated further into the future. Uncertainties such as land use, water use, technological innovation, regulations, and economic values will have an effect that cannot be accurately predicted. The applicant may assume adaptive management techniques to capture these scenarios based on the comparison of with- and without-project conditions, if appropriate.

Table 2-3. Key Contracts and Agreements Affecting Operations of the SWP and CVP.

Contract/Agreement	Relationship of Contract/Agreement to SWP, CVP Operations
SWP Water Supply and Feather River Settlement Contracts and Allocation Criteria	Settlement contracts in the Feather River Service Area: Deliveries and other operational criteria vary by contract.
	Agricultural and Municipal and Industrial (M&I) water supply contracts: Annual delivery depends on supply; Monterey Agreement established equal prioritization between agriculture and M&I; South-of-Delta allocations are additionally limited due to State Water Board Water Right Decision 1641 and USFWS Biological Opinion (USFWS, 2008) and NMFS Biological Opinion (NMFS, 2009) export restrictions; includes Monterey Agreement turn-back provisions and Article 56 contractor carryover.
	Monterey Agreement Article 21 interruptible water is available to contractors when San Luis Reservoir is full. Amount available is based on Delta excess flows, export capacity, and conveyance capacity.
CVP Water Service, Sacramento River Settlement, and San Joaquin River Exchange Contracts and Allocation Criteria	Settlement and Exchange contractors are entitled to receive full contract delivery, except in Shasta critical years when Settlement contractors receive 75 percent and Exchange contractors receive 77 percent
	National Wildlife Refuges receive 100 percent of Firm Level 2 delivery, except in Shasta critical years when they receive 75 percent
	M&I Water Service –Delivery ranges between 50 and 100 percent of contract quantity based on supply. South-of-Delta allocations are additionally limited due to State Water Board Water Right Decision 1641, USFWS Biological Opinion (USFWS, 2008), and NMFS Biological Opinion (NMFS, 2009) export restrictions.
	Agricultural (Irrigation) Water Service – Delivery ranges between 0 and 100 percent based on supply. South-of-Delta allocations are additionally limited due to State Water Board Water Right Decision 1641, USFWS Biological Opinion (Dec 2008), and NMFS Biological Opinion (June 2009) export restrictions
SWP-CVP Coordinated Operations	The 1986 COA determines the projects' share of responsibility for in-basin-use (i.e., Freeport Regional Water Project East Bay Municipal Utility District and two thirds of the North Bay Aqueduct diversions considered as Delta Export; one third of the North Bay Aqueduct diversion as in-basin-use).
	The 1986 COA determines how the projects share surplus flows
SWP-CVP Sharing of Allowable Export Capacity	The projects share equally in export capacity for project-specific priority pumping under State Water Board Water Right Decision 1641, USFWS Biological Opinion (USFWS, 2008), and NMFS Biological Opinion (NMFS, 2009) export restrictions.
	The projects share export capacity for lesser priority and wheeling-related pumping, including Cross Valley Canal wheeling (at a maximum of 128 thousand acre-feet [TAF]/year). The CALFED Bay Delta Program (CALFED) Record of Decision defined the Joint Point of Diversion.
Use of Export Capacity for Conveyance of Water Transfers	Monterey Agreement Article 55 provides SWP contractors the priority use of Banks Pumping Plant capacity for water transfers.
	Lower Yuba River Accord: Acquisitions of Component I are used to reduce impact of NMFS Biological Opinion export restrictions on SWP; acquisitions for SWP contractors are wheeled at priority in Banks Pumping Plant over non-SWP users.
Trinity River Mainstream Fishery Restoration Record of Decision	Trinity River Mainstem Fishery Restoration EIS/EIR preferred alternative sets minimum flow below Lewiston Dam ranging from 369 to 815 TAF/year (U.S. Department of the Interior, 2000).

2.6.4 Other Surface Water and Groundwater Conditions and Management

Applicants must describe other surface water and groundwater conditions and management activities that may affect the quantified benefits or impacts of the proposed water storage project. Conditions must be consistent with information and management activities presented in the environmental documentation for the proposed project and with applicable local plans, including agricultural and urban water management plans and groundwater management plans. Section 4.3, Surface Water Operations Analysis, and Section 4.4, Groundwater Analysis, include additional information and references that applicants can use to develop descriptions of without-project conditions.

For without-project future conditions, applicants must also rely on projections based on modeling, trend analysis, or other methods. Known projects and requirements that may not exist under current conditions must also be included. For example, applicants must consider the effect of full implementation of the Sustainable Groundwater Management Act (SGMA) on future conditions in their study area. An applicant's planning horizon analysis shall assume that full implementation is in effect by the dates specified in SGMA unless the local groundwater management agencies have adopted a groundwater sustainability plan (GSP) that requires full implementation sooner.

SGMA implementation is occurring concurrently with the writing of this document. At the time that WSIP applications are developed, the specific groundwater management actions and numerical sustainable yield targets will not be known. Applicants should strive to use analysis, data, and management assumptions that they expect will be reasonably consistent with SGMA's requirements, its implementing regulations, and the study area's GSP. Applicants must provide and justify a best estimate of the future effect of SGMA implementation. Uncertainty associated with this estimate may be evaluated using sensitivity analysis as described in Section 10, Evaluating Sources of Uncertainty.

2.7 Socioeconomic Conditions

Applicants must define future demographic and economic conditions to the extent needed to quantify benefits or impacts. Physical and/or monetized benefits and impacts clearly depend on future population, land use, and water demands served by or affected by a project. Applicants need not include in their analysis socioeconomic characteristics that do not affect physical or monetized water-related benefits or impacts, even if such characteristics are relevant to and included in the CEQA impact analysis. Examples include age distribution, employment, and income distribution within an area receiving water-related benefits or impacts.

2.7.1 Future Population Levels

Future population levels are needed to estimate future M&I water demand levels and may be relevant for quantifying benefits or impacts of ecosystem improvements, water quality improvement, flood control, emergency response, and recreation.

The California Department of Finance (DOF) (DOF, 2016a) provides online access to its most recent population forecasts for California counties, cities, and designated census places. Where future population levels are relevant to benefits calculations, the applicant shall use the most recent population forecasts from DOF or that are derived from and consistent with the most recent DOF population projections.

DOF forecasts are available through 2060. For years beyond 2060 the average annual growth rate between 2050 and 2060 should be assumed unless other estimates provided by a local planning agency have been developed and published. Other published, well-documented population forecasts can also be used, including from Urban Water Management Plans (UWMPs) or local general plans, if they are consistent with DOF projections.

2.7.2 Future Land Use

Future land use should be based on existing, published documents whenever possible, including local general plans, agricultural water management plans, UWMPs, and the California Water Plan Update. Land use projections should, to the extent possible, be consistent across the models or analyses used to quantify benefits and impacts. Applicants must describe the methods used to modify land uses and projections if necessary to conform them to a proposed project’s study area.

2.7.3 Future M&I Water Demand Levels

Existing demand forecasts are provided for a large portion of California’s urban water use through the water suppliers’ UWMPs. These plans are developed by individual water suppliers at 5-year intervals, with 2015 UWMPs the most recent available at the time of WSIP applications. The UWMPs also provide information about future availability of local water supplies, which, combined with demand projections, indicate future need for additional water supplies.

Where M&I water demands are needed to quantify public or non-public benefits, M&I water demands levels should be consistent with UWMPs where they exist, and with population forecasts otherwise. Urban water demands shall meet the required 20 percent per capita reduction target by 2020. Applicants shall calculate water demands projected beyond the years in UWMPs as the product of the 2020 average gallons per capita per day, including all urban water use sectors, estimated in the UWMP and the population forecast.

2.8 Ecosystem Conditions

Without-project future conditions for ecosystem resources must include characteristics of habitats and species that are included in project benefits or impacts. These include the abundance, distribution, and condition of species and populations, ecological associations, habitats, and physical processes that create or contribute to these conditions (e.g., hydrogeomorphic flows) in the study area. The project's CEQA (and NEPA, if applicable) document resource areas that should inform the description of ecosystem condition primarily include biological resources (terrestrial and aquatic), water resources, and water quality. Other CEQA resources areas that may influence ecosystem conditions to a lesser extent or indirectly may include land use, hazards and hazardous materials, agricultural resources, soils and geology, noise, and air quality.

The project's environmental document and feasibility study should be the primary information source for assessing ecosystem conditions, but other sources of information may include other, more recently prepared environmental documents (generally defined as those prepared within the last 5 years of the WSIP application) whose project footprints or impact areas overlap a proposed WSIP project's study area. Similarly, recently-prepared Habitat Conservation Plans or species Recovery Plans may provide information for current and future without-project conditions. An example might include a future land acquisition and management plan required under a Habitat Conservation Plan for the benefit of ESA-listed species. Such existing and future conditions would be reasonably certain to occur, so the benefits of implementing a Habitat Conservation Plan would form part of the without-project future condition against which future WSIP benefits and impacts would be assessed.

Environmental permits for existing projects also provide useful information for describing without-project future conditions. Such permits often include long-term implementation schedules and commonly include monitoring, reporting, and management protocols. Reports prepared to satisfy permit requirements may describe resource trends over time, including target conditions at some future time. Permit implementation reports may be developed or held by local land planning entities (cities, counties), non-profit land trusts, state agencies (e.g., CDFW or the California Coastal Commission), and federal agencies that regulate species or habitats (e.g., USFWS, NMFS, and USACE). Documents describing activities and resulting conditions realized under environmental permitting should be reviewed if publically available.

2.9 Water Quality Conditions

Similar to ecosystem conditions, a proposed project's environmental document and feasibility study should provide information for describing without-project future water quality conditions. Waste Discharge Requirements and other orders issued by the State Water Board are additional sources of information for describing future water quality conditions. Additional information sources are described in Section 4.8, Water Quality Analysis, and in the references to that section.

2.10 Other Resource Conditions

A proposed project's environmental document and feasibility study should provide the primary information for describing without-project future conditions for most other resource conditions. However, information to describe without-project future conditions affecting recreation, flood control conditions, and emergency response conditions may not be included in the project's environmental documents. CEQA Guidelines do not specifically require analysis of these resource areas unless they are identified as being potentially affected.

Applicants should also draw information from the proposed project's feasibility study to describe and quantify where possible the effects that the project is expected to have on other benefit categories and other resource conditions. Later sections in this document describe the sources of information, metrics, methods that applicants must use or may use to quantify benefits in both physical and monetary terms. The information sources described in these later sections provide the basis for without-project future conditions in cases where neither the environmental document nor the feasibility study provides the information.

2.11 Observed and Simulated Without-Project Conditions

A complete description and quantification of without-project future conditions requires a combination of assumptions, data, and analysis. Most of the information presented in this section focuses on assumptions and data, but the actual description and quantification of 2030 and 2070 future conditions require analysis, including modeling.

Section 2.12 describes the climate change and sea level rise conditions that applicants must use. Methods and processes for combining assumptions, data, and analysis are described in Section 4. These methods must be consistently applied to both without-project and with-project future conditions to quantify benefits and impacts.

2.12 Climate Change and Sea-Level Rise

2.12.1 Introduction

Climate change is required in the quantification of public benefits of water storage projects to comply with Executive Order B-30-15 (2015) and Assembly Bill 1482 (2015), which require state agencies to account for climate change in project planning and investment decisions.

Climate projections, and rainfall-runoff modeling (using variable infiltration capacity [VIC]), and sea-level rise, SWP and CVP operations modeling (using CalSim II), and Delta hydrodynamic modeling (using DSM2) and related datasets have been developed for use by the WSIP applicants to analyze their proposed projects as required for consideration by the Commission. This section presents information on:

- Description of the 2030 future and 2070 future climate projections
- Development of models and datasets
- Use of models and datasets by applicants

The climate projections include datasets of temperature, precipitation, potential evaporation, and potential runoff derived for California. All applicants shall use these climate projections for the detailed analysis of their proposed projects. In addition, applicants identified in section 6004(a)(1)(E) of the regulation must use the CalSim II and DSM2 model products provided to analyze interactions of the proposed water storage projects with the SWP, CVP, and Delta. Methods used to develop these products are presented in Appendix A. Applicants shall use these same methods if the products need to be extended or modified to complete the analysis required for their projects. Additional methods may be used by the applicant if justified and documented.

2.12.2 2030 Future and 2070 Future Climate Projections

2.12.2.1 Description of Projections

Applicants are required to analyze their proposed projects using projections that represent the change in future climate and sea-level conditions for California at two reference points to demonstrate the project’s ability to provide public benefits under both “near-future” and “late-future” conditions. The 2030 (near-future) reference point captures climate conditions for the 30-year period surrounding 2030 (2016 to 2045), and the 2070 (late-future) reference point captures climate conditions for the 30-year period surrounding 2070 (2056 to 2085).

For each projection, the following datasets are provided:

- Temperature, precipitation, evaporation, and potential runoff for 1/16th degree (approximately 6 kilometers [km], or approximately 3.75 miles) spatial resolution derived for California for a time series of 96 water years. This 96-year time series was developed by adjusting the historical observed conditions (1915 through 2011) with the amount of climate change expected to occur at the reference climate period i.e., 2030 or 2070. (See Appendix A Climate Change and Sea-Level Rise for additional information).

- Variable infiltration capacity (VIC), CalSim II, and DSM2 model simulations of storage, flows, and diversions for the major tributaries of the Central Valley and Delta flows and salinity conditions for a time series of 82 water years. This 82-year time series was developed using historical water years 1922 through 2003 with climatologic and hydrologic conditions adjusted for the reference climate period (i.e., 2030 or 2070). (See Appendix A Climate Change and Sea-Level Rise for additional information).

These products are available on the California Water Commission Website at: https://cwc.ca.gov/Pages/QuantificationRulemaking.aspx.

These products are also available on DVD-ROM by request.

The amount of change in precipitation and temperature varies by region throughout California as shown in Table 2-4, according to the regions shown on Figure 2-1.

Table 2-4. Projected Changes in Climate Conditions for 2030 and 2070 Future Conditions with Respect to the 1995 Reference

Basin		2030 Future		2070 Future	
Number	**Watershed Name (USGS HUC-6; Figure 2-1)**	**Average Precipitation Change (%)**	**Average Temperature Change (degrees F)**	**Average Precipitation Change (%)**	**Average Temperature Change (degrees F)**
Statewide					
Statewide (all watersheds in figure)		2.9%	2.4	5.3%	5.4
Central Valley Regions					
Central Valley (watersheds 8, 9, 10 and 11)		3.2%	2.6	5.6%	5.9
8	Upper Sacramento	3.4%	2.5	5.9%	5.7
9	Lower Sacramento	3.8%	2.4	7.0%	5.3
10	San Joaquin	3.1%	2.4	5.2%	5.4
11	Tulare-Buena Vista Lakes	1.8%	2.3	2.6%	5.2
Other Regions					
1	Klamath	3.2%	2.5	5.1%	5.6
2	Northern California Coastal	3.7%	2.0	7.5%	4.7
3	San Francisco Bay	4.6%	2.0	10.2%	4.6
4	Central California Coastal	2.8%	2.1	6.5%	4.6
5	Ventura-San Gabriel Coastal	-0.4%	2.5	-0.5%	5.3
6	Santa Ana	-0.6%	2.7	-3.0%	5.7
7	Laguna-San Diego Coastal	0.0%	2.4	-4.0%	5.2
12	North Lahontan	5.2%	2.8	10.1%	6.2
13	Mono-Owens Lakes	3.4%	2.6	7.5%	5.9
14	Northern Mojave	0.3%	2.6	0.3%	5.8
15	Southern Mojave	-1.3%	2.6	-2.8%	5.7
16	Lower Colorado	-1.2%	2.7	-3.4%	5.8
17	Salton Sea	-1.1%	2.6	-2.5%	5.6

Notes
*Watershed climate metrics calculated over entire watershed (includes areas outside of CA state border
*Statewide climate metrics calculated using only grid cells within CA state border

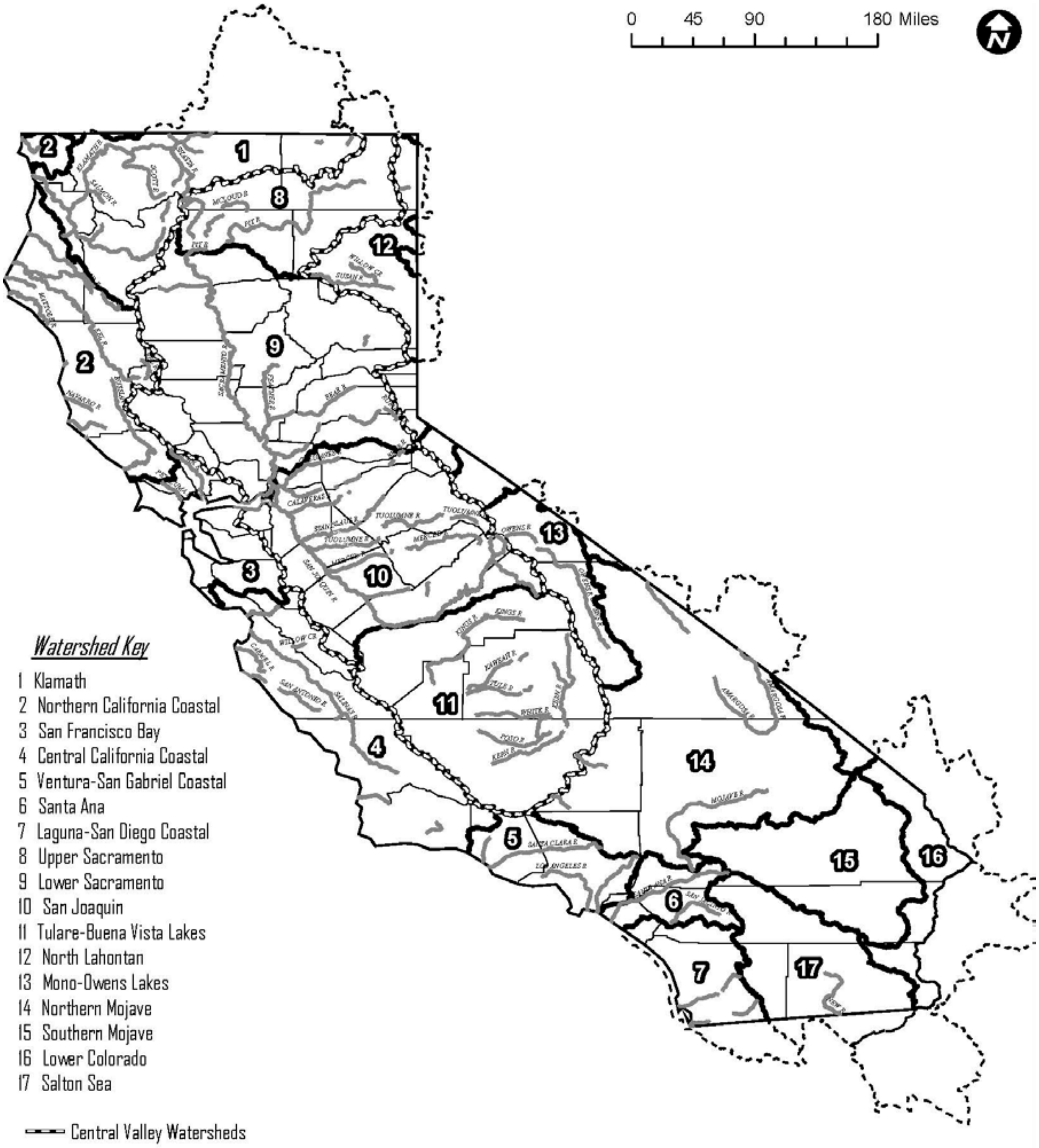


Figure 2-1. USGS Hydrologic Unit Code (HUC) 6 Watershed Boundaries in California

Note: HUC 6 watersheds extending outside California shown in thin black dashes.

2.12.2.2 Climate Change

There is consensus in the scientific community regarding that the observed global warming trend is directly related to the increased concentration of greenhouse gases (GHGs) in the atmosphere and that this trend will continue into the future.

Climate change projections are made primarily on the basis of coupled atmosphere-ocean general circulation model simulations under a range of future emission scenarios. Climate projections used in this climate change analysis are based on climate model simulations from the Coupled Model Intercomparison Project Phase 5 (CMIP5).

The climate models in the CMIP5 archive (Taylor et al., 2012; Rupp et al., 2013) use a set of emission scenarios called representative concentration pathways (RCPs) to reflect possible trajectories of GHG emissions throughout this century. Each RCP defines a specific emissions trajectory and subsequent radiative forcing (radiative forcing measures the balance of incoming and outgoing energy in the Earth-atmosphere system and is measured in watts per meter squared).

Commission staff selected the 20 climate model and RCP combinations recommended by DWR’s Climate Change Technical Advisory Group (CCTAG) as being most appropriate for California water resource planning and analysis (DWR CCTAG, 2015).

Because of the coarse scale of general circulation models, it is necessary to downscale model results (translate changes simulated at the coarse global grid scale to changes at a regional or watershed scale). Climate projection datasets were developed by downscaling the 20 general circulation model projections to a 1/16th degree (approximately 6 kilometers, or approximately 3.75 miles) grid resolution across California using the localized constructed analog (LOCA) spatial downscaling method (Pierce et al., 2014). Developed by researchers at the Scripps Institution of Oceanography, the LOCA method is also being used for analysis of California’s Fourth Climate Change Assessment methodology. The 20-climate model and RCP combinations were composed of 10 general circulation models run with two RCPs: one optimistic (RCP 4.5) and one pessimistic (RCP 8.5).

Table 2-5 summarizes the emission scenarios and models used in this analysis.

Table 2-5. Climate Model and RCP combinations used in this analysis

Model Name	RCPs used
ACCESS-1.0	4.5, 8.5
CanESM2	4.5, 8.5
CCSM4	4.5, 8.5
CESM1-BGC	4.5, 8.5
CMCC-CMS	4.5, 8.5
CNRM-CM5	4.5, 8.5
GFDL-CM3	4.5, 8.5
HadGEM2-CC	4.5, 8.5
HadGEM2-ES	4.5, 8.5
MIROC5	4.5, 8.5

The results of the 20 spatially downscaled climate model and RCP combinations were used to create ensemble projections for 2030 and 2070. Appendix A provides a detailed description of this procedure. The ensemble projections for the 2030 future and 2070 future conditions are summarized in Table 2-4, which shows that the impacts of climate change are quite heterogeneous across the state with some areas getting wetter and some getting drier. All areas experience warming but the degree of warming varies significantly by watershed.

2.12.2.3 Analysis of Uncertainty in Projected Climate Conditions

In addition to quantifying the benefits of the projects with climate conditions at 2030 and 2070, applicants shall disclose how the expected public and non-public benefits of the projects might change under a wider range of climate conditions and describe how the operations of their projects can be adapted to sustain the benefits claimed. This uncertainty analysis can be done qualitatively or quantitatively, but in either case, shall rely on the bounding scenarios described below. Projects that perform well across a wide range of potential climate conditions will be considered as more resilient.

This analysis is a type of stress-test that explores the vulnerability and potential opportunities of projects to future conditions that are less likely, though still within the range of potential expected conditions. The wider range of climate conditions have been informed by the range of the 20 individual climate model–RCP combinations shown in Table 2-5.

To explore the range of uncertainty in future climate conditions, the following models shall be used as the basis for the extreme levels of climate change in the applicants' uncertainty analysis. The selection of these models is based on guidance provided by DWR CCTAG (2016) for the 4th California Climate Change Assessment.

- HadGEM2-ES with RCP 8.5
- CNRM-CM5 with RCP 4.5

The projected extreme levels of climate change for 2070 (climate period 2056 – 2085) with respect to the 1995 reference period (climate period 1981 – 2010) are shown in Table 2-6.

Table 2-6. Projected Extreme Levels of Climate Change for 2070 with Respect to the 1995 Reference, Based on LOCA Downscaling of GCMs

Basin		**HadGEM2-ES with RCP 8.5**		**CNRM-CM5 with RCP 4.5**	
(USGS HUC-6; Figure 2-1)		**Average Precipitation Change (%)**	**Average Temperature Change (degrees F)**	**Average Precipitation Change (%)**	**Average Temperature Change (degrees F)**
Statewide					
Statewide (all regions in figure)		-7.1	8.4	20.4	3.5
Central Valley Regions					
Central Valley (Regions 8, 9, 10 and 11)		-8.6	9.2	21.1	3.9
8	Upper Sacramento	-10.1	9.0	16.1	3.9
9	Lower Sacramento	-6.3	8.2	24.2	3.6
10	San Joaquin	-7.5	8.4	23.6	3.5
11	Tulare-Buena Vista Lakes	-12.9	8.2	20.1	3.2
Other Regions					
1	Klamath	-6.8	8.9	13.1	3.7
2	Northern California Coastal	-3.3	7.1	21.6	2.8
3	San Francisco Bay	0.2	7.3	30.0	2.8
4	Central California Coastal	-1.4	7.6	23.6	2.7
5	Ventura-San Gabriel Coastal	-9.8	8.1	14.8	3.2
6	Santa Ana	-16.4	8.4	14.3	3.5
7	Laguna-San Diego Coastal	-17.1	8.2	14.1	3.2
12	North Lahontan	-5.4	9.4	19.4	4.5
13	Mono-Owens Lakes	-5.9	8.8	23.9	4.1
14	Northern Mojave	-15.2	8.8	14.9	3.6

Table 2-6. Projected Extreme Levels of Climate Change for 2070 with Respect to the 1995 Reference, Based on LOCA Downscaling of GCMs

Basin		**HadGEM2-ES with RCP 8.5**		**CNRM-CM5 with RCP 4.5**	
(USGS HUC-6; Figure 2-1)		**Average Precipitation Change (%)**	**Average Temperature Change (degrees F)**	**Average Precipitation Change (%)**	**Average Temperature Change (degrees F)**
15	Southern Mojave	-16.9	8.5	12	3.5
16	Lower Colorado	-13.4	8.6	7.6	3.5
17	Salton Sea	-13.3	8.3	12.4	3.5

2.12.2.4 Sea-Level Rise

Global and regional sea levels have increased steadily over the past century and are expected to continue to increase throughout this century. As sea-level rise progresses, the hydrodynamics of the Delta will change, increasing the salinity in the Delta. This increasing salinity will have significant impacts on water management throughout California. In the past century, global mean sea level has increased by 17 to 21 centimeters (7 to 8 inches) (Intergovernmental Panel on Climate Change [IPCC], 2013). Sea level continues to rise due to a combination of melting glaciers and ice sheets and thermal expansion of seawater as it warms. Global estimates of sea-level rise made in the most recent assessment by the IPCC 5th Assessment Report (IPCC, 2013) indicate a likely range of 26 to 82 centimeters (10.2 to 32.3 inches) this century. These ranges are derived from CMIP5 climate projections in combination with process-based models and assessment of glacier and ice sheet contributions.

The National Research Council (NRC) has assessed potential future sea-level rise throughout this century (NRC, 2012). The NRC study on west coast sea-level rise relies on estimates of the individual components that contribute to sea-level rise and sums those to produce the projections. The NRC projections have been adopted by the California Ocean Protection Council as guidance for incorporating sea-level rise projections into planning and decision making for projects in California.

At 2030 and 2070 the median range of expected sea-level rise as estimated by the NRC and by other sources widely accepted within the scientific community is around 15 and 45 centimeters, respectively. These sources are presented in Appendix A. For this analysis, sea-level rise projections of 15 centimeters and 45 centimeters were selected to represent 2030 future and 2070 future sea-level rise conditions, respectively in the CalSim II and DSM2 models.

2.12.3 Development of Models and Datasets

This section summarizes data and methods used to evaluate climate change and sea-level rise for the WSIP. Detailed information on these data and methods is provided in Appendix A.

2.12.3.1 Climate Data (Temperature and Precipitation) and Methods

The climate projections at 2030 future and 2070 future conditions were derived based on a quantile mapping approach using changes in temperature and precipitation from 20 downscaled general circulation model projections composed of 10 general circulation models run with two RCPs (RCP 4.5 and RCP 8.5).

The 10 general circulation models were chosen by the DWR CCTAG based on a three-tiered evaluation of global, regional, and California water management criteria of climate model ability to reproduce a range of historical climate conditions (DWR CCTAG, 2015). The 20 climate model projections were downscaled using the LOCA statistical downscaling method at 1/16th degree (approximately 6 kilometers, or approximately 3.75 miles) spatial resolution by Scripps Institution of Oceanography (Pierce et al., 2014). The LOCA method uses future climate projections combined with historical analog events to produce daily downscaled precipitation and temperature time series.

The quantile mapping approach starts with climate model simulation results for all 20 climate model projections and builds statistical relationships from downscaled climate data from these results for each ensemble projection. The statistical relationships are used to derive modified temperature and precipitation results for every grid in California, for each projection. The quantile mapping procedure is presented in more detail in Appendix A.

The products provided include temperature and precipitation results for the 2030 future and 2070 future conditions for 1/16th degree (approximately 6 kilometers, or approximately 3.75 miles) spatial resolution derived for California for water years 1915 through 2011.

2.12.3.2 Rainfall-Runoff Modeling using VIC

Regional hydrologic modeling is necessary to understand the watershed-scale impacts of historical and projected climate patterns on rainfall, snowpack development and snowmelt, soil moisture depletion, evapotranspiration, and changes in stream flow patterns.

VIC has been used to simulate regional hydrology for historical and future conditions for California as well as many major basins in the United States.

For the WSIP, VIC model simulations were performed to simulate runoff, base flow, soil moisture, evapotranspiration, and snowmelt and depletion for every grid cell in California for both 2030 and 2070 conditions using the temperature and precipitation data obtained from quantile mapping described above. Detailed information on VIC modeling for the WSIP is presented in Appendix A.

The products provided include the VIC models and potential evapotranspiration and potential runoff results for the 2030 future and 2070 future conditions for 1/16th degree (approximately 6 kilometers, or approximately 3.75 miles) spatial resolution derived for California for water years 1915 through 2011. The products provided also include VIC models and routed stream flow results for selected locations in the Central Valley for water years 1922 through 2003.

2.12.3.3 CalSim II Modeling

CalSim II, developed by DWR and Reclamation, has been widely used for water resources planning and management in California. The model uses a sequence of historical hydrology plus projected land use conditions to simulate system-wide CVP and SWP operations under existing regulatory conditions. To simulate operations that comply with salinity standards in the Delta, an Artificial Neural Network (ANN) is embedded in CalSim II. This ANN was developed by DWR to mimic flow-salinity relationships as simulated by DWR’s hydrodynamics model, DSM2. Detailed information on retraining of ANN under sea-level rise conditions is provided in Appendix A.

Climate and sea-level change is incorporated into the CalSim II model in two ways: changes to the input hydrology, and changes to the flow-salinity relationship in the Delta due to sea-level rise. For the WSIP, changes in runoff and stream flow are simulated through VIC modeling under two climate projections: 2030 and 2070. These simulated changes in runoff are propagated to the CalSim II inflows, water year types, and other hydrologic indices that govern water operations, or compliance requirements are adjusted to be consistent with the new hydrologic regime. The following methods are used in calculating projected CalSim II inflow data:

1. For larger watersheds, projected runoff amounts obtained from VIC are used as the CalSim II inflows.
2. For inflows from smaller watersheds, CalSim II inflows and downstream accretions/depletions are modified by applying a fractional change, or perturbation, based on the flow changes estimated by the VIC modeling. These fractional changes are first applied for every month of the 82-year period consistent with the VIC simulated patterns. A second order correction is then applied to ensure that the annual shifts in runoff at each location are consistent with that generated from the VIC modeling.
3. For larger watersheds where VIC simulated stream flows are directly used for CalSim modeling, a statistical bias-correction process is applied to correct biases in VIC simulations.
4. For larger watersheds where stream flows are heavily impaired, a process is implemented to calculate historical impairment based on observed data and add that impairment back onto the VIC simulated flows that were bias-corrected to unimpaired at a location upstream of the impairment.
5. Water year types and other indices used in system operation decisions by CalSim II are regenerated using projected flows, precipitation, or temperature as needed in their respective methods.

6. Sea-level rise effects on the flow-salinity response in CalSim II are incorporated by a separate ANN for each climate projection (2030 and 2070).
7. Sea-level rise effects on the flow split between the Sacramento River and Georgiana Slough at times when the Delta Cross Channel is open or closed are estimated by use of regression equations that are developed based on DSM2 simulations.

Appendix A provides detailed information on the methodology followed and specific input parameters that are modified for climate change projections.

It is important to note that the CalSim II simulations do not consider future climate change adaptation that may require management of the CVP/SWP system in a manner different from today to reduce climate impacts. For example, future changes in reservoir flood control reservation to accommodate a different seasonal hydrograph may be considered under future programs, but the changes to those operations are currently unknown and are not incorporated in CalSim II. Similarly, potential changes in land use (e.g., crop acreage and mix, urbanization) and resulting changes in water demands on the system cannot be reasonably forecasted at this time. Thus, the CalSim II modeling results represent how the current system would respond to climate change, but do not incorporate dynamic adaptation of the system to climate change.

The products provided include the CalSim II models and results for the 2030 future and 2070 future conditions for water years 1922 through 2003.

2.12.3.4 DSM2 Modeling

DSM2, a one-dimensional hydrodynamics model developed by DWR, analyzes flow and water quality conditions within the Bay-Delta estuary (see also Section 4.6). DSM2 is often used to assess potential effects of projects on the Delta flows and salinity conditions and how those affect ecosystem and human uses of the Delta waters. Therefore, a DSM2 model that reflects the conditions for each of the 2030 and 2070 climate projections is developed.

A sea-level rise at the Golden Gate Bridge of 15 centimeters in 2030 and 45 centimeters in 2070 was assumed for the WSIP analyses. The hydrodynamics and salinity changes in the Delta due to sea-level rise were determined from the UnTRIM 3D Bay-Delta model. DSM2 model results were then corroborated for the assumed sea level to the UnTRIM results to accommodate mixing and dispersion effects of sea-level rise that cannot be captured in 1D modeling. Detailed information on corroboration of DSM2 is provided in Appendix A.

Based on the outcome of the sea-level rise corroboration, an updated DSM2 model setup for each of the 2030 and 2070 projections was prepared for use in the WSIP analyses to account for the projected 15-centimeters and 45-centimeters sea-level rise.

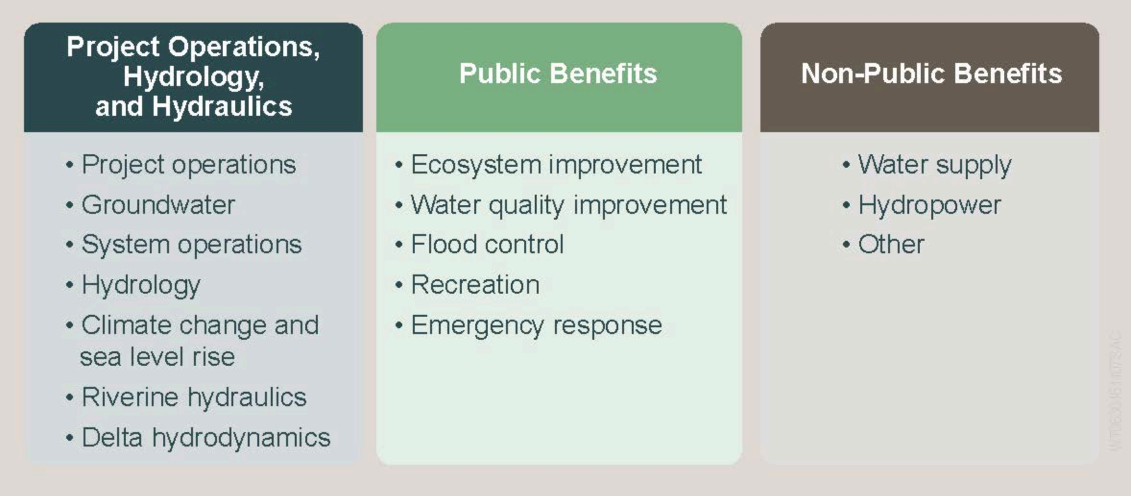
The products provided include the DSM2 models and results for the 2030 future and 2070 future conditions for water years 1922 through 2003.

Defining the With-Project Future Conditions

3.1 Background

The with-project future conditions include a detailed description of a proposed water storage project's physical features and a preliminary operations plan that describes how the water storage project may be operated to provide the public and non-public benefits. The with-project future conditions are based on additions or modifications to the without-project future conditions as a result of an applicant's proposed water storage project. The with-project future conditions are a quantitative and qualitative description of a water resources system with operation of a proposed water storage project. The expected physical changes created or caused by a proposed water storage project must be calculated by comparing the with-project conditions to the without-project conditions; therefore, changes in the description of the with-project conditions should be limited to include only additions and modifications that are based on an applicant's proposed water storage project description and operations plan, or other changes that can be directly related to the proposed water storage project (Figure 3-1).

A description of the with-project future conditions must support the analysis of the expected physical changes related to the project description, operations plan, and potential benefits or impacts of the proposed water storage project, including all resource areas described in Section 4. The with-project future conditions must be consistent across all analyses including physical benefits and impacts, monetary benefits, and project costs.



Project Operations, Hydrology, and Hydraulics	Public Benefits	Non-Public Benefits
• Project operations • Groundwater • System operations • Hydrology • Climate change and sea level rise • Riverine hydraulics • Delta hydrodynamics	• Ecosystem improvement • Water quality improvement • Flood control • Recreation • Emergency response	• Water supply • Hydropower • Other

Figure 3-1. Resource Areas for Assessing Benefits and Impacts of Storage Projects.

3.2 Project Formulation

Applicants shall describe how the water storage project was developed as a general concept and shall explain how the proposed water storage project's specific size, location, features, and operations were determined. The description should explain why the project will be an improvement over the without-project condition. Alternatives to the project and alternative sizes and operational characteristics must be discussed. This description must be consistent with, though not as detailed as, information provided in the feasibility study and environmental documentation. Applicants may summarize project formulation in their application and reference more detailed information in the feasibility study and environmental documentation provided with the application.

3.3 Describing the Project

The project description must include, where applicable:

- Location of the water storage facility(ies)
- Total and active water storage capacity
- Sources of water supply
- Conveyance capacities for sources of water supply, if applicable
- Capacities for storage facility outlets, spillways, and direct diversions, if any
- Storage facility capacity-elevation and area-capacity curves
- All appurtenant facilities, including hydropower, recreation, ecosystem, and water quality management facilities, if any
- Expected beneficiaries and the location of benefits
- Relationships to existing water project facilities
- Water storage evaporation loss or other losses as a function of time-of-year and area
- Any other features that affect benefits or impacts

Applicants must provide quantitative and qualitative with- and without-project future conditions for use as the basis of identifying and calculating the expected physical changes caused or created by the proposed water storage project.

3.4 Preliminary Operations Plan

A preliminary operations plan must describe how a proposed water storage project may be operated to provide public and non-public benefits. The preliminary operations plan should include:

- Project operations and public benefits under a range of hydrologic conditions, including wettest and driest years and multiple dry years

- Benefit categories (both public and non-public) to be served by the project's operations
- A description of expected commitments for providing operations or water supply for public benefits
- Amount of flood reservation space and, for other benefit categories, dedicated storage space, if any
- Storage rules, priorities, and contingencies for providing benefits and for compliance and mitigation, if applicable, under the full range of hydrologic conditions
- How operations will be monitored to ensure public benefit outcomes
- How operations at other facilities may be coordinated and affected
- How operations may change based on future climate and sea-level conditions
- Other specific objectives and constraints of project operations
- Preliminary adaptive management strategies, including:
    - Potential uncertainties that may affect project operations in the future
    - Potential measurable objectives, performance measures, thresholds, and triggers to monitor project performance and achievement of desired outcomes
    - Potential management or corrective actions that could be taken if monitoring results fall outside of the range of expected values or if intended outcomes are not achieved by the project
    - How operational decisions will be made if conditions fall outside the range of anticipated conditions or if public benefits are not provided as anticipated in the application

3.5 Feasibility Study

The Commission must make a determination that the project is feasible (Water Code Section 79755 (a)(5)(B)). The feasibility study is also a primary information source for the detailed project description and project analyses. A completed project feasibility study is required by January 1, 2022 as part of project eligibility requirement of the WSIP (Water Code Section 79757).

An applicant must provide the following components of project feasibility, either within an available draft feasibility study or as part of its application:

- **Project objectives** – the applicant must identify the project objectives, including all public and non-public benefits the proposed project is designed to provide.
- **Project description** – the applicant must describe the proposed project, including facilities, operations, and relationships with existing facilities and operations.
- **Project costs** – the applicant must identify and describe all project costs, including construction costs, interest during construction, replacement costs, operations and maintenance costs consistent with the operations plan, and costs of mitigation for

adverse environmental consequences identified in the draft environmental documentation.

- **Project benefits** – the applicant must describe and quantify all proposed project benefits, consistent with the operations plan. Public benefits and non-public benefits shall be quantified using physical measures and, where possible, monetary measures. Proposed project benefits must be displayed as expected average annual values for each year of the planning horizon. For benefits that vary according to hydrologic condition, applicants must display that variability using, for example specific water year types (such as dry and critical), or exceedance probabilities. Appropriate ways to display variability depend on the benefit category and how the physical benefit is to be monetized, as discussed in later sections of this document.
- **Cost allocation** – the applicant must conduct a benefits-based cost allocation to determine the costs to be assigned to the project beneficiaries. The federal government's Separable Costs-Remaining Benefits method is a commonly acceptable method to do a cost allocation.
- **Technical feasibility** – the applicant must demonstrate that the project is technically feasible consistent with the operations plan, including a description of data and analytical methods, the hydrologic period, development conditions, hydrologic time step, and water balance analysis showing, for the with- and without-project condition, all flows and water supplies relevant to the benefits analysis.
- **Environmental feasibility** – the applicant must demonstrate that the project is environmentally feasible. The applicant must describe how significant environmental issues will be mitigated or indicate if the Lead Agency has or will file a Statement of Overriding Considerations.
- **Economic feasibility** – the applicant must demonstrate that the expected benefits of the project equal or exceed the expected costs, considering all benefits and costs related to or caused by the project.
- **Financial feasibility** – the applicant must demonstrate that sufficient funds will be available from public (including the funds requested in the application) and non-public sources to cover the construction and operation and maintenance of the project over the planning horizon. It must also show that beneficiaries of non-public benefits are allocated costs that are consistent with and do not exceed the benefits they receive.
- **Constructability** – the applicant must demonstrate that the project can be constructed with existing technology and availability of construction materials, work force, and equipment.

3.6 Other Modifications

Any differences between with- and without-project future conditions not specified as an addition or modification associated with the proposed water storage project or its operation must be disclosed. For example, if the proposed water storage project would result in the elimination or modification of another project or planned activity that is included in the without-project condition, the applicant must describe and justify why the proposed water storage project would cause the change. If another existing or planned water storage project would be modified or eliminated due to the proposed water storage project, an applicant can count an avoided cost benefit; see Section 5 for a discussion of avoided cost.

3.7 Observed and Simulated With-Project Future Conditions

A complete description and quantification of with-project conditions requires a combination of assumptions, data, and analysis. Most of the information presented in this section focuses on assumptions about the features and planned operations of the proposed project, but the actual description and quantification of conditions requires analysis, including modeling. Because the project does not yet exist, most aspects of the current and future with-project conditions must be simulated. Methods and processes for combining assumptions, data, and analysis are described in Section 4. These methods must be consistently applied to both the without-project and with-project conditions to quantify benefits and impacts.

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Calculating Physical Changes

4.1 Background

The WSIP provides funding for public benefits associated with water storage projects. Quantification of physical changes is fundamental to demonstrating benefits. The legislation authorizing the WSIP states that projects shall be selected through a competitive process that ranks projects based on the expected return for public investment as measured by the magnitude of the public benefits provided. In other words, the public benefits must be quantified. The process of quantifying benefits for a water storage project involves a sequence of modeling or other analysis that links the project and its operation to the resulting changes in the physical resources and finally to the monetary value of the physical changes.

This section provides technical information to assist, and in some cases direct, applicants in quantifying the physical benefits and impacts of proposed projects. The section begins with a discussion of general concepts of sound water storage project analysis (Section 4.2, General Project Analysis). The remaining subsections focus on concepts and methods of quantification and are divided by particular type of analysis (e.g., surface water or groundwater) or the specific benefit category being analyzed (e.g., ecosystem improvements, water quality improvements). These subsections are provided as standalone, pull out references that applicants may use as needed based on their project type and the potential benefits of the project (i.e., all subsections will not be applicable to every project).

Subsections 4.3 through 4.6 provide information on methods and models that may be needed to demonstrate benefits or impacts for the following types of conditions:

- Surface water operations (Section 4.3)
- Groundwater analysis (Section 4.4)
- Riverine hydrologic/hydraulic analysis (Section 4.5)
- Delta hydrodynamic/hydraulic analysis (Section 4.6)

Subsections 4.7 through 4.13 include detailed information on methods and models for analyzing the following benefit-specific categories:

- Ecosystem improvements (Section 4.7)
- Water quality improvements (Section 4.8)
- Flood control (Section 4.9)
- Recreation (Section 4.10)

- Emergency response (Section 4.11)
- Water supply (Section 4.12)
- Hydropower (Section 4.13)

The section also provides information on how methods can be or must be linked together to form a consistent, defensible analysis.

4.2 General Project Analysis

Change is an important word in this Technical Reference and it is used in two different ways. Change over time is important as a way to assess how a proposed water storage project performs over time, from current conditions through the project's planning horizon. An equally important meaning of change is the change (positive or negative) caused by the project (i.e., comparison of with- and without-project future conditions). This section provides information on how to perform a consistent, structured analysis of the without-project and with-project future conditions.

Analyzing the effect of a water storage project is inherently complex, involving the interaction of climate, engineered structures, hydrologic and hydraulic systems, natural ecosystems, and the demands, decisions, and unintentional influences of human society. The methods needed to simulate how this complex system would react to a proposed water storage project may range from simple to complex. Methods span simple calculations to large computer models. So for purposes of brevity, the words method and model are often used interchangeably in this section.

The applicant shall use the data and model products described and provided in Appendix A for the two without-project future conditions, 2030 Future and 2070 Future conditions. If the model products provided by the WSIP do not adequately describe the without-project future conditions relevant to the project, applicants may also use additional tools or models to complete the description of the without-project future conditions.

4.2.1 Model Selection Criteria and Quality of Analysis

The appropriate methods for evaluating changes resulting from a water storage project depend on a number of factors such as the project's location, size, features, and expected benefits or impacts. The purpose of any method is to simulate how the project and its operation lead to the specific magnitudes of public benefits for which WSIP funding is requested. The method must provide sufficient temporal and spatial scope and resolution to discern important effects. For example, if seasonal changes in conditions lead to benefits or impacts, those benefits or impacts cannot be measured using a method with an annual time step. Finally, complex models tend to be more defensible because they account for more potential interactions, but complexity and defensibility must be weighed against data availability, ease of use, and analysis cost.

4.2.1.1 Model Selection Criteria

The sections on quantification methods include criteria, or at least important considerations, that applicants should consider in selecting the appropriate model. The criteria vary depending on the topic, but in general include the following.

- The model must be scientifically defensible. It should represent physical and biological processes consistent with best available science, and the quality and resolution (both temporal and spatial) of its data must be appropriate to the analysis. The model's uncertainty and error should be understood and within acceptable standards of science.
- The model should be capable of interacting with the other models used to quantify benefits without requiring excessive time and effort to create pre- and post-processing modules or spreadsheets. Specifically, it should be able to process relatively easily the information provided to it from other models or from the physical and operational features of the proposed project. Also, it should be capable of providing output in units and locations that link to subsequent models in the chain of analysis.
- The model must encompass the geographic scope necessary to quantify all benefits or impacts.
- The model must operate at a time step sufficient to quantify benefits or impacts. For example, quantifying flood control benefits requires a reservoir operations or riverine analysis with shorter time step (daily or hourly) than quantifying annual water supply benefits (yearly).
- The model's data and assumptions should be consistent with those of other models in the chain of analysis.
- The applicant should have the time and expertise required to implement the model, and sufficient data to meet the model's requirements.

It is apparent that some criteria should be weighed against other criteria in order to select the best set of models. The model that incorporates the best available science is often, but not always, the most complex and costly to implement. Therefore, an applicant may use judgment to weigh these criteria and select appropriate models that provide sufficient quality of analysis to demonstrate benefits and reveal impacts. In all cases, applicants must justify their use of models used. If a model that is considered best available science cannot be used, for example due to lack of data, the applicant must explain why the model was not used.

4.2.1.2 Quality of Analysis

Applications will be evaluated based on the appropriate selection of analytical methods, the proper use of the methods, the quality of data, and the soundness of assumptions. The following criteria will be used by reviewers to assess the quality of analysis.

- Assumptions, data, and analysis are based on best available science, consistent with this Technical Reference and the requirements and evaluation criteria in the WSIP regulation.
- Applicants show how methods and models were implemented to evaluate with-project and without-project future conditions. Key input data and assumptions are summarized and presented.
- Uncertainties related to the data, methods, and results are discussed.
- Results are clearly presented and reproducible by reviewers. Upon request, applicants shall provide full input files, spreadsheets, model code, and output files so that reviewers can verify the analysis.

4.2.1.3 Projected Conditions

A projected condition is the state of the water resource and related systems at a future time in the planning horizon. Natural variability associated with hydrological and meteorological outcomes means that a full description of a projected condition must incorporate a range of results, often expressed as a probability distribution or a hydrologic sequence. Applicants cannot know the specific weather and hydrology that will occur in the future, so the projected condition must account for the range of possibilities. For example, the 2030 projected condition of average monthly flow in a river affected by a potential project could show results for every year in a hydrologic sequence, as a probability distribution (or exceedance curve), or as average monthly flows by defined water year types (see Section 4.2.2.1 Water Year Types)

An applicant must determine the appropriate ways to display variable outcomes for projected conditions, based on features of its project and the benefits and impacts to be quantified. The Commission’s evaluation and the relative environmental values (REVs) for ecosystem and water quality benefits provided by CDFW and State Water Board, respectively, rely on metrics that must be calculated from each applicant’s analysis. For example, metrics for projected conditions may include cubic feet per second (cfs) discharge and water temperature in degrees Fahrenheit.

4.2.1.4 Future Hydrology

Historical datasets of precipitation, land use, river flows, diversions, reservoir storages, and groundwater levels provide information to understand the system and its behavior in the past. However, unmodified historical hydrologic data has limited usefulness in analyzing the potential behavior of a water resources system because it does not account for the changes in climate, water development, land use, and other changes that have occurred and will continue to occur into the future.

When using or modifying historical hydrologic data, it is strongly recommended that the entire period of record be used. If only a subset of the historical record is used to develop a sequential dataset for the analysis, an applicant must justify why and how that subset was chosen. Short sequences may be appropriate for benefits that depend on analyzing specific events, and could be several days to assess a specific storm event for flood control purposes, or several years to assess a severe drought's effect on ecosystem condition. However, even such short-duration analyses must be evaluated in the context of the long-term operation of the water storage project.

In developing the sequential dataset, applicants must use a period of record that represents the range of variability and distribution of values observed in the full record. If record length varies by hydrologic parameter, applicants should attempt to represent the variability in the longest record. Applicants must also use initial conditions that represent median values that would result from the analysis of the full period of record. Changes in the amount of surface and groundwater storage between initial conditions and final conditions must be reported. Application reviewers will check whether datasets appear to be "constructed" so that benefits are larger (or impacts smaller) than they would be using median initial conditions and a full historical record.

Section 4.2.2, Hydrology Datasets, describes how to modify historical hydrologic data to support analysis of projected conditions. Applicants that use the CalSim II operations model shall use the sequential dataset provided with that model (see Section 4.3, Surface Water Operations Analysis). The CalSim II model package for the without-project conditions, including hydrologic data, are provided to applicants for their use.

4.2.1.5 Future Condition Years

All applicants shall develop with- and without-project future conditions assumptions and perform benefits analysis for two future points in time: 2030 and 2070. These years correspond to the climate and sea-level conditions that are provided for applicants to use in their analysis. Applicants may also include additional future condition years if they are needed to account for other, known changes in future conditions. If an applicant's project needs to use an additional future condition year, a justification must be provided. If the proposed project has a planning horizon that ends prior to 2070, the applicant may interpolate without-project conditions between 2030 and 2070 conditions to develop its future conditions at the end of its planning horizon.

4.2.1.6 Use of Trends and Interpolation to Construct Planning Horizon Analysis

Monetization of the public benefits provided by a proposed project is required in order to calculate the return on public investment and to support the WSIP cost share requested by an applicant. Section 7, Comparing Benefits to Costs, describes how applicants must discount benefits and costs to a common point in time in order to provide a consistent comparison and rank projects.

Discounting to present value uses the entire sequence of costs and benefits over the planning horizon of a project. However, most of the analysis and quantification methods described in this Technical Reference are based on discrete points in time, namely the two future condition years, 2030 and 2070. If an applicant can document that a change is expected to occur at a different future year than these two dates (for example a law or regulation takes effect, or a known future project is completed), then the resulting metrics may be shown in that year. In order to create a full sequence of projected conditions over the planning horizon, applicants may interpolate between benefits and impacts (or net benefits where appropriate) occurring at any adjacent years for which quantification is provided.

If current conditions estimates are not available, applicants shall extrapolate from the quantification under 2030 future conditions and the next quantified year to obtain quantified benefits and impacts for the years of operation before 2030. To calculate the benefits and impacts for years between 2030 and 2070, applicants shall interpolate using a linear trend between two adjacent years. To calculate the benefits and impacts from 2070 until the end of the planning horizon (as applicable to project with an expected project life extending beyond 2070), applicants shall assume 2070 benefits. An example of how to use two or more years to construct a planning horizon analysis is provided in Section 5.2.8.2.

4.2.2 Hydrology Datasets

A number of datasets must be developed for use in a hydrologic analysis to generate the physical change metrics described below. Hydrology datasets include:

- Precipitation
- Watershed inflows
- Reservoir storage
- Stream flows
- Water diversions
- Water consumption (crop consumptive use and urban demand)

Groundwater datasets are also available and further described in Section 4.4, Groundwater Analysis.

Meteorology (or climate) and hydrology datasets are linked through processes at the land surface; precipitation generates overland flow and recharges streams and aquifers. Climate information used for physical change analysis includes temperature, precipitation, evaporation, and evapotranspiration, as appropriate. Sources of climate data and information on climate change are provided in Appendix A.

The development of these datasets typically starts with compiling historical time series (or sequential sets of observed data) spanning a timeframe that includes a variety of meteorological and hydrologic periods. Although a hydrology dataset that reflects current climate conditions is useful to assess physical changes that occur due to the project, analysis of future conditions at the completion of the project will require a hydrology dataset that represents the future conditions under climate change (see Appendix A).

In addition, water consumption is based on current and projected land use changes, and is linked to evapotranspiration through crop consumptive use. Applicants shall use land and water use projections that are consistent with existing, published projections to the extent possible, such as urban and agricultural water management plans, California Water Plan Update (available at http://www.water.ca.gov/waterplan/cwpu2013/final), county or city general plans, or other published documents. If no published projections are available for the geographic and time scale of the proposed project, applicants must demonstrate and justify the development of land and water use projections.

Applicants must use the spatial and temporal hydrology resolution that is sufficient to support the analysis used for the quantification of physical changes and associated benefits/impacts of the proposed project. The simplicity or complexity of the proposed project and water resources system being analyzed will determine the level of complexity required in the development of the hydrologic dataset.

Applicants shall use the hydrology data described in Appendix A for the two without-project future conditions, 2030 Future and 2070 Future conditions. Applicants may augment this data with other information specific to their project.

4.2.2.1 Water Year Types

When analyzing a water system, water years of similar characteristics in a hydrology dataset are often grouped together according to water year types. Different indices are used to define the water year types in different watersheds or regions, depending on the characteristics of the region and planning purposes of the water year typing. An index may be specific to a sub-watershed (for example, the Tuolumne River index used for a FERC licensing classification), or the index may be a larger scale, valley-wide index (for example, the San Joaquin Valley index). Indices use different numbers of and definitions of water year types (i.e., some indices have five water year categories and some have six or seven water year categories). Applicants shall use the water year type index most appropriate for the location of the proposed project, benefits analyzed, and methods used. To the extent possible, the applicant must use consistent water year types across all methods and quantified benefits. For example, if a unit economic value is defined for a dry year defined according to a specific index, the methods used to quantify the physical benefit must, where possible, use the same index to identify water year types. If full consistency is not possible due to data or model requirements, applicants must explain the differences.

DWR calculates and reports Sacramento Valley and San Joaquin Valley indices, as well as the Eight-River Index (to represent total inflow to Sacramento-San Joaquin Delta from all eight major contributing rivers) for each year from the early 1900s (1901 for the San Joaquin and 1906 for the Sacramento) to 2015. These indices are generally used for system-wide analysis of Sacramento and San Joaquin river basins and can be found online at: http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST.

Chronological Reconstructed Water Year Hydrologic Classification Indices are computed separately for the Sacramento and San Joaquin watersheds, with water years classified as follows:

- Wet
- Above normal
- Below normal
- Dry
- Critical

A water year category has been assigned to each year since the early 1900s.

Applicants must use complete hydrologic datasets that represent historical hydrology, with variations in wet years, dry years, and drought periods. For example, the CalSim II operations model includes an 82-year sequential hydrologic dataset from 1922 through 2003. Other models use a shorter sequence, often determined by the available data for model calibration. If a sequence of years different than or shorter than the available hydrologic dataset is used, an applicant must justify why and how that sequence was chosen.

Appendix A provides sequential datasets of hydrologic information for applicants to use. For other local information, applicants must provide and document the source of data used. Desirable characteristics of the dataset include:

- Availability of the full range of water year types, from wettest to driest
- A sequence of consecutive dry years
- A sequence of consecutive wet years
- High quality data records, with measurements made at the same location and in a consistent manner over the sequence
- Clearly recorded and disclosed adjustments to data; for example, the data source should disclose whether data points are single measurements or averages of several measurements, and whether data gaps have been filled using statistical analysis of nearby stations

4.2.2.2 Sources of Hydrology and Climate Data

Climate data is found in a range of sources. The following are commonly used for hydrology computations in California:

- PRISM climate data (http://www.prism.oregonstate.edu/), which includes precipitation, minimum and maximum temperature information
- CIMIS data (http://www.cimis.water.ca.gov/), which includes data collection at various weather stations throughout California, including the computation of reference evapotranspiration data used to determine crop water consumption

- National Water Information System data (http://waterdata.usgs.gov/nwis). Provides data on the occurrence, quantity, quality, distribution, and movement of surface and underground waters in all 50 states.

DWR has measured, compiled and made publicly available online several hydrologic datasets that can be accessed and downloaded for further refinement and use with various applications. These include:

- Water Data Library (http://www.water.ca.gov/waterdatalibrary/), which includes groundwater level, quality information, and stream flow information for historical datasets and continuous measurements
- California Data Exchange Center (http://cdec.water.ca.gov/), which includes DWR's hydrologic data collection network, including river stage sensors and streamflow gages
- DWR reservoir storage information reservoirs (http://www.water.ca.gov/swp/operationscontrol/monthly.cfm)

Other data sources include:

- Reclamation compiles and makes available online storage information for the CVP reservoirs (http://www.usbr.gov/mp/cvo/reports.html).
- USACE provides monthly, daily, and hourly reservoir conditions for Central Valley reservoirs (http://www.spk-wc.usace.army.mil/)

In addition, existing, publicly available hydrologic models (as discussed in the methodology sections of this Technical Reference) such as the CalSim II operations model and watershed models such as Water Evaluation and Planning (WEAP), Soil and Water Assessment Tool (SWAT), or Watershed Analysis Risk Management Framework (WARMF) contain sequential historical datasets that can be extracted and used with other applications. However, applicants should not assume that data used in an existing model are accurate enough for and well-suited to their projects. When selecting, developing, and using a hydrologic dataset, the applicant is responsible for the validity and defensibility of the dataset used.

For localized datasets, such as water diversions and water consumption, local water providers often report the best available information in their Agricultural Water Management Plans and UWMPs. Applicants may also find quality sources of local and regional hydrologic information in Integrated Water Resources Management Plans and Groundwater Management Plans, and future GSPs as they are developed.

All datasets must be adapted for the analysis of future conditions using appropriate information on climate change and sea-level rise. Sources of climate data and information on climate change are provided in Appendix A. Data files shall be provided for applicants to use to adapt hydrology datasets to account for climate change and sea-level rise.

4.2.2.3 Resolution and Scale of Hydrology Data

Hydrology data need to be developed at a scale and resolution that supports the analysis used for the quantification of physical changes and associated benefits/impacts (as required in the proposed regulation).

Geographic Scope

Geographic scope relates to the overall scale and boundary of the study area required for the analysis, tool development and application. Applicants shall use a geographic scope that encompasses, at a minimum, the immediate vicinity of the project, including the boundary of the applicable sub-watershed or groundwater sub-basin. For benefits claimed outside of the immediate vicinity of the project, the analysis study area should be extended to encompass those areas that may be affected by the construction and operation of the proposed project. For example, if the re-operation of a reservoir affects flows to the Delta, the Delta shall be included in the analysis' geographic scope.

Spatial Resolution of Data and Analysis

Spatial resolution, in the context of technical analysis and modeling, refers to the amount of spatial and physical detail incorporated within each portion of the analysis. In surface water modeling, spatial resolution is generally guided by the node spacing (the distance between points of data input and calculation) at which information is provided, or the sub-watershed catchment size. Groundwater models are normally constructed using a three dimensional grid, with each node a point of intersection in the grid. The spacing between the nodes determines the amount of spatial detail that needs to be included in the model's inputs. The node spacing of a model needs to be suitable for the analysis scale and level of detail required to quantify benefits. For example, for a smaller local project, spatial resolution will be fine (that is, detailed); for a regional analysis of a larger-scale project, spatial resolution may be coarse.

Appropriate spatial resolution must also consider the available dataset; the dataset must be adequate to support physical change quantification and benefits claimed.

4.2.2.4 Time Scale

The time scale included in a model (also referred to as time step) refers to the time duration and discretization at which changes are calculated. Most large-scale Central Valley models have a monthly time step (e.g., CalSim II, C2VSim). Others may be daily or hourly depending on the datasets analyzed (e.g., fisheries models, DSM2).

If customized spreadsheet tools are developed for analysis and quantification of benefits, applicants must consider the appropriate time scale. Time scales are determined based on the availability of data and the life-cycle of the change under analysis. For example, fish flows need to be determined at finer (or shorter) time scales, whereas groundwater changes occur at a slower pace and can be evaluated with a coarser time scale. Flood analysis requires a time scale that allows a calculation of peak flow or peak river stage, and therefore requires a finer time scale for analysis (such as hourly or daily). Planning-level studies of water supply often analyze operations over longer periods, so hourly and daily variations do not affect outcomes significantly. Monthly time steps are generally sufficient for planning-level water supply studies.

4.2.3 Model Integration

The physical changes created or caused by a potential project can be diverse in location and time. Assessing potential benefits to ecosystem, water supply, water quality, flood control, emergency response, hydropower, and recreation will usually require a sequence of modeling analysis. Figure 4-1 illustrates the way the potential modeling steps integrate to quantify multiple public and non-public benefits.

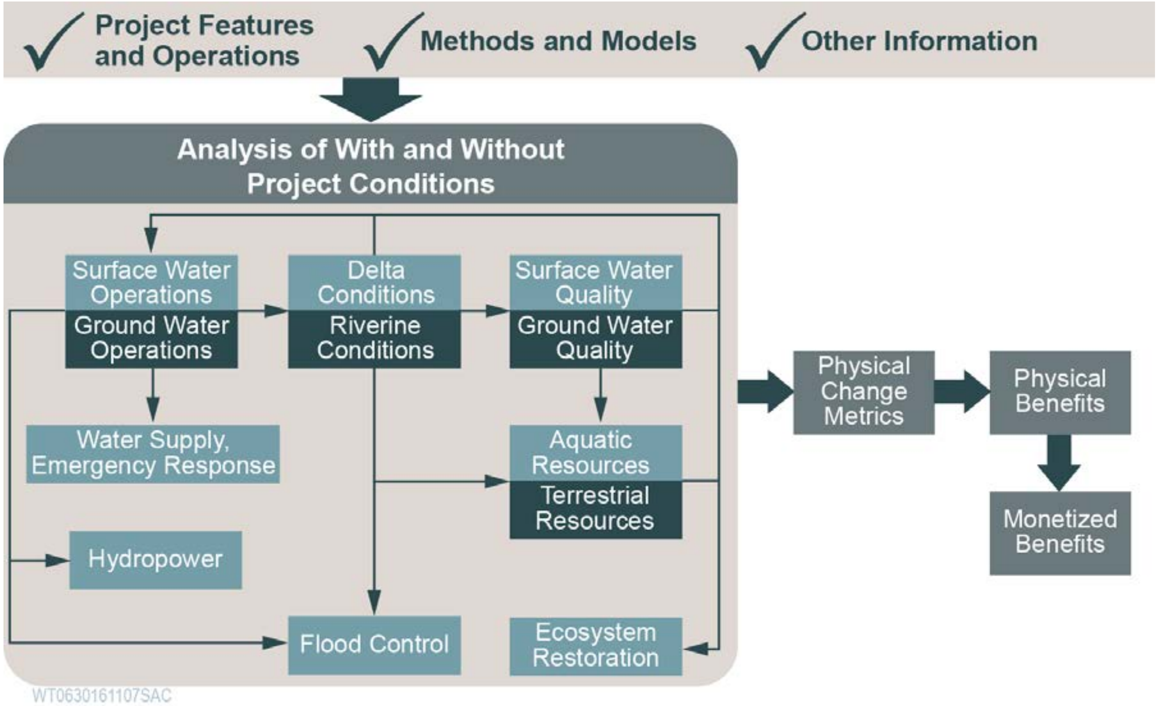

Figure 4-1. Linking of Project Features, Methods, and Metrics.

The linkages shown in Figure 4-1 do not adequately illustrate the issues faced in model integration. An integrated analysis must link diverse models having different assumptions, geographic boundaries and resolution, periods of record, and time steps. For each interface between models shown in the figure, some form of conversion procedure is needed to make the models interact in a scientifically consistent manner. The conversion procedure could be as simple as changing the units of measurement or as complex as a feedback loop coded into one or both of two interacting models.

In most cases, relatively simple conversions between models will suffice to account for differences in time step, geographic boundary, and units. Applicants are not required to develop complex conversion routines that account for all possible interactions and feedback. Applicants shall identify cases where a complex interaction or conversion between models has been approximated with a simplified conversion routine, and the implications for benefits quantification discussed.

4.2.4 Metrics

Metrics are quantitative or qualitative measures derived from the analysis of with-project and without-project conditions. Metrics used in the final evaluation of projects represent differences between the with-project and without-project conditions, but metrics used to quantify intermediate steps in the analysis also include direct results of the with-project or the without-project analysis.

Specific and detailed descriptions of metrics are presented in the methods sections of this document, organized by benefit category and resource area. Each application will include the methods and metrics needed to support its analysis of benefits and impacts. The selected methods and metrics used to link methods will be specific to each application. For each metric, an applicant must display its numerical value and unit of measurement, the specific model or analysis that generated the metric, and how it is used in subsequent analyses. The applicant shall provide summary statistics (including mean or median) for metrics having multiple values, such as a sequence of results over a hydrologic period. The applicant must also display how the metric's value changes by location, time in the planning horizon, and hydrologic condition (e.g., year type or every year in the hydrologic sequence). Generally, the applicant will display the level of the metric, both with and without project, and the amount of difference, defined at the future condition years, 2030 and 2070. Metrics for any other selected years should also be displayed. For the relative environmental values of ecosystem and water quality improvement, applicants shall also display metrics at current condition.

The metrics provide a framework for technical review by Commission staff, DWR, CDFW, and the State Water Board. Metrics must be displayed in a way that reviewers can assess quality of analysis and trace the chain of analysis. Please refer to the quality of analysis criteria described in Section 4.2.1.2.

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4.3 Surface Water Operations Analysis

This section describes the components of water resources system operations, and how water resources system operations relates to assessing physical changes that connect to other resources. It describes the components of surface water operations, the physical changes that occur in a water resources system due to a project, the tools available to analyze these changes, and finally, how these changes relate to the evaluation of benefits or impacts on other natural resources. This section focuses on the operations of surface water resources systems, and to a lesser extent, groundwater operations, as groundwater operations are often assessed as a post-process to surface water operations. See Section 4.4, Groundwater Analysis, for a more complete description of groundwater operations and methods.

Water resources system operations are decisions or actions, purposeful or incidental, to control or regulate the movement of water by diverting to, impounding in, or releasing from a surface or groundwater storage or other facility(ies). Based on the project description and operations plan for a water storage project, a surface water and groundwater operations analysis accounts for all water controlled or regulated by the water storage project, and describes the operations (i.e., decisions and actions) that result in expected physical changes due to the movement of water. All other benefits analyses for WSIP depend on a primary water operations analysis.

As shown in Figure 4-2, a water operations analysis includes the following components:

- Developing hydrologic information for quantifying water balances defined (e.g., inflows, water use quantities, return flow factors, etc.)
- Defining and describing water balances for the water storage project, the watershed(s)/region(s), and the water resources system affected by the project
- Defining and describing physical features and constraints and relationships for quantifying water balances defined (e.g., reach flow capacities, reservoir storage capacities, flow relationships for hydraulic features, groundwater-surface water interactions, etc.)
- Defining and describing requirements, agreements and operations criteria (e.g., flood control rules, water right terms, minimum instream flow criteria, water service contracts)
- Developing decision frameworks to describe water operations (e.g., forecasting, prioritized decisions, allocation decisions, simulation, accounting)

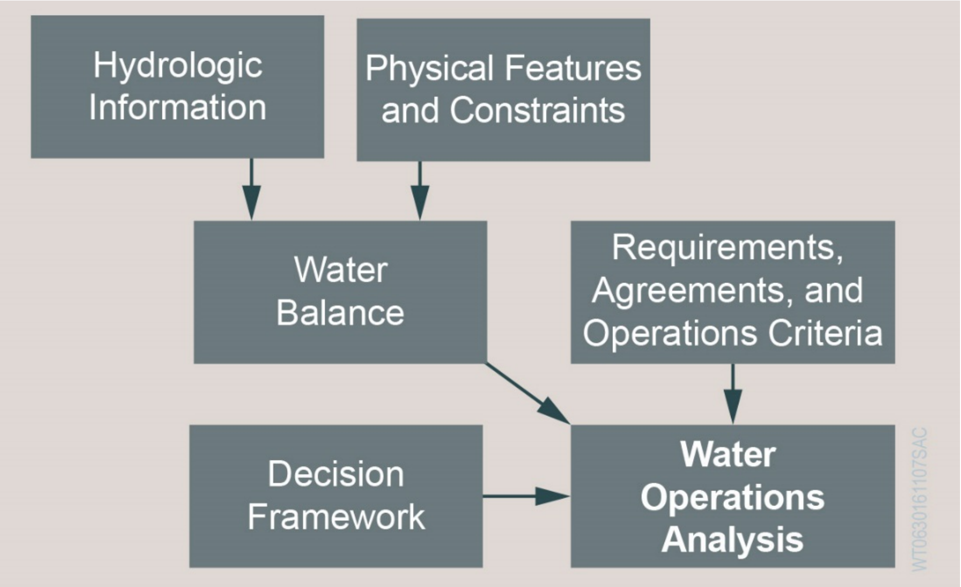

Figure 4-2. Schematic of the Major Components of a Water Operations Analysis.

Each of the components of Figure 4-2 are described in the following sections.

4.3.1 Water Balance

A water balance is an accounting of all the flows of water into and out from an account for a defined period of time. An account could represent a location or geographic boundary, such as a stream reach, reservoir, watershed, or region. A water balance is a mathematical equation that adds the flows of water into and subtracts the flows of water out of the account for a defined period of time. The boundary that the account represents and the time period for which the accounting is performed defines what flows are considered in the equation. A fundamental component of any water balance is that all water defined for a given account must balance for each time period. That is, all water must be accounted for both entering and leaving, and there can be no net gain or loss within the account that is unaccounted for. The gains or losses and accumulation over time within a water balance are also included to represent changes in storage conditions in surface water and groundwater features/facilities.

Water accounts and balance equations can be defined for all aspects of managing water flow and storage, including:

- Monitoring surface and groundwater flow and storage conditions
- Performing operations of water control
- Storage or conveyance facilities and interactions between existing and/or proposed facilities
- Complying with requirements, agreements, or related criteria
- Making decisions on water operations through time

Accounting for water flow and storage in this way is useful for developing conceptual models for operating a water resources system, and for developing analyses/models for simulating “what-if” questions about the system. In simulation models, an analyst may want to track accounts for certain outcomes, check for residuals or errors in an analysis, or perform other forensic analyses to identify and address various issues in the input data, calculations, and outputs.

Water balances for a water storage project should be defined and described for the project and the watershed/region the project is located in, and watershed(s)/region(s) that may be influenced by the water storage project’s operations. These definitions and descriptions are necessary for analyzing project operations decisions, verifying compliance with requirements and agreements, and monitoring resulting operational conditions.

4.3.2 Hydrologic Information

In the context of water operations, hydrology is often used as a general term for every component of the hydrologic processes affecting a water balance within a water resources system. This includes all inflows, such as river inflows and runoff due to precipitation, hydrologic processes such as evaporation and evapotranspiration, water demands within the system including the consumptive use of those demands, and their return flows.

For any representation of a water resources system, hydrologic components need to be carefully selected to provide a complete water balance of the water storage project, related watershed(s)/ region(s) and the water resources system. Hydrologic information needs to include within the simulation period the full range of potential hydrologic sequences that have occurred or could occur during project operations, such as two or three successive dry years, or a wet period following a dry period.

Many of the required inputs for hydrologic components of the water balance, can be derived from measured information as described in Section 4.2, General Project Analysis. However, some inputs are selected by the hydrologist or operations analyst based on professional judgment.

4.3.3 Physical Features and Constraints

Water operations analysis involves accounting for flow, storage, and movement of water in an operated system. The analysis must maintain water balance(s) and must consider the capabilities and constraints related to the features and facilities modeled, including stream channels, reservoirs, penstocks, diversion structures, canals, pumps, drains, gates, and weirs. Specifications for the facilities and physical features must adequately describe the capabilities and constraints of the water resources system under both without-project and with-project conditions. Facilities and physical features of the watershed(s)/region(s) that may be influenced by water storage project operations must be considered in addition to the proposed project’s features. These specifications must include adequate spatial and temporal resolution to support subsequent analyses and quantify the benefits claimed.

4.3.4 Requirements, Agreements and Operations Criteria

In addition to the water balance requirements, a water system operations analysis must consider a wide variety of requirements, agreements and operations criteria as presented in Section 4.2, General Project Analysis.

- **Requirements** for a water operations analysis include terms contained within permits, licenses, decisions, water rights, biological opinions, and water control manuals. An example of a requirement is the schedule of minimum flow requirements for a specified stream location contained within a biological opinion.
- **Agreements** to consider for a water operations analysis include terms contained within contracts, settlement agreements, a coordinated operation agreement with another water project, memoranda of understanding, or other legally binding agreements for delivery, storage, or conveyance of water. Often, contract or agreement terms specify how two or more parties to the agreement must act under a range of conditions that may vary with hydrology and operations. An example is an agreement for a diversion of water under a water service contract specified for a maximum annual volume, diverted for use at specified locations. The agreement may specify the conditions for service, and how the allocation of available supply may vary according to hydrology, ability to store and convey water, and other operating conditions.
- **Operations criteria** to consider for a water operations analysis may be formal or informal. They may be embodied in statute or regulation, or they may be derived based on the experience and past decisions that water project operators used to meet the terms of the requirements and agreements previously discussed. Criteria describe an operator’s response to the range of hydrologic or other operational conditions that may occur. For example, an operations criterion could state that water in storage be maintained at or above a certain level at a certain time of year or during a defined period, such as between the end of May and the end of September. A criterion such as this often reflects one or more underlying objectives or constraints, such as meeting temperature management requirements in a biological opinion, meeting the terms of a lake recreation agreement, or ensuring adequate water storage conditions for next year’s water supply contract allocations. Operations criteria often rely in part on forecasts of uncertain information, such as a forecast in March of the anticipated runoff into a reservoir over the April through July period. The ability to forecast and then manage for operational objectives is often critical to achieve the benefits claimed for a proposed project.

A water operations analysis may need to include additional criteria that are based on the analysis results of riverine or Delta conditions, water quality or other resource areas. For example, a riverine analysis may be needed to determine whether an operational decision made within an operations model results in meeting or violating a water quality standard. In complex systems where modeling is needed to capture all components of mass balance and operational requirements, incorporating these feedbacks in a water operations model can involve the iterative solution of a suite of models, embedding one model in another, or adding surrogate constraints or adjustments to the solution process.

Regardless of how complex a water operations model may be, the model is always a simplified representation of a water resources system. Therefore, a model cannot capture all uncertainty and complexity involved in water operations. An example of this limitation often appears when modeling water operations for a drought year. Even though certain rules and practices apply in a drought year, every drought year is unique, and generalized rules cannot be developed to capture every possible outcome of each and every drought year.

Specifications for requirements, agreements and operations criteria must adequately describe the constraints and conditions affecting the water resources system under both with- and without-project conditions. Requirements, agreements and operations criteria for the watershed(s)/region(s) that may be influenced by the proposed project's operations must be considered in addition to those for the proposed project. These specifications must include adequate spatial and temporal resolution to support subsequent analyses and quantify the benefits claimed. Any proposed methods to forecast information required for applying operations criteria must be described.

4.3.5 Developing Decision Frameworks

The operator of a water operations model must follow a schedule of decisions for the year, season, month, and, if applicable, week and day of the hydrologic sequence used for analysis. For example:

- In the spring, a decision must be made to allocate water to water supply contracts or other water supply agreements
- In the summer, a decision must be made to release flow to dilute and maintain Delta salinity requirements, and to balance the remaining storage between reservoirs (for the reservoirs that could serve the requirement)
- For each day in the summer, a decision must be made to release flow cool enough to maintain temperature conditions for fish habitat

In a water resources system with complex water balance interactions, multiple watersheds, developed infrastructure, and various requirements, agreements, and operations criteria, a hierarchy of decisions need to be made. At the system level, only a dozen or so decisions may be needed on an annual or seasonal schedule. However, at the level of a stream reach or location, many hundreds of decisions may be needed for all the reaches, locations, and points in time during the season.

A water operations decision framework may use a variety of methods to make decisions, including:

- A set of procedural steps and calculations (these may involve iterative calculations)
- An optimization approach to solve for a set of decisions and conditions that best achieve a defined objective
- A combination of procedural steps, solvers, and other models

An important part of the decision framework is the prioritization of certain operations/outcomes over others. For example, general reservoir operations priorities, in descending order, typically are:

1. Flood control (highest priority)
2. Minimum instream flows and water quality
3. Water supply diversions
4. Hydropower
5. Recreation

The order of the lower priorities may vary for different reservoirs. Prioritization of reservoir operations may be dictated by the language of requirements and agreements related to the reservoir. Priorities can be described for an individual water facility, such as a reservoir or a pump station, or for a system of water facilities, such as SWP and CVP facilities operating for Delta requirements mentioned in Section 4.2, General Project Analysis.

For many decisions, forecasting is needed in water operations analysis. Hydrologic conditions can vary significantly from year to year and month to month. Prioritization and allocation decisions have to be made in advance so that releases from storage and diversions can be scheduled to achieve the intended outcome. One example of when forecasting is needed is during drawdown of a reservoir in advance of forecasted flood flow arriving. Another example is the announcement of an allocation for water supply contracts. Farmers use this information to make planting and other financial decisions in advance of actually receiving the water.

The ability to forecast and subsequently select and manage for operational objectives is often critical to achieve the benefits claimed for a proposed project. Forecasting procedures for water operators vary widely, therefore they are not discussed further in this section. Applicants should consider current operations practices when determining the appropriateness of forecasting for the system and facilities being analyzed. Modeling analysis must attempt to simulate how a proposed project will actually perform as its operators make decisions under conditions of uncertainty, therefore the use of perfect foresight in modeling is untenable.

Tracking and accounting of water over time is important for water operations analysis. Almost all water agreements and many requirements include some conditions that require tracking and accounting. For example, a water right permit might allow for an instantaneous rate of diversion of 100 cfs, but limit the total diversion over the irrigation season to a maximum of 15 TAF. Another example is the COA for the CVP and SWP (Reclamation and DWR, 1986). The COA requires tracking and accounting of, among other quantities, in-basin water use, storage, Delta export and outflow, and each project’s share of water used for each purpose.

Water operations must meet all requirements and agreements based on defined standard operating procedures. Therefore, when developing or using a water operations model, applicants must include decision frameworks that are based on real-life forecasted information and are representative of real-life priority and allocation decisions. These operating procedures must be described in enough detail for reviewers to determine they are realistic. The analysis must also demonstrate that the decision framework is implemented consistently with the project description and operations plan to achieve the physical benefits claimed.

4.3.6 Water Resources System Operations Methodology

Analyzing physical changes that occur in a water resources system due to a water storage project requires that the system is adequately represented via hydrologic conditions, water demands, the regulatory environment affecting operations, and the physical properties of its hydraulic features/facilities, both natural and constructed. Changes to flow patterns, demands, regulations, or facilities will influence the operation of surface water reservoirs. The operations of these facilities, in turn, influence river flows, water quality, and reservoir storage. The interaction between hydrology, operations, and regulations is not always intuitive, and detailed analysis of this interaction often results in new understanding of system responses. The use of modeling tools is often necessary to approximate these complex interactions under current or future conditions. Given the complexity of assessing physical changes to a water resources system due to operations, and WSIP’s need to quantify benefits based on these changes, qualitative methods are insufficient.

Water operations analysis often requires a numerical model or set of models that puts all of these components together to describe, through simulation modeling techniques, the outcome of a given set of assumptions. Using assumptions such as hydrology, water demands, regulations and hydraulic features/facilities, with-project conditions and without-project conditions simulation, results can be compared to determine the expected physical changes in movement of water associated with the water storage project. The usefulness of operations analysis results depends on the completeness and quality of information used. Many analysis inputs can be assumed from measured information as described in Section 4.2, General Project Analysis. However, many other inputs are selected by the hydrologist and operations analyst based on professional judgment.

As discussed throughout this section, any water operations analysis shall:

- Cover a geographic scope large enough to measure project benefits and impacts
- Simulate water flows, storage, and deliveries over a representative hydrologic period of years
- Account for all water entering and leaving the system with no unaccounted for gains or losses
- Use a time step appropriate for the type of physical benefits being modelled. Refer to the benefit-specific sections to determine the appropriate time steps necessary for quantifying each benefit.

- Include all relevant without-project future conditions, including hydrologic conditions, facilities, water rights, other priorities, demands, agreements, compliance obligations, and available supplies, including:
    - Required operations related to the Delta, the Biological Opinions, the CVP, and SWP as summarized in Section 4.2, General Project Analysis
    - Full implementation of SGMA for years beyond 2042
- Track changes between initial and ending storage conditions, and account for the difference
- Include all relevant with-project conditions, including those needed for any sensitivity analyses
- Produce outputs that can be converted to appropriate metrics for quantifying the physical benefits claimed

SGMA implementation is occurring concurrently with the writing of this document. At the time that WSIP applications are developed, the specific groundwater management actions and numerical sustainable yield targets will not be known. Applicants shall use analysis, data, and management assumptions that are reasonably consistent with SGMA's requirements, its implementing regulations, and the study area's GSP. Uncertainty associated with SGMA implementation may be evaluated using sensitivity analysis as described in Section 10, Evaluating Sources of Uncertainty.

The following sections introduce methods and some models for surface water analysis that may be helpful for applicants when preparing water storage project analysis.

4.3.7 Model Representation of Water Resources Systems

Selection of the appropriate tool to model water operations depends on the complexity of the water storage project, its geographical location, and its potential effects on California water resources from a system-wide perspective. The tool(s) selected need(s) to be capable of quantifying a water storage project's targeted benefits and potential impacts. Water resources system operations can be analyzed at different scales (i.e., local, watershed/regional, and system-wide). For the purposes of WSIP:

- Local operations refer to the operations of the proposed water storage project and any other facilities on the same stream requiring closely coordinated operation
- Watershed/regional operations refers to operations affecting multiple facilities and resources within a watershed and the Delta
- System-wide operations refers to operations that affect and require coordination with facilities and resources in multiple watersheds and regions of the state (e.g., CVP and SWP operations)

The type of analysis and model selection is determined on the potential scale of the targeted benefits of a water storage project. For example, for a storage facility at a tributary river that is disconnected from the Sacramento-San Joaquin river systems, a simpler, local model may be sufficient, whereas for a storage facility on a tributary of the

Sacramento-San Joaquin river systems, a more complex, system-wide model may be needed. A system-wide model will be needed, in addition to the local river representation, to assess system-wide effects of the water storage project, and to quantify public benefits to the Sacramento-San Joaquin Delta.

Applicants shall determine the level of analysis needed for their project specifically, and choose an appropriate modeling tool or tools to use. Applicants are encouraged to make use of existing model(s) if the model fits the needs of the analysis. These models could include operations models used for environmental compliance, FERC relicensing, and other local to regional planning studies. This again will depend on the scale of the targeted benefits. For example, if an operations model was used for a FERC relicensing project, that model may be useful for quantifying local benefits, such as improved instream flows for aquatic species within that watershed. However, that model may not be useful for benefits within the Delta because of the interrelated operations of other watersheds (e.g., the CVP and SWP) that affect Delta conditions. In that case, a system-wide operations model such as CalSim II is needed in addition to a local model.

If an applicant decides to develop a new water operations model, the complexity of that model and the platform used will depend on the scale of the analysis. For example, a simple operations model developed in Microsoft Excel may be sufficient for calculating water supply benefits for a small watershed with a small number of reservoirs and diversions. Scaling the effects of a local project to regional or system-wide benefits (such as ecosystem benefits in the Delta) will require more complex analysis.

Different tools have different applicability and usefulness depending on the scale of the operations and benefits/impacts of the proposed project. Simulation models use equations and other computer logic to represent the way a complex system actually operates. An optimization model includes many, and sometimes all, of the equations and logic of the simulation model, but also searches numerically for the system operation that best meets a defined objective. A list of the most commonly used models/modeling tools capable of simulating water resources system operations are provided in the next section. The scale and types of benefits will dictate the appropriate model selection. See Section 4.2.1.1, Model Selection Criteria, for guidelines about model selection.

All of the models listed below are simulation models. Optimization models of water resources system operations may not apply to WSIP, which requires quantification of benefits under a descriptive system operation scheme in comparison to without-project conditions. Optimization models might be used to determine the best operational scenario under certain conditions.

4.3.8 Commonly Used Water Resources System Operation Modeling Platforms

The following section summarizes the most commonly used software platforms for water resources systems modeling. The models are also briefly summarized in Table 4-1.

4.3.8.1 Microsoft Excel

Excel-based spreadsheet models can be sufficient for evaluating simple water resources systems that may only have local benefits and impacts. Excel provides a freeform, flexible platform for developing calculations and creating simple models. It can be useful for developing screening models to investigate project concepts, and to investigate specific relationships or tradeoffs that are important for water storage project formulation. This type of screening is efficient and helps the analyst understand the scope needed for more detailed analysis of a proposed water storage project, including study area, water balances, hydrologic, physical, regulatory, and operational assumptions, and inputs and outputs required (i.e., locations, time step and period of analysis).

As the complexity of a water resources system increases, the computational limits of Excel are reached. Excel models are often used to supplement and pre- and/or post-process information for other models. Even with their limitations, they are efficient to develop, modify, and incorporate into a system of models for analysis. Excel's freeform, flexible structure means that the quality of the resulting analysis depends on the skill and experience of the developer. All Excel models used for WSIP analysis, including pre- and post-processors, must be non-proprietary, available to reviewers, and documented. Reviewers must be able to verify all calculations, inputs and outputs, and information used by other models in the applicant's overall analysis.

Several studies in California have used Excel-based spreadsheet models for water operations analyses, including the Turlock and Modesto Irrigation Districts' FERC Relicensing (Steiner, 2013) and a water supply study for the Friant Water Users Authority and Natural Resources Defense Council as part of the San Joaquin River Restoration Program (URS Corporation [URS], 2002).

4.3.8.2 HEC-ResSim

HEC-ResSim was developed by USACE's Institute for Water Resources Hydrologic Engineering Center (HEC). HEC-ResSim is a hydrologic routing and reservoir simulation model capable of simulating the operations of a single reservoir, a local water resources system including a reservoir and diversions, and a system-wide network of reservoirs (USACE-HEC, 2013). HEC-ResSim uses a hierarchical, rule-based approach to simulate operations at a reservoir, and then simulates flows throughout the system based on those outflows. The model can be used for a variety of purposes, including reservoir operations for flood management, water supply planning studies, detailed reservoir regulation plan investigations, and real-time decision support.

HEC-ResSim has been applied in many studies in California, including the Central Valley Flood Protection Plan (CVFPP), where HEC-ResSim is being used to simulate flood operations of the major reservoirs for the Sacramento and San Joaquin basins (public release of the Basinwide Feasibility Study is expected in 2016).

4.3.8.3 RiverWare

RiverWare, a proprietary tool, developed by the University of Colorado’s Center for Advanced Decision Support for Water and Environmental Systems (CADSWES), is a hydrologic routing and reservoir simulation model capable of simulating the operations of a single reservoir, a local water resources system, and a system-wide network of reservoirs. It has similar reservoir simulation capabilities as HEC-ResSim but includes other features such as optimization capabilities.

The RiverWare model has been applied to a variety of water management studies across the United States, including Reclamation’s long-term planning on the Colorado River. In California, RiverWare was used by the El Dorado Irrigation District for its FERC relicensing of Hydroelectric Project 184 on the South Fork of the American River (Setzer, 2008). For the purposes of WSIP, RiverWare is better suited for local operations due its ability to simulate daily hydrology and operations.

4.3.8.4 WEAP

WEAP is an integrated water resources management modeling platform. WEAP, a proprietary tool developed by the Stockholm Environment Institute, has been applied in a wide variety of watersheds and water management settings worldwide. It is capable of simulating key water management aspects such as water demand, supply, instream flow requirements, reservoir operations, and water quality considerations under a variety of hydrology, policy, climate, land use and socio-economic scenarios. WEAP is useful for operations at the watershed scale for both local and system-wide analysis.

WEAP has been applied in California as part of the California Water Plan Update process to calculate general changes in water use throughout California over a variety of water management, climate, and hydrologic scenarios (Joyce et al., 2010; DWR, 2013). It was also applied to the Tuolumne and Merced River watersheds to assess potential climate impacts on water supply reliability (Kiparsky et al., 2014).

For the purposes of WSIP, WEAP is better suited for analyzing benefits at the local scale. While a system-level water supply model of the CVP and SWP could be developed, this would be time consuming and laborious, and it would be more appropriate to use an existing, publicly available model such as CalSim II or CalLite (described below), which have been reviewed by the California water resources community.

4.3.8.5 MODSIM

MODSIM is a river basin operations modeling platform developed by Colorado State University. It is capable of simulating both simple and large complex water resources systems for both long-term planning and real-time operations (Colorado State University, 2016). Its operational capabilities include reservoir operating rules, water allocations, conjunctive use operations, hydropower generation, and hydrologic routing. The model can also perform Monte Carlo simulations and simulate operations at the monthly, weekly, and daily time steps.

MODSIM has been used in multiple applications in California. Reclamation has developed a monthly time step version of MODSIM of the San Joaquin River basin to investigate improved water management on the San Joaquin River. (Colorado State University, 2007). Imperial Irrigation District used MODSIM to assess water quantity and quality impacts of its potential water transfers as part of the Quantification Settlement Agreement (Imperial Irrigation District, 2001).

4.3.8.6 GoldSim

GoldSim, developed by the GoldSim Technology Group, is a dynamic simulation model that can be applied in a variety of analysis settings, including water resources system modeling. It is capable of simulating simple and large complex water systems for a variety of water management purposes. The model can also perform Monte Carlo simulations and simulate operations at the monthly, weekly, and daily time steps. GoldSim software is a flexible platform for developing simple to complex models. It can be used to investigate general operational concepts and to investigate specific relationships or tradeoffs that are important for water storage project formulation. This type of screening is efficient and helps the analyst understand the scope and level of analysis needed for more detailed analysis of a proposed project, including study area, water balance, hydrologic, physical, regulatory and operational assumptions, and inputs and outputs required (i.e., locations, time step and period of analysis).

As with other flexible platforms, no water balance or other restrictions are built into GoldSim. The quality of the resulting application and analysis depends on the skill and experience of the developer. All GoldSim models used for an analysis for WSIP must be made available and must be documented to allow reviewers to independently verify all calculations and inputs and outputs, and use by other models, as required for review. GoldSim was used as the basis for an earlier version of the CalLite model, but that version is now superseded by DWR’s Water Resource Integrated Modeling System (WRIMS)-based CalLite model.

4.3.8.7 WRIMS

WRIMS is a general water resources modeling system developed by DWR. WRIMS is a reservoir-river basin simulation model that allows for specification and achievement of user-specified allocation targets or goals.

WRIMS software is a flexible platform for developing simple to complex models. It can be used to investigate general operational concepts and to investigate specific relationships or tradeoffs that are important for water storage project formulation. This type of screening is efficient and helps the analyst understand the scope and level of analysis needed for more detailed analysis of a proposed project, including study area, water balance, hydrologic, physical, regulatory and operational assumptions, and inputs and outputs required (i.e., locations, time step and period of analysis).

As with other flexible platforms, no water balance or other restrictions are built into WRIMS models. The quality of the resulting analysis depends on the skill and experience of the developer. All WRIMS models used for WSIP analysis must be made available and documented so that reviewers can independently verify all calculations, inputs, and outputs used by other models, as required for review.

The primary application of WRIMS in California is CalSim II (See Section 4.3.8.9). CalSim II is a monthly time step planning model used to simulate the coordinated operation of the CVP and SWP. The model simulates the hydrology of the Central Valley, reservoir operations, SWP and CVP operations and delivery, allocation decisions, existing water sharing agreements, and Delta salinity responses to river flow and export changes. It represents the best available planning model for the CVP and SWP system operations, and has been used in all recent, system-wide evaluations of CVP and SWP operations, including coordinated long-term operation of the CVP and SWP (Reclamation, 2015).

CalLite (See Section 4.3.8.8 below) is another application of WRIMS in California that has the same level of operational complexity, but with a less complex geospatial resolution than the CVP and SWP model. CalSim III is another application of WRIMS in California, and is the next generation of the CalSim II model. CalSim III is not yet available for WSIP use.

4.3.8.8 CalLite

CalLite was developed by DWR and Reclamation as a rapid, interactive screening model for Central Valley water management to bridge the gap between the more detailed system model (CalSim II) managed by these agencies and policy/stakeholder demands for rapid and interactive policy evaluations. This screening model simulates the hydrology of the Central Valley, reservoir operations, SWP and CVP operations and delivery allocation decisions, existing water sharing agreements, and Delta salinity responses to river flow and export changes. It is intended to be a simpler version of CalSim II that still incorporates these fundamental components. The existing hydrology and operations planning model, CalSim II (Draper et al., 2004), was used to provide aggregated hydrology and system operating rules for CalLite

CalLite simulates water conditions in the Central Valley over an 82-year planning period (i.e., water years 1922 to 2003), and allows interactive modification of a variety of water management actions including enlargement of existing storage facilities, demand management, and river and Delta channel flow and salinity targets. In addition, CalLite can simulate observed or possible future hydrologic regimes to enable the user to determine climate change impacts. The tool is designed to assist in the screening of a variety of water management options and for use in a variety of stakeholder processes for improved understanding of water resources system operations and future management.

While CalLite simulates the hydrology and operations over much of the same geographic area as the CalSim II model, the CalSim II model provides more detailed results to perform a benefits/impacts analysis, whereas CalLite is intended to test different operational scenarios until a proposed operation is selected. CalSim II would then be used for a detailed analysis of the proposed operation.

4.3.8.9 CalSim II

CalSim II is a water operations planning model developed by DWR and Reclamation. It simulates the SWP and CVP, and areas tributary to the Sacramento-San Joaquin Delta. CalSim II provides quantitative hydrologic-based information to those responsible for planning, managing and operating the SWP and CVP. The model was developed to evaluate changes to the complex water resources system of California under alternative conditions, and approximate changes in the major storage reservoirs, river flows, and exports from the Delta that would result from a change in hydrologic conditions, water supply demands, facilities, requirements or operational policies. As the official model for those projects, CalSim II is typically the system model used for any inter-regional or statewide analysis in California. CalSim II uses descriptive optimization and rules-based simulation techniques to route water through a CVP/SWP system network representation. CalSim II includes specialized algorithms to capture select physical features such as the relationship between Delta salinity and flow conditions. The network includes over 300 nodes and over 900 arcs (i.e., stream or canal reaches), representing 24 surface water reservoirs and the interconnected flow system.

CalSim II incorporates all areas that contribute major flows to the San Francisco Bay-Delta. The geographical coverage includes the Sacramento River Valley, the San Joaquin River Valley, the Sacramento-San Joaquin Delta, the Upper Trinity River, and the CVP and SWP service areas. The CalSim II model assumptions are consistent with the Biological Assessment on the Continued Long Term Operations of the CVP and the SWP (Reclamation, 2008a, 2008b) as modified by the December 2008 USFWS BiOp RPA (USFWS, 2008) and the June 2009 NMFS BiOp RPA (NMFS, 2009) and many other requirements and operating criteria governing the CVP and SWP facilities operations on the Sacramento, Feather and American Rivers and Delta (State Water Board, 1999; DWR, 2015a, 2015b) including the COA (Reclamation and DWR, 1986).

CalSim II operates on a monthly time step from water year 1922 through 2003. It uses historical streamflow data, which have been adjusted to describe existing and future projected conditions, including changes in water and land use that have occurred or may occur in the future. The conditions are modelled as if the projected conditions, including population, land and water use, regulatory requirements, facilities and operating agreements, were present throughout the entire hydrologic record. Inputs to the model describe assumptions of hydrology at projected levels of climate, land and water use, existing and proposed facilities, and riverine and Delta regulatory conditions. The model simulates the operation of the water resources infrastructure in the Sacramento and San Joaquin river basins on a month-to-month basis during this 82-year period. The model is operated to meet multiple purposes and requirements, including flood control, water rights, Delta water quality, instream flow and temperature, and deliveries to water contractors.

The model operates the reservoirs and pumping facilities of the SWP and CVP to assure the flow and selected water quality requirements for these systems are met. For a projected condition, the model assumes that facilities, land use, water supply contracts, and regulatory requirements are constant over 82 years from 1922 to 2003, representing a fixed level of development. The model output includes monthly reservoir releases, channel flows, reservoir storage volumes, water diversions, Delta pumping, and parameters describing San Joaquin River and Delta water quality conditions. CalSim II is a simplified and generalized representation of a complex system. Due to the wide range of uncertainty in projecting existing and future conditions in model inputs, model results have limited usefulness in predicting the probability of existing and future compliance with regulatory and operational objectives. Therefore, the use of CalSim II results should be limited to long-term planning analyses and evaluating changes and trends over a broad range of conditions. Appendix B provides a more complete description of CalSim II.

4.3.9 Guidelines for Model Selection

For WSIP, it is up to the discretion of the applicants to determine what level of analysis, and thus what modeling approach/tool(s), is best suited for their projects. An applicant is encouraged to make use of existing models if it thinks that model is suitable for its analysis. Figure 4-3 shows a schematic of what tools would be most appropriate for quantifying impacts and benefits at different scales. Other tools may be used if justified and documented.

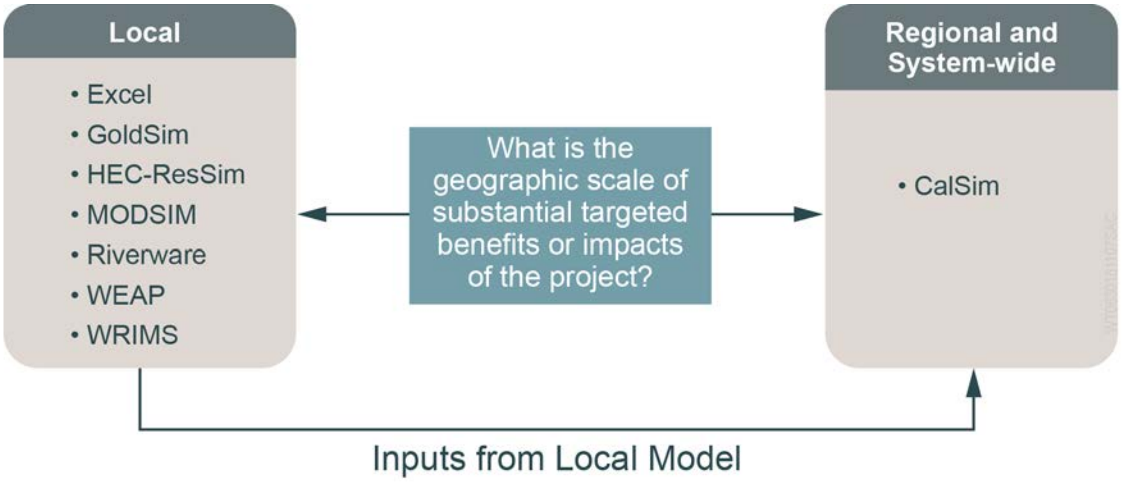

Figure 4-3. Schematic of Tools for Quantifying Impacts and Benefits at Different Scales.

In general, tools such as Excel or HEC-ResSim, may be useful for quantifying local benefits and impacts. Regional and system-wide benefits and impacts that include the Delta will require applicants to use CalSim II, since CalSim II is the accepted water resources system operations model for modeling changes in the Delta. CalSim II models of the without-project conditions will be made available for applicants to use. For modeling with-project conditions using the Commission provided CalSim II model, the applicant will need to modify the CalSim II model to include the proposed water storage project. Technical adjustments to the CalSim II model code shall be limited to modifications needed to complete the description of the proposed project and depiction of public and non-public benefits. Adjustments made to the without-project future conditions must also be included in the with-project future conditions and must be justified as requirements for the analysis of the proposed project. Regulatory requirements, agreements, and operations criteria of the SWP and CVP in the CalSim II model code for the 2030 without-project and 2070 without-project future conditions shall not be modified.

For proposed projects whose operation is not dependent on the operation of existing facilities, the applicant could use outputs from the local benefits/impacts analysis as an input to the CalSim II model. For example, a new water storage project on Butte Creek could develop a local operations model using RiverWare and then use the outputs from that model as an inflow time series to CalSim II to quantify the resulting physical changes to the Delta and CVP/SWP operations. The following section discusses the rationale for requiring applicants to use CalSim II for regional and system-wide impacts that include the Delta.

Rationale for Using CalSim II

CalSim II is the model most capable of providing inter-regional or statewide analysis of water operations in the Central Valley of California. CalSim II has important strengths as a systems operations planning model, particularly compared with available alternatives. Its primary strengths are as follows:

- CalSim II is the official SWP/CVP operations planning model. DWR and Reclamation have made substantial investments in creating a model that best represents the operational objectives and constraints that the two projects face. CalSim II reflects the operational cooperation required between DWR and Reclamation (2004).
- CalSim II is a simulation model with an optimization engine, with a detailed dataset that the two agencies have invested substantial coordinated effort to develop. This modeling approach provides much greater flexibility than its predecessors and other, more traditional approaches to water resources simulation.

The CalSim II model and data are in the public domain, facilitating transparency and adaptability for California’s decentralized water resources system.

Assumptions/Limitations

The CalSim II model is used to simulate an 82-year period approximating future conditions and like all models, CalSim II has limitations, as described below.

One of the main limitations of the CalSim II model is the time step of simulation, data, and results. CalSim II includes monthly hydrologic data sets and simulates operations and river flows at the same monthly time step. Averaging flows over the monthly time step will obscure daily variations that may occur in the rivers due to dynamic system-routing effects or natural hydrologic variability. The monthly time step also requires averaging (usually day-weighted) to simulate operations for regulatory criteria that are specified for periods shorter than a month. The averaging process can lead to either under- or over-estimation of water availability or other metrics associated with the criteria.

The CalSim II model also uses generalized rules to specify the operations of the CVP and SWP systems. These rules have been developed based on significant CVP/SWP operator input, and represents coarse estimates of project operations over all hydrologic conditions. The results from a single CalSim II simulation may not necessarily represent the exact operations for a specific month or year, but should reflect long-term trends.

CalSim II is intended to be used in a comparative mode. The results from a proposed with-project operational scenario are compared to the results of the without-project operations to determine the incremental effects of a project. The model should be used with caution to prescribe seasonal or to guide real-time operations, predict flows or water deliveries for any real-time operations.

The model assumes that facilities, land use, water supply contracts and regulatory requirements are constant at a given point in time (current or future condition year), representing a fixed level of development rather than one that varies in response to hydrologic conditions or changes over time.

Groundwater has limited representation in CalSim II. Important benefits or impacts on groundwater must not be analyzed using CalSim II. See Section 4.4, Groundwater Analysis, for methods and concepts to use for assessing groundwater.

4.3.10 Linking Water Resources System Operation Models to Quantification of Benefits

Changes in operation of a proposed surface water or groundwater storage facility may affect use of other reservoirs, may provide benefits through conjunctive use of surface water and groundwater, or may provide increased flexibility system-wide (such as CVP and SWP systems). Due to the complexity and interconnection of water resources systems, a systematic way of quantifying and comparing benefits or impacts is required. This is often an iterative process where an operations model is run under different criteria to maximize outcome of targeted benefits subject to operational requirements and constraints. Applicants should use an iterative process of this kind to develop the operations plan for the feasibility study and the WSIP application. Applicants must perform an adequate level of analysis to link the final operations plan to the benefits claimed.

Figure 4-4 shows the process of identifying, formulating, and adjusting water operations of a water storage project for certain targeted benefits.

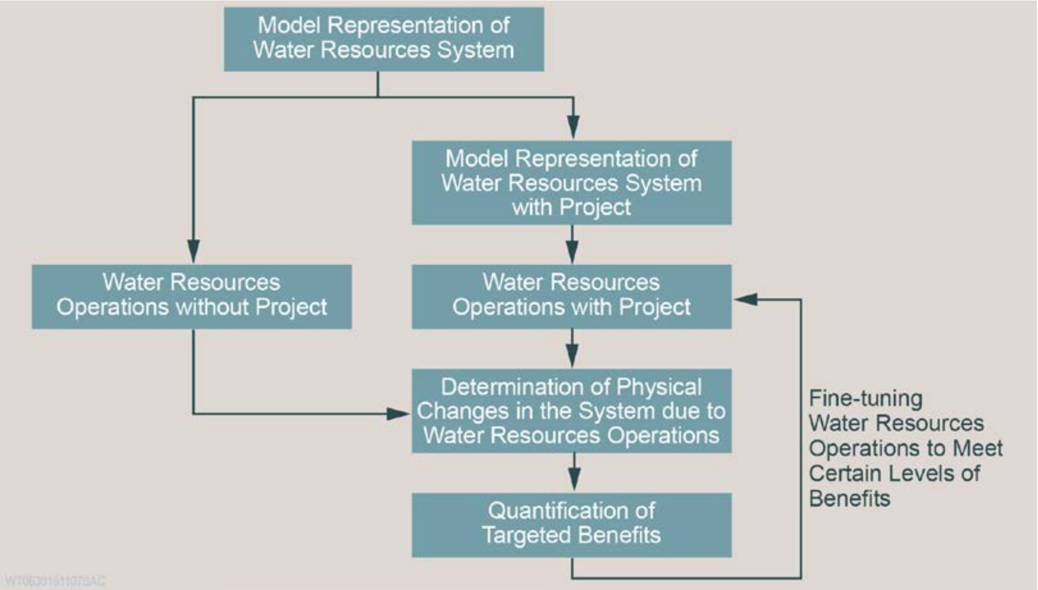

Figure 4-4. Schematic of the Process for Quantifying Targeting Benefits from the Water Resources System Operations Analysis.

Once an operations plan is developed, physical changes that are simulated by an operations model (e.g., reservoir storage, river flows, water deliveries) are converted into metrics that directly quantify benefits and impacts, or that provide input to subsequent analysis. These metrics could include:

- Changes in frequency of flood releases
- Changes in stored water (at certain times of the year such as end of April or end of September)
- Changes in reservoir water and reservoir release temperature
- Changes in reservoir release scheme (could be related to ecosystem benefits, power generation, recreation, water deliveries, etc.)
- Changes in reservoir surface water elevation (could be related to recreation or ecosystem benefits for reservoir species)

A framework of integrated analyses including hydrologic, operations, hydrodynamics, water quality, and fisheries analyses is required to provide information for the comparative analysis of several resources such as water supply, surface water, groundwater, water quality, and aquatic resources. The analytical framework usually involves more than one model, where each model provides information to the subsequent model to provide various results to support the benefit/impact analyses.

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Table 4-1. Summary of Water Resources System Operations Modeling Platforms.

Model	Developer	Key Inputs and Assumptions	Outputs	Benefit Categories	Applications to California	Notes/Limitations/Links
HEC-ResSim	USACE	Hydrology, Physical Characteristics, Operating Rules, other inputs depend on type of analysis	Flows and Storages at the timescale of the input hydrology	Model can provide inputs for Water Supply, Ecosystem, Water Quality, Hydropower, and Flood Control	• CVFPP • Yuba-Feather Forecast-Coordinated Operations Study	Modeling platform is publicly available at http://www.hec.usace.army.mil/software/hec-ressim/
GoldSim	GoldSim Technology Group	Hydrology, Physical Characteristics, Operating Rules, other inputs depend on type of analysis	Flows and Storages at the timescale of the input hydrology	Model can provide inputs for Water Supply, Ecosystem, Water Quality, Hydropower, and Flood Control	• CalLite	Proprietary Tool: Model is available at http://goldsim.com/Home/
MODSIM	Colorado State University	Hydrology, Physical Characteristics, Operating Rules, other inputs depend on type of analysis	Variety of parameters including flows and storages at the timescale of the input hydrology	Model can provide inputs for Water Supply, Ecosystem, Water Quality, Hydropower, and Flood Control	• San Joaquin River • Imperial Irrigation District • Klamath River	Model is publically available at http://modsim.engr.colostate.edu/index.shtml
RiverWare	University of Colorado's CADSWES	Hydrology, Physical Characteristics, Operating Rules, other inputs depend on type of analysis	Flows and Storages at the timescale of the input hydrology	Model can provide inputs for Water Supply, Ecosystem, Water Quality, Hydropower, and Flood Control	• East Bay Municipal Utility District operations model • Metropolitan Water District	Model is publicly available but requires the purchase of a license. Information is at http://www.riverware.org/
WRIMS (e.g., CalSim)	DWR	Hydrology, Water Demands, Regulations	Flows and Storages at the timescale of the input hydrology	Model can provide inputs for Water Supply, Ecosystem, Water Quality, Hydropower, and Flood Control	• CalSim II • CalLite	WRIMS is publicly available at http://baydeltaoffice.water.ca.gov/modeling/hydrology/CalSim/index.cfm.
WEAP	Stockholm Environmental Institute	Hydrology, Water Demands, Regulations, Climate, Economics	Flows and Storages at the timescale of the input hydrology	Model can provide inputs for Water Supply, Ecosystem, Water Quality, Hydropower, and Flood Control	• California Water Plan	Model is publicly available at http://www.weap21.org/

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4.4 Groundwater Analysis

This section describes concepts and methods for quantifying physical changes that may be associated with benefits or impacts related to groundwater resources and operations that could result from water storage projects. First, a brief overview of the types of storage projects and their potential effects on groundwater are presented. Next, potential benefits related to groundwater physical changes are summarized so applicants can better understand how project elements and operations may contribute to achieving public benefits. SGMA-related considerations are included separately for reference. Finally, methods and approaches, metrics, and models are described so that applicants can consider a range of approaches to quantify the groundwater changes and assess the value of a particular project in enhancing public benefits. Applicants may use other methods or tools not specifically included in this section. Any method used must be justified as using best available science, and applicants must determine the appropriate level of analysis for the project being evaluated.

This information is related to groundwater analysis and associated potential benefits, and includes a mix of required technical considerations, recommended analyses and methods, and available analysis tools.

All concepts and methods apply to quantifying both benefits and impacts on groundwater resources created or caused by a water storage project, but for brevity, the narrative often refers only to benefits. Applicants must describe and quantify, where possible, all physical changes to groundwater resources that may result in both benefits and impacts, of the proposed project.

4.4.1 Types of Storage Projects and How They May Affect Groundwater

According to Section 79751 of the Water Code, eligible project types include groundwater related projects, such as:

- Groundwater storage projects
- Groundwater contamination prevention or remediation projects that provide water storage benefits
- Conjunctive use projects

Definitions for each of these project types are provided in the proposed regulations (also provided in Section 11, Glossary). These project categories affect groundwater resources differently, and analysis methods will need to be adapted to the specific proposed project.

Groundwater storage projects may include the banking of water within the aquifer system for future use, which can improve aquifer conditions. Groundwater remediation projects may also lead to additional available water supply in areas where groundwater resources are present, but have been impacted by contamination and are of degraded water quality that preclude its current beneficial use.

Further, surface water projects may result in groundwater impacts/benefits, such as increased use of surface water and decreased use of groundwater through conjunctive use operations. Projects may also provide in-lieu recharge benefits to the aquifer or store surface water in wet years to support groundwater recharge operations.

4.4.2 Overview of Methods

Several technical analysis methods are available to evaluate changes in groundwater conditions and availability due to the implementation of a water storage project. The most common methods include (from simplest to more complex):

- A qualitative approach can link the relative change in groundwater supply with physical changes based on the change in surface water use in some areas. This approach may be acceptable for surface storage projects that have a minor or likely limited effect on groundwater conditions.
- Simple analytical tools (such as spreadsheet tools) can be used for more locally focused analysis of specific changes to groundwater use resulting from implementation of a project. Simple analytical methods provide a solution to the governing groundwater flow equations based on known (or assumed) parameters. Due to the simplifying assumptions necessary to develop analytically based tools, these tools are limited to the analysis of simplified representations of the groundwater system.
- Complex, detailed numerical modeling packages, such as three-dimensional groundwater flow models, transport models, and integrated surface water and groundwater models, generate a variety of output data. These models provide a holistic view of changes occurring in a groundwater basin as a result of project implementation, and allow for the simulation of complex, 3-D site geometry and better spatial and temporal project representation.

In addition, forecasts of land and water use changes in the future need to be considered in any assessment of potential benefits from project implementation. Land and water use projections shall be consistent with existing, published projections to the extent possible, such as urban and agricultural water management plans, the California Water Plan Update, county or city general plans, or other published documents. If no published projections are available for the geographic and time scale of the proposed project, the applicant shall show how it developed the projections. Methods must be consistent with the criteria discussed in Section 2.3, Planning Horizon. Additional information on hydrologic datasets is provided in Section 4.2.2, Hydrology Datasets. Specific methods for calculating projected crop evapotranspiration (ET) and water demands related to projected land use for groundwater modeling considerations are provided in Section 4.4.6, Methods, Approaches, and Tools for Quantifying Physical Changes to Groundwater.

4.4.3 Benefits Related to Groundwater Physical Changes

This section describes the benefits that could be provided via physical changes to a groundwater system as a result of project operations. Other benefits and interactions may be associated with groundwater, and it is the applicant’s responsibility to assess the types of benefits that may be provided by the proposed project. The applicant must determine the appropriate level of analysis required to support the estimates of claimed benefits.

A detailed discussion of each of these potential benefits and how they may be affected by water storage projects is provided in the respective sections about benefits.

Water supply benefits may be affected by the following groundwater physical changes:

- Groundwater levels (related to well yields and pumping cost)
- Groundwater storage (related to quantities available for pumping)
- Groundwater quality (related to usability of the supply)
- Groundwater flow gradient/direction (related to groundwater quality)
- Surface water/groundwater interaction (related to gaining and losing streams)

Public benefits related to ecosystems may be affected by the following groundwater physical changes:

- Surface water/groundwater interaction (for riparian habitat considerations and fish flows)
- Ponded water may be available for migratory birds and fish

Characteristics of groundwater recharge projects (e.g., deep versus shallow groundwater storage projects) will influence the type of ecosystem benefits that projects may support. Ecosystem benefits are more likely to occur with shallow groundwater storage projects such as surface recharge facilities than with deep groundwater storage projects such as aquifer storage and recovery well fields. Surface ponded water in recharge basins may provide habitat for migratory birds and increase shallow groundwater levels that could discharge into surface streams for improved fish flows. Deep injection wells provide additional storage into the deeper aquifers and may not be as beneficial to ecosystems at the surface.

CDFW’s ecosystem priorities specifically related to groundwater include: “Maintain groundwater and surface water interconnections to support instream benefits and groundwater-dependent ecosystems,” and “Provide water to enhance seasonal wetlands, permanent wetlands, and riparian habitat for aquatic and terrestrial species on state and federal wildlife refuges and on other public and private lands managed for ecosystem values.” Applicants should describe how their groundwater projects may support these priorities, or other priorities as appropriate.

Public benefits related to water quality (also see Section 4.8.5.2) may be affected by the following groundwater physical changes:

- Groundwater quality improvements (clean-up)
- Containment of existing plumes
- Hydraulic barriers to contaminant migration
- Changes in groundwater flow gradients which may affect the movement of existing contaminants in the aquifer.
- Groundwater recharge of better quality water

State Water Board water quality priority specifically related to groundwater states: “Protect, clean up, or restore groundwater resources in high- and medium-priority basins designated by the Department.” Applicants must describe how their groundwater projects support this claimed priority, or other priorities as appropriate.

Public benefits related to flood control may be affected by the following groundwater physical changes:

- Groundwater levels and storage conditions (potential for recharge and storage of flood flows underground)
- Reduction in or cessation of land subsidence (leads to flood control benefits due to the reduction of impacts on canals and other conveyance, storage, or flood control infrastructure)

Other flood control benefits may be associated with points of diversions on the stream and recharge locations and conveyance. In addition, considerations of the seasonality of flooding need to be taken into account.

Public benefits related to emergency supply may be affected by the following groundwater physical changes:

- Groundwater levels (related to well yields)
- Groundwater storage (related to quantities available for pumping)
- Groundwater quality (related to usability of the supply)

Public benefits related to recreation may be affected by the following groundwater physical changes:

Surface water/groundwater interaction (for water levels in surface water bodies used for recreation such as rivers and lakes)

4.4.4 SGMA-Related Considerations

Applicants shall use analysis, data, and management assumptions that are reasonably consistent with SGMA's requirements, its implementing regulations, and the study area's GSP. GSPs are required for all high- and medium-priority basins as defined by DWR's statewide basin prioritization. The basin prioritization was based on groundwater use and current conditions of the basin. However, WSIP applications and GSP development and implementation are happening concurrently, so all aspects of GSPs will not be known at the time WSIP applications are submitted. Groundwater analysis and water system analysis (see Section 4.3.6) must incorporate elements of consistency with SGMA requirements. Important elements include:

- Identifying which of the six undesirable results defined in SGMA and listed in the proposed WSIP regulation may be improved or worsened by the proposed project.
- Describing how the management and operation of the proposed storage project might be integrated with the study area's overall groundwater management, as described in a GSP.
- Coordinating with GSAs overlying the groundwater basins in which the proposed project is to be constructed to ensure local buy in and consistency with local management decisions and groundwater sustainability goals.

4.4.5 Groundwater Physical Changes

This section identifies and describes the physical changes related to groundwater resources that could result from implementing a water storage project, and which may affect one of the public or non-public benefits. The analysis of physical change will be discussed in terms of different types of assessment methodologies in the next section. The physical change analysis will support the monetization of benefits as discussed in Section 5. The physical change must be quantified (provide both an estimate of magnitude and direction – increase or decrease), and the spatial and temporal scale must be analyzed.

Groundwater physical changes are generally grouped into two categories: those that affect groundwater quantity (i.e., levels, storage, and flows) and those that affect groundwater quality. The five metrics that can be used to quantify and evaluate the groundwater physical changes due to a proposed water storage project are described below.

4.4.5.1 Change in Groundwater Levels

Groundwater levels can increase or decrease depending on the amount of water pumped out of an aquifer or that is recharged into an aquifer as a result of a water storage project, or natural processes such as precipitation and snowmelt. When groundwater levels decline, well yields in the vicinity may be affected, and the cost of pumping may increase. This could result in an impact on water supplies. On the other hand, if groundwater levels increase, overall aquifer storage increases, well yields may improve, and pumping costs may decline. Groundwater levels are the most important physical change to quantify as it relates to numerous other groundwater physical changes such as change in storage, groundwater exchange with adjacent basins, extent of surface water/groundwater interaction, subsidence, and water quality. Subsidence can occur when the groundwater level (or the potentiometric surface in confined aquifers) is drawn below the historical low level in an aquifer comprised of compressible geologic and sedimentary materials such as clayey or silty layers. This phenomenon has occurred in various parts of the Central Valley, most prominently in the San Joaquin Valley, and has affected the integrity and performance of infrastructures overlying the basin, including water and flood control infrastructures.

4.4.5.2 Change in Groundwater Storage

Groundwater storage refers to the amount of water in storage in a basin that is available for beneficial use. This component is related to the quantity of water available for pumping. The computation of a groundwater budget helps establish the change in groundwater storage over a specified period of time. Groundwater storage is linked to the balance between inputs and outputs of water to the aquifer system in a particular basin. If more water is pumped out of the basin than is recharged into the basin, groundwater storage declines, which in turn impacts water supply and other related benefits, such as water quality.

4.4.5.3 Change in Groundwater Gradient

The groundwater hydraulic gradient dictates groundwater flow direction (horizontal and vertical); groundwater flows from areas of higher groundwater levels (i.e., head) to areas of lower groundwater levels. A gradient can be changed through recharge or pumping; for example, pumping depresses water levels and causes water to flow toward the pumping center. Groundwater flow gradients may also impact groundwater quality by inducing the movement of contaminants in groundwater from areas of low quality to areas of better quality.

4.4.5.4 Change in Groundwater Quality

Groundwater quality may be affected by actions at the ground surface such as changes in land use, point source and non-point source discharges to streams, discharges to an unsaturated zone that seep into groundwater, or flushing of salts that have been concentrated in the soil profile due to agricultural operations. Aquifers currently contaminated by any of these processes may not be usable; remediation projects that improve water quality within these aquifer systems may increase the available usable storage. Depending on the levels of contamination, groundwater with poor quality may need to be remediated before it can be beneficially used.

4.4.5.5 Change in Surface Water/Groundwater Interaction

For streams that are in hydraulic connection with shallow groundwater (which is the case for most streams in the Sacramento Valley, and in areas of the Eastern San Joaquin basin), the interaction between surface water and groundwater can occur in either direction. In other words, a stream can gain water from groundwater (i.e., gaining stream) or lose water to groundwater through seepage (i.e., losing stream). The direction of flow between a stream and groundwater can vary seasonally depending on stream stages and underlying groundwater levels. Stream stages are influenced by changing stream flows and precipitation events, whereas groundwater levels are primarily influenced by the pumping of groundwater and recharge from snowmelt or precipitation. The interconnection of streams and aquifers is crucial for maintenance of ecosystems and riparian habitat. The groundwater exchange with other water bodies such as lakes and wetlands is also influenced by changes in groundwater levels that may impact local aquatic ecosystems. In other areas, streams are disconnected from the aquifer system and these streams generally act as recharge sources to groundwater; this is more common in the southern San Joaquin Valley. A water storage project may affect the balance and direction of flow between surface water and groundwater.

4.4.6 Methods, Approaches, and Tools for Quantifying Physical Changes to Groundwater

This section identifies and describes various approaches, methods, and tools for computing physical changes to groundwater resources due to implementation of a water storage project. The discussion centers on the type of method to be used to identify a particular type of benefit and/or potential impact.

This section does not provide an exhaustive list of potential tools nor documentation of specific methodologies for groundwater analysis; rather, the section focuses on general technical concepts and references a few widely-used methods and/or models. The applicant is responsible for determining the appropriate method and level of detail needed to demonstrate and quantify benefits and impacts due to a proposed water storage project.

All methodologies shall be consistent with other technical approaches and guidelines developed by other programs, such as those described or being established to support a GSP development under SGMA. Technical analysis performed and methodology used during the project feasibility analysis should be used (and expanded upon, if needed) for this benefits quantification effort.

According to the regulations, the planning horizon for this effort is defined as the construction period of the project followed by the useful life of the project; not to exceed 100 years. For projects whose operations vary depending on hydrologic conditions, the applicant shall evaluate and report benefits/impacts by the applicable water year type indexing for the project’s location (refer to Section 4.2.2.1, Water Year Types, for discussion of water year indexes).

The following discussion provides additional information regarding several potential approaches to evaluating physical changes to groundwater systems using various methods.

4.4.6.1 General Analysis Considerations

When selecting the appropriate approach and specific methods for the benefits analysis, applicants should consider the following:

- The geographic reach of physical changes
- The temporal extent of project benefits linked to physical changes
- The types of benefits or impacts related to physical changes
- The availability of key information needed for the analysis
- The method’s complexity and ease of use
- Cost of implementing the method
- The method’s defensibility and credibility

4.4.6.2 Qualitative Approaches

Qualitative approaches refer to methods in which changes are not quantified numerically but rather described as an expected positive change (benefit) or negative change (impact) based on inferred responses of the physical system to external stresses.

This type of analysis approach may be applicable for a surface storage project that would not significantly affect groundwater; however, it would not be appropriate for any type of groundwater storage, remediation, or conjunctive use project; in those cases, the applicant must use a quantitative analysis approach.

Another case for which a qualitative analysis may be adequate is when a surface storage project might provide an improvement in groundwater conditions, but the benefit is not large enough for the applicant to attempt to quantify.

4.4.6.3 Simple Analytical Methods and Tools

For groundwater change analysis, the development of methods that use analytical (or exact) solutions to the groundwater flow equation requires assumptions that significantly simplify the physical system being evaluated. For example, physical boundary conditions are generally omitted in these solutions, and aquifer properties are often required to be homogeneous and isotropic. The physical configuration of the project is also typically idealized for the purposes of analysis, and therefore influences related to project geometry are ignored. Often only one component (a measured or simulated value or relationship) of the groundwater system is evaluated at a time, and this approach omits the evaluation of potential interactions with other components. For example, a spreadsheet could use a simple equation to estimate the aquifer drawdown in one location based on pumping at another location, without considering the potential influence on nearby streams. Therefore, the applicability of this approach is limited to simpler projects or systems that can be more easily simplified for the required analysis.

Simple analytical methods described below can be used to compute groundwater changes such as:

- Using the groundwater storage equation and Darcy's law to calculate change in head and flow to/from neighboring areas, such as:

  From: $Sy = d(Vw)/A*d(h)$

  Obtain: $d(h) = d(Vw)/(Sy.A)$

  Where the variables are defined as:

  Sy: specific yield

  Vw: water volume

  A: cross-sectional area of aquifer

  h: hydraulic head

  Note: d() means "change in"

- Using transient methods to compute recharge over time from a ponded storage basin with a given future climate (precipitation) value
- Using streamflow depletion calculations
- Estimating amount of groundwater discharge to stream
- Using analytical solutions to solve the advection-dispersion equation, which is used to estimate the travel time of a plume given the assumptions of dispersion, adsorption, and first-order biodegradation (for example, using the spreadsheet tool Bioscreen)

For some of the methods described above, existing publicly-available modeling tools can be used (such as those available from the U.S. Geological Survey [USGS] and the U.S. Environmental Protection Agency [EPA]). A compilation of USGS groundwater analysis tools is available at: http://water.usgs.gov/software/lists/groundwater.

Specific tools can also be built using different types of applications or platforms, such as Microsoft Excel, or object-oriented platforms with graphic user interfaces such as GoldSim.

Groundwater budget analysis to compute changes in groundwater storage can be performed using a spreadsheet tool that includes estimates of basin inflows and outflows. Existing spreadsheet tools can be used that include water supply estimates in a given region (or by agency). To develop a new spreadsheet tool for analytical solution, specific data needs include:

- Current and projected water demands and land uses
- All existing water supply sources
- All sources of recharge and discharge to the basin

The spreadsheet tool can then be used for the water budget change assessment by:

- Computing initial water/groundwater balance
- Identifying changes to water supplies based on proposed storage project
- Identifying projected future water demands
- Computing changes in water balance and the resulting changes in groundwater storage

Typical Components of a Groundwater Budget

Water supplies (or inputs to groundwater system) include:

- Infiltration (deep percolation) of precipitation
- Infiltration (deep percolation) from applied (irrigation) water
- Infiltration from surface water systems (stream seepage) or spreading basins
- Subsurface groundwater inflow (e.g., mountain front recharge or lateral inflow from adjacent basins)
- Water injection from wells

Water demands (or outputs from the groundwater system) include:

- Evapotranspiration from vegetation (including crop consumptive use)
- Evaporation from shallow groundwater
- Groundwater extraction (pumping wells for supply)
- Groundwater discharge to surface water sources
- Subsurface groundwater outflow

Some water budget component data (see reference box above) are easily obtainable, computed, or simulated, while others are more challenging to estimate (such as subsurface inflows and outflows). Groundwater models, as described below, are useful tools to estimate complex water budgets with uncertain datasets. Water budget requirements for a GSP are listed in the GSP regulations, paragraph 354.18 (in Subarticle 2).

Pros and cons of using simple analytical methods to compute changes in groundwater are listed in Table 4-2.

Table 4-2. Pros and Cons of Using Simple Analytical Methods to Compute Changes in Groundwater.

Pros	Cons
• Relatively simple to use	• Does not provide change at a larger geographic scale
• Might be appropriate for smaller-scale and simpler projects	• Not appropriate for complex large scale projects
• Inexpensive	• May need a suite of tools to compute all potential changes that may affect public benefits

4.4.6.4 Complex Numerical Methods and Tools

Complex three-dimensional numerical modeling tools are widely used in groundwater flow and contaminant transport analysis to evaluate the change to the groundwater system due to changes in external stresses related to the construction and operation of projects. These numerical models allow for a more realistic representation of the physical system, including geologic layering, complex boundary conditions, stresses due to pumping and recharge, and land use demands. Applicants that propose more complex regional water storage projects should use a numerical groundwater model for the physical change analysis related to benefits and impacts.

Currently, no standardized, regularly-updated and publically-available models exist for most regions outside of the Central Valley. However, stand-alone project-specific and basin-wide models have been developed for projects, applications, and resource management by water agencies (specifically in the Bay Area, Southern California, and Central Coast areas). These models use similar platforms and codes as described below.

Applicants shall use the most recent, readily-available model that is applicable to the proposed project's geographic area. Alternatively, new models can be developed to assess physical groundwater changes due to the proposed project. Several groundwater flow model applications exist, and may be publicly available. Potential groundwater flow modeling approaches include the following:

- Using a locally-developed model based on an existing groundwater model, such as MODFLOW or Integrated Water Flow Model (IWFM)
- Using a project-specific model built and used for the storage project's feasibility analysis or CEQA analysis
- Building a new numerical model specifically to quantify benefits, using an existing groundwater model code such as MODFLOW or IWFM
- Using existing model applications that cover all or large portions of the Central Valley, such as C2VSim, Central Valley Hydrologic Model (CVHM), or SACFEM; a brief description of these models is provided below.

Using a Numerical Model to Quantify Benefits of a Storage Project

Purpose: Use numerical model for calculating change in:

- Water budgets (change in storage) which links to water supply
- Water levels (increase/decrease)
- Interaction with surface water (gaining/losing stream)
- Gradient changes (potential for contaminants to move to other parts of the basin)

Method to quantify physical change:

- Develop or use an existing historical calibrated groundwater flow model, and modify appropriate input datasets to represent future conditions with climate change (as applicable)
- Extract calibrated heads from last stress period in historical model, and use them as initial heads in the future projected model simulation
- Make changes in the model related to the type of storage project proposed:
    - Surface water reservoir:
        - Changes in surface water inflows (from reservoir releases)
        - Changes in surface water deliveries (increase/decrease)
        - Refer to Section 4.3, Surface Water Operations Analysis
    - Groundwater storage:
        - Recharge ponds: simulate as additional recharge at the surface, which would add deep percolation to groundwater storage –include size of pond and depth of ponded water
        - Injection wells (aquifer storage and recovery): include injection wells with assumed injection rate
- Run the model(s)
- Review outputs from changed models and compare to existing conditions model
    - Spatial: water level contour maps, groundwater level change maps, surface water/groundwater interaction maps, flow direction maps, contaminant plume maps, particle tracking maps (as needed)
    - Temporal: hydrographs
    - Numeric: water budgets

Outcome: Assess potential for public benefits from proposed project based on physical changes to groundwater parameters discussed above.

For projects that include groundwater contamination prevention or remediation actions, a numerical transport model may be necessary. Contaminant transport models are described below.

Use of an existing, recently-calibrated regional or local model, whose boundaries include the study area of the proposed water storage project, is recommended, because it is likely the best available tool for simulating the without-project future conditions. Project-specific changes could then be implemented in the model for a with-project future conditions simulation, and the two model simulations could be compared to analyze physical changes due to project implementation.

Existing Central Valley Model Applications

There are currently three existing, calibrated, and actively updated and maintained groundwater model applications that cover all or parts of the Central Valley aquifer. A brief description of these models is provided below. Other regional applications of these models have also been developed for specific purposes; these applications may be appropriate for a proposed project but are not described here.

California Central Valley Groundwater-Surface Water Simulation Model (C2VSim)

DWR developed, maintains, and regularly updates C2VSim. It has been used for several larger-scale Central Valley studies. C2VSim is an integrated numerical model based on the finite element grid IWFM that simulates the movement of water through a linked land surface, groundwater, and surface water flow systems. The C2VSim model includes monthly historical stream inflows, surface water diversions, precipitation, land use, and crop acreage data from October 1921 through September 2009. The model simulates the historical response of the Central Valley's groundwater and surface water flow system to historical stresses, and can also be used to simulate response to projected future stresses (DWR, 2016).

CVHM

CVHM is a three-dimensional numerical groundwater flow model developed by USGS and documented in *Groundwater Availability of the Central Valley Aquifer, California* (USGS, 2009). CVHM simulates primarily subsurface and limited-surface hydrologic processes over the Central Valley at a uniform grid-cell spacing of 1 mile on a monthly basis using data from April 1961 to September 2003. CVHM simulates surface water flows, groundwater flows, and land subsidence in response to stresses from water use and climate variability throughout the Central Valley. It uses the MODFLOW-2000 (USGS, 2000) finite-difference groundwater flow model code combined with a module called the farm process (FMP) (USGS, 2006) to simulate groundwater and surface water flow, irrigated agriculture, and other key hydrologic processes. It can be used in a similar manner to C2VSim.

Sacramento Valley Finite Element Groundwater Flow Model (SACFEM2013)

SACFEM2013 is a high-resolution, numerical groundwater modeling tool developed to estimate the impacts of potential future conjunctive water management projects on surface water and groundwater resources in the Sacramento Valley. SACFEM2013 is built on the finite-element code MicroFEM (Hemker, 1997), which is a three-dimensional, integrated groundwater modeling package. MicroFEM is capable of modeling saturated, single-density groundwater flow in layered systems. SACFEM2013 uses MicroFEM to simulate the groundwater system under confined conditions in all model layers and the agricultural processes are captured using DWR's IDC (integrated water flow model demand calculator). SACFEM2013 simulates transient groundwater flow conditions on a monthly basis using data from 1970 through 2010.

Contaminant Transport Modeling Approaches

Contaminant transport model codes add a layer of complexity beyond what is provided by groundwater flow models. These models allow for the assessment of the potential migration of existing contaminant plumes due to storage project implementation, or the resulting groundwater quality over time after a remediation project is implemented.

These types of models are not as widely used for water resources planning but need to be considered for proposed water storage projects that may affect an existing nearby plume, are designed to prevent contamination, or contain groundwater remediation elements. Particle tracking applications that compute advective paths of simulated particles released at specific locations in the groundwater basin may be acceptable for some of these projects; however, contaminant transport models provide more robust estimates of contaminant fate and transport.

Several publicly-available groundwater transport modeling codes include MODFLOW-Surfact and MT3D, which include processes of advection, dispersion, adsorption, and first-order decay, and RT3D, which includes all of the processes listed above along with sequential reactive transport. The MT3D and RT3D packages are designed to work with standard versions of the MODFLOW code as post-processors to the flow simulation. MODFLOW-Surfact is an integrated flow and transport package that includes additional capabilities for simulating processes such as density-driven flow, subsurface air flow, and non-aqueous phase liquid source behavior. The public-domain model SEAWAT can also be used to evaluate systems where density-driven flow is important for analysis (such as sea-water intrusion).

Land Use and Water Demand Projection Approaches for Groundwater Modeling

Land use and water use projections must be consistent with existing, published projections from state or local planning agencies, modified as needed to represent a specific study area and future conditions in the planning horizon. In particular, water use projections for municipal and agricultural uses must be consistent with the urban and agricultural water management plans of areas served or impacted by the proposed project. If existing plans do not provide the geographic coverage or time frame needed, applicants may use existing datasets or models to estimate projected land and water use. Information can be developed and obtained from sources such as DWR land use surveys, county general plans, and satellite-based estimates of ET rates (e.g., metric calculations). The evaluation of scenarios for future water demand must account for uncertainty due to climate change and other factors, as specified in the quantification requirements of the proposed regulations.

Different approaches may be used to estimate current and projected water demand. Applicants may use DWR's current unit value estimates of crop use and municipal uses (available for download at http://www.water.ca.gov/landwateruse/anlwuest.cfm), adjusted for future conditions. Stand-alone models that estimate crop water use are provided by DWR (http://www.water.ca.gov/landwateruse/models.cfm). Other stand-alone methods are also available. Applicants may also use any data related to land use and ET released by DWR as part of the SGMA program technical assistance.

Another approach uses stand-alone modules that can be used in conjunction with groundwater model codes, or modules built into existing groundwater model codes. These modules are useful if the applicant is using such a groundwater flow model for its analysis. The modules include:

- IDC: the demand calculator used in many IWFM-based models, including C2VSIM
- FMP: the farm process module for MODFLOW-based models (now integrated within MODFLOW-OWHM), including CVHM

These modules compute crop consumptive use which translates into agricultural water demand, and also compute limited urban water demand. Based on the water demand and available supply, these modules estimate the deep percolation of applied water to groundwater past the root zone, which is used by the groundwater flow model simulation. Therefore, these modules provide estimates of important components of the overall water demand and supply projections used in groundwater flow modeling.

Numerical Model Output Examples

Groundwater physical change evaluation and analysis results can be presented through graphic or numeric outputs using existing or customized post-processing tools. Examples of methods for presenting results include:

- Spatial presentation, such as water level contour maps or surface water/groundwater interaction maps
- Temporal presentation, such as a water level hydrograph
- Numeric presentation, such as water budgets or changes in storage calculations

A particle tracking analysis (for example using MODPATH, a post-processing code developed by the USGS for MODFLOW) allows for visual interpretation of groundwater flow lines and changes in groundwater flow directions due to project implementation, and allows assessment of potential inducement of groundwater flow from areas with poor quality water to better quality water. MODPATH is commonly used as a surrogate for groundwater quality modeling. The pros and cons of using numerical methods are listed in Table 4-3.

Table 4-3. Pros and Cons of Using Numerical Methods to Compute Changes in Groundwater.

Pros	Cons
• Provides representation of change at a spatially and temporally distributed scale	• More complex set up; requires knowledge of the computer codes
• Can more accurately depict the specific geometry of the proposed project layout	• More costly; applicants will need specialized expertise
• Can consider more complex distributions of aquifer properties and boundary conditions	• May require the development of post-processing tools for data and results interpretation
• Appropriate for assessing interactions between project and surrounding region; can assess complex large scale regional projects	
• Provides more detailed estimates of water balance components incorporated in simpler tools	
• Provides more detailed estimates of project benefits and potential impacts	

4.4.6.5 Tool Selection Considerations

The selection of a particular tool to evaluate groundwater physical change may be based on the following criteria:

- Project type (surface storage, groundwater storage, conjunctive use, groundwater remediation)
- Benefits to quantify (e.g., water supply, ecosystem, water quality, flood control)
- Physical changes to quantify (groundwater quantity versus groundwater quality)
- Model domain extent versus scale of project
- Model grid resolution versus scale of the project
- Model calibration considerations such as hydrologic variability already incorporated into tool relative to the project timeframe
- Ability of model to evaluate seasonality
- Availability of key input data
- Model complexity/ease of use
- Cost of application/acquisition of model (public domain versus commercially available)
- Tool defensibility/credibility

Table 4-4 summarizes project analysis and method types, and Table 4-5 lists the pros and cons of each method.

Table 4-4. Considerations for Selecting Groundwater Analysis Method.

		Project Type			
		Surface Water Storage	**Groundwater Storage**	**Conjunctive Use**	**Remediation**
Physical Changes		• SW/GW interaction • Groundwater levels/storage	• Groundwater levels/storage • SW/GW interaction	• Groundwater levels/storage • SW/GW interaction • Flow gradient	• Groundwater quality
Tool Selection	**Local Scale**	Simple analytical methods Qualitative approach possible	Simple analytical methods	Local groundwater flow model	Local groundwater flow model with particle tracking
	Regional Scale	Regional groundwater flow model	Regional groundwater flow model	Regional groundwater flow model	Regional groundwater flow and transport model

Table 4-5. Methods, Key Features, and Pros and Cons.

Method or Model	**Key Features**	**Pros**	**Cons**
Qualitative Approaches	• Narrative and deductive logic approach • No computational analysis	• Simple, inexpensive, and quick qualitative evaluation	• No quantification of benefits possible
Simple Analytical Methods (e.g. USGS, EPA tools)	• Analytical solutions to the groundwater flow equation requires associated assumptions that significantly simplify the physical system being evaluated. • Can compute water budgets	• Relatively simple and cost-efficient to use • Might be appropriate for smaller scale and simpler projects	• Does not provide change at a larger geographic scale • Not appropriate for complex large-scale projects • Application requires significant simplification of site geometry, boundary conditions, and hydrogeologic properties; limits representativeness of results.
Complex Numerical Groundwater Flow Models (e.g. C2VSim, CVHM, SACFEM)	• Allow for a more realistic representation of the physical system including geologic layering, boundary conditions, stresses due to pumping and recharge, land use demands, etc. • Appropriate for large scale complex projects	• Provides representation of change at a spatially and temporally distributed scale • Appropriate for assessing interactions between project and surrounding region; can assess complex large scale regional projects • Provides more detailed estimates of water balance components incorporated in simpler tools	• More complex set up; requires some knowledge of the computer codes • More costly; applicants will need specialized expertise • May require the development of post-processing tools for data and results interpretation

Table 4-5. Methods, Key Features, and Pros and Cons.

Method or Model	Key Features	Pros	Cons
Complex Numerical Contaminant Transport Models (e.g. MODFLOW-SURFACT, MT3D, RT3D)	• Allow for the assessment of the potential migration of existing contaminant plumes due to storage project implementation, or the resulting groundwater quality over time after a remediation project is implemented.	• Provides representation of groundwater quality change at a spatially distributed scale • Quantifies subsurface plume reductions	• Need to first build or utilize a calibrated numerical flow model • Requires additional inputs and assumptions regarding nature and magnitude of contaminant releases – information often not readily available • No regional scale transport models of the Central Valley currently exist.

Table 4-6 summarizes commonly used groundwater modeling tools.

Table 4-6. Summary of Groundwater Modeling Tools and Resources.

Model Code or Application				
MODFLOW	Finite-difference groundwater flow code; several versions available with related modules.	http://water.usgs.gov/ogw/modflow/	Current core version is MODFLOW -2005: USGS. 2005. MODFLOW-2005, The U.S. Geological Survey Modular Ground-Water Model—the Ground-Water Flow Process. USGS Techniques and Methods 6–A16	USGS
MODFLOW - OWHM	MODFLOW based integrated hydrologic flow model (One Water Hydrologic Flow Model)	http://water.usgs.gov/ogw/modflow-owhm/	USGS. 2014, One-Water Hydrologic Flow Model (MODFLOW-OWHM). U.S. Geological Survey Techniques and Methods 6-A51.	USGS
MODPATH	Particle-Tracking post-processing tool for MODFLOW	http://water.usgs.gov/ogw/modpath/	USGS. 2012, User guide for MODPATH version 6—A particle-tracking model for MODFLOW: U.S. Geological Survey Techniques and Methods, book 6, chap. A41	USGS
CVHM	MODFLOW application for the Central Valley Aquifer	http://ca.water.usgs.gov/projects/central-valley/central-valley-hydrologic-model.html	U.S. Geological Survey. 2009. *Groundwater Availability of the Central Valley Aquifer, California*. U.S. Geological Survey Professional Paper 1766. Groundwater Resources Program. Reston, VA.	USGS

Table 4-6. Summary of Groundwater Modeling Tools and Resources.

Model Code or Application				
IWFM	Finite-element code for integrated water resources modeling	http://baydeltaoffice.water.ca.gov/modeling/hydrology/IWFM/	DWR, 2016. *Integrated Water Flow Model: IWFM -2015, Theoretical Documentation*, Central Valley Modeling Unit Support Branch Bay-Delta Office	DWR
C2VSIM	IWFM application for the Central Valley Aquifer	http://baydeltaoffice.water.ca.gov/modeling/hydrology/C2VSim/index_C2VSIM.cfm	Brush, C.F., and Dogrul, E.C. *June 2013*. User Manual for the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim), Version 3.02-CG.	DWR
MicroFEM	Finite-element groundwater flow code	http://www.microfem.com/	Hemker, C.J., MicroFEM for Windows – Short User's Guide	Dr. C.J. Hemker
SACFEM	MicroFEM application for the Sacramento Valley Groundwater Basin		Reclamation. 2015. SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model User's Manual	CH2M
IDC	Stand-alone executable version of IWFM root zone component (IWFM Demand Calculator)	http://baydeltaoffice.water.ca.gov/modeling/hydrology/IDC/index_IDC.cfm	DWR, 2016. IWFM Demand Calculator: IDC-2015, Theoretical Documentation and User's Manual, Central Valley Modeling Unit Support Branch Bay-Delta Office	DWR
INFIL 3.0	Watershed model to estimate net infiltration below the root zone	http://water.usgs.gov/nrp/gwsoftware/Infil/Infil.html	U.S. Geological Survey, 2008, Documentation of computer program INFIL3.0-A distributed-parameter watershed model to estimate net infiltration below the root zone: U.S. Geological Survey Scientific Investigations Report 2008-5006.	USGS
BIOSCREEN	Screening model that simulates remediation through natural attenuation	https://www.epa.gov/water-research/bioscreen-natural-attenuation-decision-support-system	EPA (1996) "BIOSCREEN, Natural Attenuation Decision Support System - User's Manual, Version 1.3 (PDF)." (100 pp, 1.15 MB, About PDF) Publication No. EPA/600/R-96/087. August 1996	EPA

Table 4-6. Summary of Groundwater Modeling Tools and Resources.

Model Code or Application				
MODFLOW-Surfact	Groundwater flow and transport simulation software based on MODFLOW	https://www.hgl.com/expertise/modeling-and-optimization/software-tools/modflow-surfact/ http://www.swstechnology.com/novametrix/index.php?option=com_k2&view=item&id=7:modflow-surfact-flow-and-transport	Panday, S. and Huyakorn, P.S., 2008. MODFLOW SURFACT: A state-of-the-art use of vadose zone flow and transport equations and numerical techniques for environmental evaluations. *Vadose Zone Journal*, *7*(2), pp.610-631.	HydroGeoLogic Inc.
MT3D	Modular 3-D Multi-Species Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems. Post-processing code to MODFLOW for transport modeling.	http://hydro.geo.ua.edu/mt3d/	Zheng, Chunmiao, 2010, *MT3DMS v5.3 Supplemental User's Guide*, Technical Report to the U.S. Army Engineer Research and Development Center, Department of Geological Sciences, University of Alabama, 51 p	University of Alabama
RT3D	Modular Code for Simulating Reactive Multi-species Transport in 3-Dimensional Groundwater Systems. Post-processing code to MODFLOW for transport modeling.	http://bioprocess.pnnl.gov/rt3d.downloads.htm#doc	Clement, P. T, 1997, A Modular Computer Code for Simulating Reactive Multi-species Transport in 3-Dimensional Groundwater Systems, Pacific Northwest National Laboratory	Pacific Northwest National Laboratory
SEAWAT	MODFLOW MT3D based model designed to simulate three-dimensional variable-density groundwater flow.	http://water.usgs.gov/ogw/seawat/	Langevin, C.D., SEAWAT: a computer program for simulation of variable-density groundwater flow and multi-species solute and heat transport: U.S. Geological Survey Fact Sheet FS 2009-3047, 2 p.	USGS

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4.5 Riverine Hydrologic/Hydraulic Analysis

This document describes the public and non-public benefits, physical changes, and modeling methods/approaches/tools associated with riverine systems. The effects on riverine systems of potential water storage projects funded by the WSIP are briefly described. Then, potential public and non-public benefits resulting from physical changes in riverine systems are described. This is followed by a description of modeling methods and tools that applicants can consider to evaluate their projects' effects. The physical changes analyzed through riverine hydrology and hydraulics provide a necessary link between water storage project operations and resulting benefits. See other sections of this document about the specific benefit categories, and to understand how results and metrics produced by the riverine analysis are used to quantify those benefits.

4.5.1 General Setting and Methods

This section provides a general setting of potential water storage projects funded by the WSIP and summarizes methods for analyzing riverine systems affected by them.

4.5.1.1 Types of Storage Projects and How They May Affect Riverine Systems

All water storage projects, surface water and groundwater, will have a direct effect on riverine systems. Changes in river flow resulting from the operation of such projects can cause (directly or indirectly) changes in: stage (water surface elevation relative to a reference point on a gage), velocity, sediment transport, and river geomorphology. Surface water projects, whether on stream or off stream, will result in changes to stream flows. Groundwater storage projects will affect the water table of nearby streams (discussed in Section 4.4, Groundwater Analysis) and may also divert streamflow for groundwater recharge during some periods and deliver water back to streams (or reduce diversions) in other periods. Changes with respect to water quality are described in Section 4.8, Water Quality Analysis.

4.5.1.2 Overview of Methods

There are several methods to analyze physical changes in a riverine system due to a water storage project:

- A qualitative approach uses known physical relationships among flow, stage, velocity, channel configuration, and other characteristics to assess directions and relative magnitudes of changes. Qualitative approaches can provide indications on whether a proposed project is likely to have a positive or negative effect on a physical metric, but do not quantify the effect.

- Analytical tools, such as a mass balance calculation or a rating curve, solve one or more equations to calculate a change in a physical metric resulting from a proposed project. This approach generally relies on a large set of simplifying assumptions to calculate quantified physical changes. Due to the simplifying assumptions, use of these tools should be limited to simplified representations of the river system.
- Numerical models such as hydrologic, hydraulic, sediment transport, or geomorphic models provide more detailed analyses of flow and other physical changes. They attempt to incorporate all of the important physical phenomena and relationships needed to quantify changes in a complex system, and rely on simplifying assumptions as little as possible. Application of numerical models requires modeling expertise.

4.5.2 Riverine Physical Changes

Physical changes in riverine systems must be analyzed using models or other methods that produce the necessary outputs to support subsequent analysis of physical and monetized benefits. Outputs may include: flow, stage, velocity, sediment transport, and geomorphic changes. Model outputs may directly show incremental changes needed for subsequent analysis, or they may need to be post-processed to display the required information (e.g., developing a flow-frequency curve based on flow-time series outputs). The following sections describe typical outputs of physical changes from hydrologic, hydraulic, sediment transport and geomorphic models.

4.5.2.1 Flows

Water storage projects will change streamflow. A storage project will reduce flow in the river during periods when storage is filling, and it will increase flow in the river when water is being released from storage for instream uses or for diversion further downstream. These changes are expressed using frequency curves, or flow hydrographs, and statistics/plots relating frequency, magnitude, timing, and duration of flow. Depending on the approach and the purpose of the analysis, flow data time steps range from months to minutes. For example, monthly time step flow data are adequate to describe the effects of water storage operations on water supply and recreation benefits or impacts. However, shorter time step flow data is required to quantify physical changes related to flood control, water quality, and ecosystem benefits or impacts. Furthermore, other riverine analyses (e.g., sediment transport and geomorphology) require even shorter time step flow data as an input. Please refer to the water quality, water supply, recreation, and ecosystem sections for information on quantifying the benefits associated with these physical changes.

4.5.2.2 Stage

Changes in river stage resulting from a water storage project are related to changes in river flow and channel geometry. Quantification of changes in river stage requires an analytical tool (such as a rating curve – graph of flowrate vs. stage relationship) or a numerical hydraulic model. Similar to flow, stage data are expressed using frequency curves, or stage hydrographs. Water surface profiles (along a channel at a given time) are also useful for interpreting stage. A detailed analysis of flood control operations requires a frequency analysis of stream stage and flow at an hourly time step. Stage and geometry data can used to determine the wetted perimeter at a location of interest. Stage data can also be used to show ecosystem benefits by providing a frequency curve indicating an increased probability of floodplain inundation.

4.5.2.3 Velocity

Velocity is a function of the flow, cross-sectional shape, slope, and roughness of a channel. Although velocity varies horizontally and vertically in a channel cross section, one-dimensional models (which are commonly used for river modeling) only provide a cross section average of velocity. A vertical velocity distribution can be estimated based on a cross section average of velocity. This method is only accurate in channels of more uniform depth across the channel width. Horizontal and vertical velocity distributions can be used to estimate the velocity of the flows at the channel bottom (affecting sediment transport and substrate vegetation) and in the floodplains.

4.5.2.4 Sediment Transport and Geomorphology

Sediment transport describes the movement of sediment in the form of bed load (movement along the channel bottom), and suspended load (sediment moving within the water column). Sediment transport can change the topographic and bathymetric features of a river over time, and therefore it is a key driver of channel geomorphology of a river. Flow and velocity outputs from hydraulic models are used as inputs to geomorphic models to calculate changes in a river’s geomorphology (river bend [or meander] migration, areas of erosion and deposition, and floodplain topography). Modeling changes in shear stress, as a result of a water project, on the channel bottom indicates the degree to which constituents are being suspended into the water column, resulting in water quality benefits or impacts. Hydrologic and hydraulic models provide changes in shear stress with empirical and physical equations, respectively. Geomorphic models provide changes in shear stress as well as the effects of shear stress on sediment transport and geomorphology over a long time scale.

4.5.3 Benefits Related to Riverine Physical Changes

This section describes the benefits or impacts that could result from physical changes in riverine systems caused by water storage projects. Several examples of benefits are included, but the list is not exhaustive, and of course impacts must also be quantified. The applicant needs to select appropriate metrics of physical changes in riverine systems to quantify the benefits or impacts of the proposed project.

Physical riverine hydrologic and hydraulic (H&H) changes related to water supply are flow and stage, which affect diversions for water supply.

Physical riverine H&H changes related to ecosystem conditions are:

- Flow: Influences total habitat area and the ability of fish to pass unscreened water diversions
- Stage: Influences extent and quality of fish rearing habitat
- Velocity: Influences migration time and suitable habitat for aquatic species
- Sediment transport and river geomorphology: Affects aquatic habitat area and quality

Physical riverine H&H changes related to water quality are:

- Flow and velocity: Affect the rate of dilution of constituents
- Sediment transport and geomorphology: Erosion and deposition of sediments influence the quantity of constituents in the water column

Physical riverine H&H changes related to flood control are:

- Flow and stage: Influences the timing and quantity of peak flow/stage of a given rain event
- Stage: Affects the location at which the maximum flood stage occurs
- Velocity and turbulence: Affect the stability of levees and other structures

Physical riverine H&H changes related to recreation include flow as related to changes that control the quantity and quality of in-water sports (i.e., rafting, paddling, swimming) and recreational fishing.

Physical riverine H&H changes related to emergency response include understanding the channel flow capacity for providing water for firefighting, or maintaining freshwater in the Delta.

4.5.4 Methods, Approaches and Tools for Quantifying Physical Changes Related to Riverine Systems

This section identifies and describes the various approaches and tools for computing physical changes related to riverine systems. The list of approaches does not encompass all of the potential options. Other acceptable methods for calculating physical changes to riverine systems may be used. Any method used must be described and justified.

4.5.4.1 General Analysis Considerations

When deciding on a tool to quantify physical changes, applicants must consider the water storage project operations and benefits, the riverine processes that must be assessed to demonstrate those benefits, and the spatial and temporal extent of the physical changes. Figure 4-5 provides a flowchart for choosing an appropriate modeling approach. The following sections describe possible modeling approaches and the pros and cons associated with each approach.

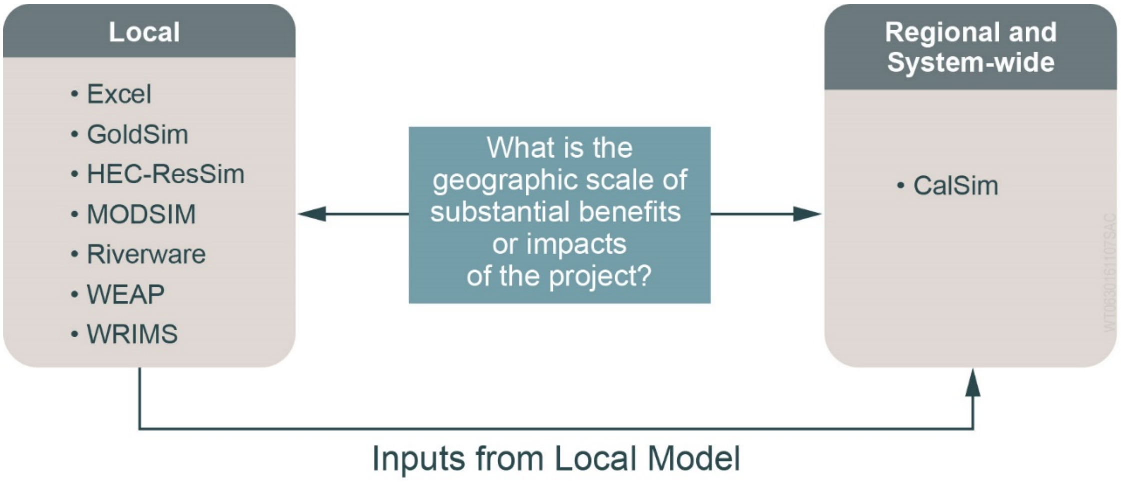

Figure 4-5. Flow Chart for Determining Appropriate Approach.

4.5.4.2 Qualitative Approaches

Qualitative approaches refer to methods that can assess the general direction of change and possibly the relative magnitude of change shift in a physical phenomenon. They are simple to employ but do not provide quantified results. Qualitative approaches can provide indications on whether a proposed project is likely to have a positive or negative effect on a physical metric. In particular, a qualitative approach may be used to determine whether a positive or negative effect is potentially large enough to warrant additional, quantitative analysis.

4.5.4.3 Analytical Methods and Tools

Analytical methods typically use spreadsheets or computer codes that solve one or more equations to calculate a change in a physical metric resulting from a proposed project. Rating curves, mass balance calculations, paired-basin comparison, vertical velocity distribution equations, sediment discharge curves, steady state flow equations, and simple flow routing tools are examples of analytical methods. These methods are usually designed to solve a specific problem without requiring large amounts of data and computation. With the exception of some flow routing methods, they do not account for physical properties of riverine channels (roughness, slope, etc.). This approach generally relies on a large set of simplifying assumptions to calculate quantified physical changes.

Due to the simplifying assumptions, use of these tools should be limited to simplified representations of the river system. For example, if a storage project does not change the channel geomorphology, a rating curve can be developed based on historical data. Once developed, the rating curve can be used to calculate flow data from stage data at locations of interest. Similarly, the assumptions of the other analytical methods must be accounted for when they are employed.

4.5.4.4 Numerical Methods and Tools

Numerical methods and tools require more resources and modeling expertise. The method selection depends on the complexity of the water storage operations and the affected resources. The numerical models and tools consist of hydrologic models, hydraulic models, and sediment transport/geomorphic models. Each of these tools calculates different physical changes in riverine systems based on different inputs or governing equations. The applicant must identify and select the appropriate model(s) for estimating expected physical changes in riverine systems. Commonly used numerical models are tabulated in Table 4-7. More models are described in the Compendium of Tools for Watershed Assessment and TMDL Development by the EPA (1997). The document “summarizes the available models and tools that can be used to support watershed assessment and TMDL development. The document includes a wide range of tools and offers selection criteria to assist the user in choosing the model(s) appropriate for a particular application” (EPA, 1997).

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Table 4-7. Summary of Riverine Modeling Tools and Resources.

Model Code or Application	Description	Key Inputs and Assumptions	Outputs	Download and Documentation	Maintained By	Other Considerations
WEAP	Hydrologic model; simulates hydrologic processes, water quality and economics; Planning tool	Hydrology, Water Demands, Regulations, Climate, Economics	Flows, demands, storages, soil moisture, water quality, and finances	• http://www.weap21.org/index.asp?action=40 • http://www.weap21.org/downloads/WEAP_User_Guide.pdf	Stockholm Environment Institute	• Not open source • Free for non-commercial use • Planning and management tool • Water quality capabilities
HEC-HMS	Hydrologic model; simulates hydrologic processes; provides multiple options for simulating hydrologic processes	Hydrology, Physical Characteristics, Climate	Flows, soil moisture, water quality	• http://www.hec.usace.army.mil/software/hec-hms/downloads.aspx • http://www.hec.usace.army.mil/software/hec-hms/documentation.aspx	HEC	• Open source • Water quality and sediment capabilities
SWAT	Hydrologic model; simulates hydrologic processes, and sediment, nutrient and pesticide yields	Hydrology, Water Demands, Climate	Flows, soil moisture, water quality, carbon cycle	• http://swat.tamu.edu/ • http://swat.tamu.edu/documentation/2012-io/	U.S. Department of Agriculture Agricultural Research Service (USDA-ARS)	• Open source • Planning and management tool • Water quality capabilities
MIKE HYDRO BASIN	Hydrologic model; simulates hydrologic processes, water quality and economics; Planning tool	Hydrology, Water Demands, Regulations, Climate, Economics	Flows, demands, storages, soil moisture, water quality, and finances	• http://www.mikepoweredbydhi.com/download/mike-2016/mike-hydro-basin?ref={181C63FF-2342-4C41-9F84-F93884595EF3} • http://dssplanning.dhigroup.com/links/MIKEBASIN_UserManual.pdf	DHI	• Not open source; free • Planning and management tool
HEC-ResSim	Hydrologic model; simulates hydrologic processes and reservoir operations; Reservoir operations planning tool	Hydrology, Physical Characteristics, Operating Rules, other inputs depend on type of analysis	Flows and storages	• http://www.hec.usace.army.mil/software/hec-ressim/downloads.aspx	HEC	• Open source • Reservoir based planning and management tool
HSPF	Hydrologic model; simulates hydrologic processes and water quality	Hydrology, Climate	Flows, soil moisture, water quality, and sediment transport	• http://water.usgs.gov/software/HSPF/	USGS	• Open source • Planning and management tool • Water quality and sediment transport modeling capabilities
WARMF	Hydrologic model; simulates hydrologic processes and water quality (nutrients, bacteria, dissolved oxygen, sediment transport and algae)	Hydrology, Demands, Regulations, Climate	Flows, soil moisture, water quality, and sediment transport	• Contact information at: http://www.systechengineering.com/Warmf_Availability.html • http://www.systechengineering.com/Warmf_Publications.html#top	Systech Water Resources, Inc.	• Not open source • Combines hydrologic modeling with water quality and sediment transport
VIC	Hydrologic model; simulates hydrologic processes, irrigation demand, and reservoir operations	Hydrology, Climate	Flows, soil moisture, carbon cycle	• http://www.hydro.washington.edu/Lettenmaier/Models/VIC/SourceCode/Download.shtml • http://www.hydro.washington.edu/Lettenmaier/Models/VIC/Overview/ModelOverview.shtml	University of Washington	• Open source
SAC-SMA	Hydrologic model; simulates hydrologic processes	Hydrology, Climate	Flows, soil moisture	• http://www.nws.noaa.gov/iao/iao_hydroSoftDoc.php	National Oceanic and Atmospheric Administration (NOAA)	• Open source
RiverWare	Hydrologic model; simulates hydrologic processes, reservoir operations, water quality, hydropower, and flood control	Hydrology, Physical Characteristics, Operating Rules, other inputs depend on type of analysis	Flows and Storages	• http://www.riverware.org/	CADSWES	• Proprietary
HEC-RAS	1D hydraulic model; simulates flows, stage, velocities, water quality, and sediment transport based on input flow/stage	Flow/Stage, Channel and Floodplain Geometry, Roughness	Flow, Velocity, Stage, Sediment Transport, Temperature	• http://www.hec.usace.army.mil/software/hec-ras/downloads.aspx • http://www.hec.usace.army.mil/software/hec-ras/documentation.aspx	HEC	• Open source

Table 4-7. Summary of Riverine Modeling Tools and Resources.

Model Code or Application	Description	Key Inputs and Assumptions	Outputs	Download and Documentation	Maintained By	Other Considerations
MIKE HYDRO RIVER	1D hydraulic model; simulates flows, stage, velocities, water quality, reservoir operations, and sediment transport based on input flow/stage	Flow/Stage, Channel and Floodplain Geometry, Channel Roughness	Flow, Velocity, Stage, Sediment Transport, Water Quality, Geomorphology	• https://www.mikepoweredbydhi.com/download/mike-2016/mike-hydro-river?ref={181C63FF-2342-4C41-9F84-F93884595EF3} • Software comes with user guide	DHI	• Free
DSM2	1D hydraulic model; simulates flows, stage, velocities, water quality, and particle tracking based on input flow/stage	Flow/Stage, Channel and Floodplain Geometry, Channel Roughness	Flow, Velocity, Stage, Water Quality	• http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm	DWR	• Open source
HEC-RAS 2D	2D hydraulic model; simulates flows, stage, velocities, water quality and sediment transport based on input flow/stage	Flow/Stage, Channel and Floodplain Geometry, Roughness	Flow, Velocity, Stage, Sediment Transport, Water Quality	• http://www.hec.usace.army.mil/software/hec-ras/downloads.aspx • http://www.hec.usace.army.mil/software/hec-ras/documentation.aspx	HEC	• Open source • Option to run 2D Saint Venant equations or 2D Diffusion Wave equations • Implicit finite volume solver
SRH	Package of models including: hydraulic (1D/2D) model, river meander model	Flow/Stage, Channel and Floodplain Geometry, Roughness, Bed Material, Sediment Loads	Flow, Velocity, Stage, Water Quality, Sediment Transport, Geomorphology, Riparian Vegetation Establishment	• Contact information at: http://www.usbr.gov/tsc/tscorganization/8200.html • User manual is attainable through contact	Reclamation	• Open source • 1D and 2D hydraulic, vegetation, and river meander models available
MIKE 21	2D hydraulic model; simulates flows, stage, velocities, water quality, particle tracking, sediment transport and geomorphology based on input flow/stage	Flow/Stage, Channel and Floodplain Geometry, Bed Material	Flow, Velocity, Stage, Water Quality, Sediment Transport, Geomorphology	• https://www.mikepoweredbydhi.com/download/mike-2016/mike-21?ref={181C63FF-2342-4C41-9F84-F93884595EF3} • Software comes with user guide	DHI	• Free • Transport of bed load (ST), erosion/deposition (MT), and suspended sediment (PT) modules are available
RMA2	2D hydrodynamic model; simulates flows, stage and velocities based on input flow/stage	Flow/Stage, Channel and Floodplain Geometry	Flow, Velocity, and Stage	• http://chl.erdc.usace.army.mil/rma2 • http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=ARTICLES;480	Coastal Hydraulics Laboratory (CHL)	• Free • Time-step is not limited by model structure
CMS-FLOW	2D hydrodynamic model; simulates flows, stage, velocities, sediment transport, and geomorphology based on input flow/stage	Flow/Stage, Channel and Floodplain Geometry, Bed Material	Flow, Velocity, Stage, Water Quality, Sediment Transport, Geomorphology	• http://cirpwiki.info/wiki/CMS_Releases#Releases • http://cirpwiki.info/wiki/CMS	Coastal Inlets Research Program (CIRP)	• Free
FESWMS-2DH	2D hydrodynamic model; simulates flows, stage and velocities based on input flow/stage	Flow/Stage, Channel and Floodplain Geometry	Flow, Velocity, and Stage	• http://water.usgs.gov/software/FESWMS-2DH/ • http://water.usgs.gov/cgi-bin/man_wrdapp?feswms-2dh	USGS and Federal Highway Administration (FHWA)	• Free
Nays2DH of iRIC	2D hydraulic model; simulates flows, stage, and velocity for sediment transport and geomorphic changes	Flow/Stage, Channel and Floodplain Geometry, Roughness, Bed Material, Sediment Loads	Flow, Velocity, Stage, Sediment Transport, Geomorphology	• Contact information at: • http://i-ric.org/en/contact • User manual is attainable through contact	iRIC	• Proprietary
FLO-2D	2D hydrodynamic model; simulates flows, stage and velocities based on input flow/stage	Flow/Stage, Channel and Floodplain Geometry	Flow, Velocity, Stage, Sediment Transport, Geomorphology	• http://www.flo-2d.com/ • http://www.flo-2d.com/download/	FLO-2D	• Proprietary

Hydrologic Models

Hydrologic models are common tools for watershed scale studies and can simulate the full hydrologic process. They provide flow time series data at various locations along channels based on inflow time series (or precipitation events), routing method, antecedent soil moisture, soil conductivity and other hydrologic processes. These hydrologic processes are modeled with empirical relationships. The runoff, due to precipitation, is translated into streamflow. Streamflow is routed with methods that conserve mass, and could use at least one parameter to attenuate flow. Some hydrologic models do not attenuate flow. They route flow by setting a time lag value, or a specified time it takes for water to travel the length of a reach, for each reach. The time step of a hydrologic model can vary from minutes to months. The temporal extent can range from a precipitation event of a few days to several decades. The spatial extent can be quite large (e.g. Delta Watershed) and the model's spatial resolution depends on the interest of the analysis and the geographic area affected by the project.

Hydrologic models can simulate flows on channels (routing), precipitation-runoff events, infiltration losses, base flow, and sediment transport, based on empirical relationships. They can provide estimates of stage and velocity with empirical equations that use the flow output data.

Commonly used hydrologic models include:

- WEAP – A planning tool to calculate water demand, supply runoff, infiltration, crop requirements, flows, and storage, and pollution generation, treatment, discharge and instream water quality under varying hydrologic and management scenarios (Stockholm Environment Institute, 2016).
- Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) – A physically based hydrologic tool. It simulates the complete hydrologic processes of watershed systems. HEC-HMS provides multiple options for simulating infiltration, routing, evapotranspiration, snowmelt, and other hydrologic processes (USACE-HEC, 2015).
- SWAT – Simulates water, sediment, nutrient and pesticide yields on large river basins (Neitsch et al., 2011).
- MIKE HYDRO BASIN – Simulates water allocation and shortage problems, climate change impact, conjunctive use, reservoir and hydropower operations optimization, and integrated water resources management studies (DHI, 2016a).
- Hydrologic Engineering Center Reservoir System Simulation (HEC-ResSim) – Models reservoir operations for flood management, water supply for planning studies, detailed reservoir regulation plan investigations, and provides real-time decision support (USACE-HEC, 2013).
- Hydrological Simulation Program – FORTRAN (HSPF) – HSPF simulates the hydrologic, and water quality processes in urban and rural watersheds. It also provides routing of flow in streams (USGS, 2016).

- WARMF – WARMF simulates hydrologic processes, but focuses on water quality: nutrients, bacteria, dissolved oxygen, sediment transport, and algae (Systech Water Resources, 2010).
- Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model –VIC simulates the physical processes in the hydrologic cycle with a mass and energy balance approach. It models irrigation demand, and reservoir operations (Gao et al., 2010).
- Sacramento Soil Moisture Accounting (SAC-SMA) – A hydrologic model that calculates discharge based on precipitation, evaporation and air temperature. “The model is ideal for large drainage basins and uses multiple years of records for calibration” (Dworak, 2012).
- RiverWare – A reservoir and river modeling software tool that simulates and optimizing reservoir operations. It accounts for reservoir operations, water quality, hydropower, and flood control (CADSWES, 2016).

Hydraulic Models

Hydraulic models provide flow, stage and velocity outputs based on the following inputs: flow and/or stage boundary conditions, channel and floodplain geometry, and channel roughness. Typically, hydraulic models for rivers and channels are based on a simplified version of the Navier-Stokes equations, where mass, energy, and, in some cases, momentum are conserved. The temporal extent of hydraulic models may range up to several years or decades, or are shorter term to model indicative flow events. Hydraulic models usually use a time step of minutes or seconds. Some hydraulic models are coupled to sediment transport/geomorphic models, meaning that the bathymetry is updated periodically such that the calculated hydraulics reflect the ongoing evolution of the channel bed. Hydraulic models for riverine conditions are usually either one- or two-dimensional. Typically, three-dimensional models are not used for applications of a large spatial scale, but can be employed for modeling small river reaches. They are not discussed in this document.

One-dimensional (1D) hydraulic models can be used for modeling river flow. 1D models not only provide stage and velocity, but can also provide sediment transport (channel dredging, levee, and encroachment alternatives). 1D hydraulic models do not provide horizontal velocity distributions (i.e., the velocity is horizontally averaged) or accurate floodplain inundation (defer to 2D models). A list of commonly used 1D hydraulic models is provided below:

- Hydrologic Engineering Center – River Analysis System (HEC-RAS) – HEC-RAS contains components for: “steady flow water surface profile computations; one- and two-dimensional unsteady flow simulation; movable boundary sediment transport computations; and water quality analysis” (USACE-HEC, 2016).
- MIKE HYDRO RIVER – MIKE HYDRO River simulates: flooding, dam breaks, reservoir optimization, water quality, sediment transport and long term assessment of river morphology changes (DHI, 2016b).

- DSM2 – DSM2 can calculate stages, flows, velocities, and transport processes: salts, some non-conservative constituents, temperature, and particles (DWR, 2016). It consists of three separate models: HYDRO (flow, stage, velocity), QUAL (water quality and temperature), and PTM (particle tracking).

When considering outputs relevant to floodplain inundation or flow in cases where understanding of flow in two directions is important, two-dimensional (2D) models are required. They provide all of the same outputs as 1D models with increased (horizontal) resolution. Although they do not provide vertical velocity distributions, there are several empirical methods to estimate bed shear, which is useful for sediment transport analysis. A list of commonly used 2D hydraulic models is provided below:

- HEC-RAS 2D – HEC-RAS contains components for: “steady flow water surface profile computations; one- and two-dimensional unsteady flow simulation; movable boundary sediment transport computations; and water quality analysis” (USACE-HEC, 2016).
- Sedimentation and River Hydraulics Two-Dimensional Model (SRH-2D) – SRH has one- and two- dimensional hydrodynamic, sediment transport, water quality, and vegetation modeling capabilities (Reclamation, 2008).
- MIKE 21 – A modeling system for 2D free-surface flows, sediment transport, particle tracking, and geomorphology (DHI, 2007).
- RMA 2 – RMA2 computes stage, flow, velocity in two dimensions (CHL, 2016).
- Coastal Modeling System (CMS)-FLOW – CMS-FLOW provides the same outputs at RMA2, but includes sediment transport and geomorphic processes detailed below.
- Finite-element surface-water modeling system for two-dimensional flow in the horizontal plane (FESWMS-2DH) – A two-dimensional model that simulates water flow, stage, and velocity (Froehlich, 1989).
- FLO-2D – FLO-2D is a flood model that simulates channel flow and overland flow (FLO-2D, 2016).

Sediment Transport and Geomorphic Models

Sediment transport models provide an estimation of changes in suspended sediment load and bed load due to changes in hydraulics. Geomorphic models provide change in channel shaping, or meandering outputs. The sediment transport and geomorphic models listed below are coupled with hydraulic models. A list of commonly used sediment transport and geomorphic models is provided below:

- SRH – “A two-dimensional hydraulic, sediment, temperature, and vegetation model for river systems” (Reclamation, 2008).
- International River Interface Cooperative (iRIC) – A computational model for simulating horizontal two-dimensional flow, sediment transport, morphological changes of bed and banks in rivers (iRIC, 2010).

- HEC-RAS 1D – A description of the model is provided above. It should be noted that HEC-RAS 1D has sediment transport modeling capabilities.
- MIKE HYDRO RIVER – A description of the model is provided above. It should be noted that MIKE HYDRO RIVER has sediment transport and geomorphic modeling capabilities.
- CMS-FLOW – A hydrodynamic model coupled with a sediment transport and geomorphic model. Typically applied are in coastal areas.
- MIKE 21 – A description of the model is provided above. It should be noted that MIKE 21 has sediment transport and geomorphology capabilities.

4.5.4.5 Numerical Model Output Examples

Simulation results must be compiled into understandable figures and tables to quantify the physical changes as a result of a water storage project. Numerical models vary greatly in the amounts and kinds of output they produce. Many require additional processing of model outputs (post-processing) to produce results that can be used directly in subsequent analyses. The post-processing methods described below do not encompass all options. There are many ways to process and display results, and the method selected depends on the quantification needs for a particular project. Typically, outputs (figures and tables) describe a physical change using either temporal or spatial units of measurement but not both. A numerical or probabilistic representation of results is also common. An example of a numerical output is through indicators of hydrologic alteration, where values are assigned to each indicator based on the quantity of change in flows. A probabilistic representation of results could be a frequency curve that shows the probability of equaling or exceeding a value of a variable, like stage, flow, or inundation area (for an example of an exceedance plot, see Figure 4-8). Applicants must determine the required set of outputs, at the appropriate temporal and spatial scales needed to support quantification of benefits, and either select a method that provides all of those needs, or post-process the model results in order to meet those needs.

A list of common outputs of numerical models, organized by spatial (showing change in location at a single time), temporal (showing change in time at a single location), and numeric/probabilistic (showing a set of numbers or tables) presentation is provided below:

- Spatial presentation (1D longitudinal profiles or 2D contours)
    - Water surface profiles
    - Horizontal/vertical velocity distribution
    - Shear stress
    - Mass bed change profiles
    - Mass bed change at a cross section
    - River meander

- Temporal presentation
    - Flow/stage hydrograph at a location of interest
    - Inundation area over time (could be probabilistic)
    - Wetted perimeter (could be probabilistic)
    - Shear stress
    - Mass bed change time series
- Numeric/probabilistic presentation
    - Frequency curve for stage and flow
    - Indicators of hydrologic alteration: changes in magnitude, duration, timing, frequency and rate of flows (Refer to Gao et al., 2009 for details concerning the statistics)

4.5.4.6 Tool Selection Considerations

Based on the physical changes of interest (and their related benefits/impacts), some models/tools are more appropriate than others. The following should be considered when selecting a model:

- Available data
- Water storage project operations and benefits
- Desired processes to be modeled
- Required inputs
- Desired simulation period
- Spatial extent
- Model complexity
- Available resources (computationally and available time)

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4.6 Delta Hydrodynamics/Hydraulic Analysis

This section describes concepts of physical change and modeling methods to assess the nature and magnitude of physical changes in the Delta created or caused by water storage projects. The relationship between a water storage project's operation and Delta hydrodynamics is first established to provide perspective on the application of hydrodynamic models. Then, potentially important physical changes, categorized by model output variables, are listed. Modeling approaches/methods are then described so applicants may evaluate their options. Applicants are referred to the other sections of this document to learn about those benefits associated with physical changes in the Delta.

4.6.1 Relationship between Project Operations and Delta Hydrodynamics

Project type and operations can result in many different physical changes to the Delta. All considerations related to sea-level rise and climate change are discussed in Appendix A. Projects within or upstream of the Delta have the capacity to physically change flows in the Delta or portions of it. These flow changes can result in complex patterns of changes in stage (i.e., water surface elevation relative to a reference point on a gage), velocity, and salinity in Delta channels. Therefore, estimating the change in flow rate is generally not adequate to describe physical changes. Section 4.6.2, Physical Changes in the Delta, describes the physical changes in the Delta, and Section 4.2.4, Metrics, describes metrics for quantifying the changes that are created or caused by a proposed water storage project.

The Delta is a physically complex area with interconnected channels and flow paths, so hydrodynamic models are often used to gain a greater understanding of how water projects can change hydrodynamics of the Delta. Some projects do not require the use of hydrodynamic modeling if the changes of flow in the Delta are slight. For example, a consistent and slight increase of flow in a main river like the Sacramento River (especially during the wet season) is not likely to cause significant changes to the hydrodynamics of the Delta. However, if a project significantly increases flow in a smaller river entering the Delta (especially during the dry season), a more thorough analysis with a hydrodynamic model is recommended to assess the impacts of this local change in conditions.

4.6.2 Physical Changes in the Delta

Physical changes in the Delta should be analyzed using models or other methods that can produce the necessary outputs to quantify the physical changes and to support subsequent analysis, such as economic evaluation. Outputs may include: flows, stage, velocity, salinity, fingerprinting, and particle tracking. Outputs could directly show incremental change, or could be post-processed to display related information such as using salinity outputs to evaluate changes in X2. X2 is the distance from a reference point (usually the Golden Gate Bridge) to the location of the daily average 2 parts per thousand (ppt) channel bottom salinity. Figure 4-6 displays key locations for X2 and other water quality compliance locations in the Delta.

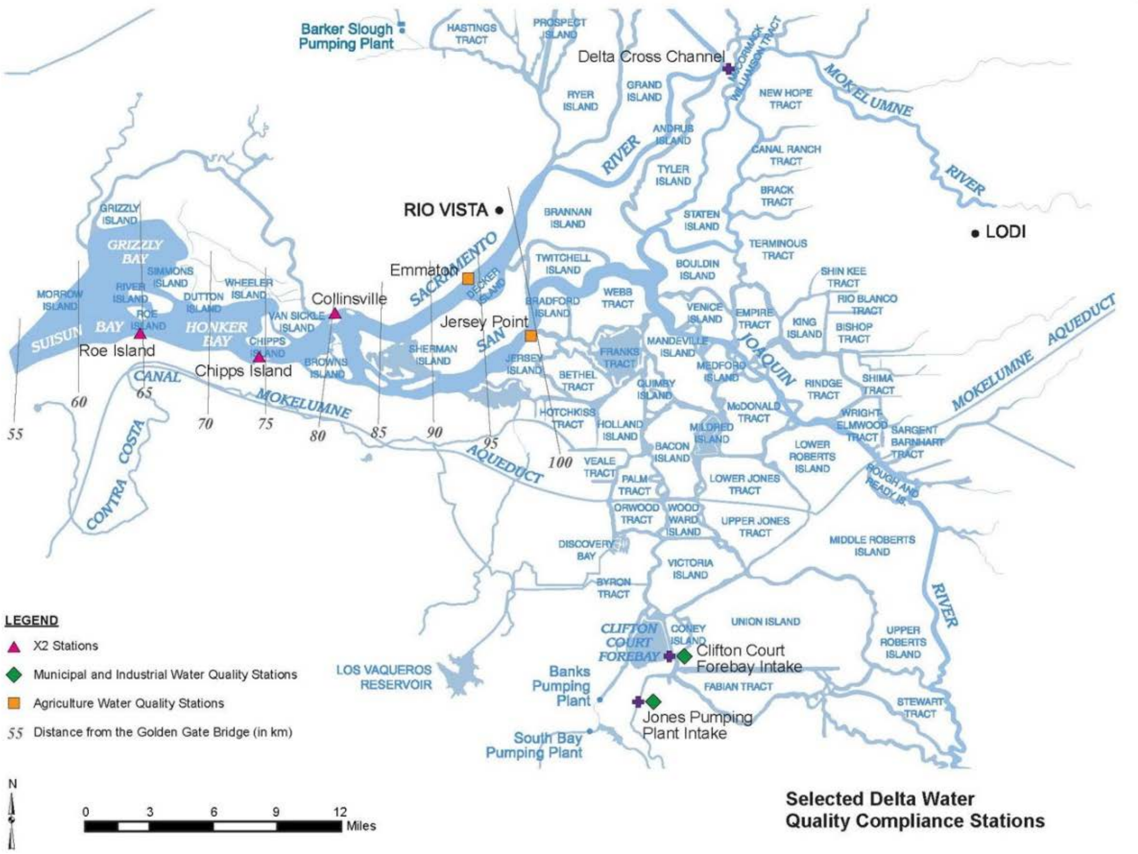

Figure 4-6.   Delta Water Quality Compliance Locations.

The physical changes in the Delta described below are typical outputs from Delta hydrodynamic models. The post-processing methods described below do not encompass all methods. There are many methods to process and display model results, and the method selected depends on the significance of Delta hydrodynamics to a proposed project's claimed benefits.

4.6.2.1 Flows

Flow data are used to quantify tidal flows, outflow, diversions, and reverse flows. Flow data outputs from hydrodynamic models are typically monthly-averaged or tidally-averaged (over one or a sequence of tidal cycles) to provide usable results. Inflows from source rivers are required to quantify the flows within the Delta. Changes of inflow to and outflow from the Delta can be used to assess incremental changes in water supply and water quality, depending on timing. Changes include:

- **Salinity.** If outflow increases during the dry season, it is likely that salinity in the Delta will decrease. Higher outflows during the wet season have less importance for water quality.

- **Reverse Flows.** Reverse flows occur when flow in a channel opposes its natural direction. They are commonly observed in the Old and Middle rivers (OMR). When Delta exports are large and inflows from source rivers are small, OMR flow south (towards the pumps) instead of north (out of the Delta). Reverse flows, or negative OMR flows, may influence fish entrainment at Delta pumping facilities. Models are available to estimate entrainment of adult, juvenile, and larval Delta smelt as a consequence of reverse flows (see Section 4.7, Ecosystem Analysis).
- **Tidal Prism.** The tidal prism is the volume of water entering or leaving the Delta between mean high tide and mean low tide. The tidal prism could indicate residence time in the Delta, which could affect water quality and ecosystem conditions.

Please refer to the water quality, water supply, and ecosystem sections to quantify the benefits associated with these physical changes.

4.6.2.2 Stage

Stage data provide information concerning water users' access to water, flood risk (frequency and depth of inundation), and tidal energies. For example, a low channel surface can reduce or eliminate flow into the intakes of Delta agricultural and urban diverters. A stage frequency curve indicates the water supply reliability provided by a particular intake. Similarly, displaying an exceedance curve of channel stage relative to the height of a levee of interest provides a measure of how a project might affect flood probability at a given location. When used with an analysis of inundation depth and area, the stage-frequency relationship provides a way to assess how a storage project might change expected flood damage or expected flood-related ecosystem benefits. Tidal energy is the potential energy in a change of water levels. Tidal energy is measurable through the amplitude of a tidal cycle. Tidal energy changes impact daily flow magnitude and, in turn, constituent transport. Tidal energy is a supplemental metric. It must be used in conjunction with other metrics to indicate changes in water quality or ecosystem conditions. These changes, along with other physical changes (such as velocity), affect water quality and ecosystem benefits. Changes in stage may affect water supply, flood control, ecosystem, and water quality benefits.

4.6.2.3 Velocity

Scour and tidal reversal are physical changes that are measured by velocity. Sediment particles have a critical erosion threshold, and once velocities go beyond a specific magnitude, the likelihood of scour increases. This can degrade water quality, affecting ecosystem conditions and even water supply. An exceedance curve of velocity with a theoretical threshold value of velocity magnitude at which scour becomes significant shows the likelihood of scour at a given location. Scour can change the type and quantity of constituent loading in a given channel. A project that increases velocity in a given area, resulting in an increase in scour, could weaken levees and pose a flood risk. Tidal reversals are the locations where the riverine energy matches the tidal energy. Velocity is also used to assess tidal energy. Estimates of channel velocity changes due to a project can be used in subsequent analysis of water quality, flood control, water supply, and ecosystem benefits.

4.6.2.4 Salinity

Physical changes in salinity due to construction and operation of a project are important to determine compliance with salinity regulations and whether other changes in operations may be required. The State Water Board lists existing salinity requirements in the Delta (State Water Board, 2016a, link provided in references).

Salinity changes are also used to measure general freshening of Delta channels, the position of X2, and water quality at urban and agricultural water supply intakes. To show an incremental change in salinity in a channel, a plot of salinity at that location is sufficient. Salinity outputs can also be used to calculate the position of X2. Quantifying the location of X2 requires salinity time series data at multiple locations; data are interpolated to locate X2.

Typically, X2 is displayed with exceedance plots or averaged end of month values. Plots for each water year type (critical, dry, normal, above normal, and wet), as well as a plot for the entire simulation period, are usually displayed. An example of a monthly-averaged plot of X2 position in dry years is shown in Figure 4-7. This would usually be accompanied by end of month X2 position plot for all years, critical years, normal years, above normal years, and wet years. Time series plots of X2 position are suggested only when simulations have input data at the daily resolution. Where the project-related changes are small, and thus visually difficult to display, tables of values should be used. Refer to Section 4.12.4, Timing for information regarding temporal scale.

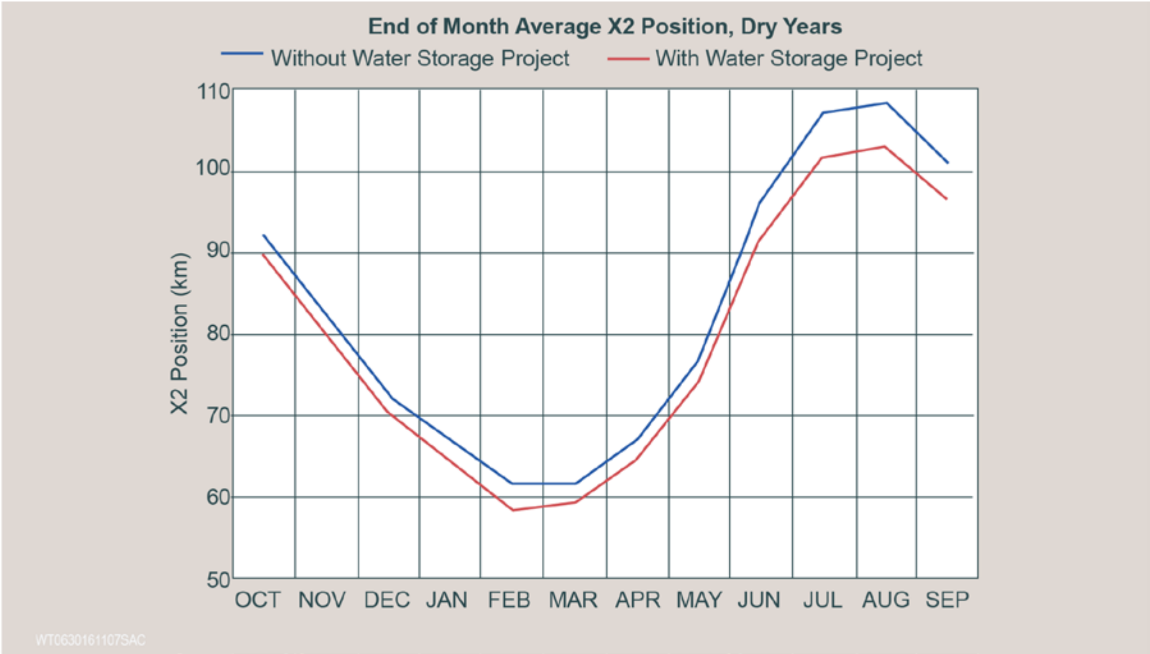

Figure 4-7. Example X2 Position Plot.

Salinity can affect operations of water supply intakes and the uses of water supplied by the intakes. If salinity at an intake location is above a certain threshold, water use is limited or cost of water use increases. Similarly, higher salinity may increase salinity management costs by agricultural users. It may also impose management costs on municipal utilities or costs on its customers. State Water Board considered the various beneficial uses of Delta water and set the salinity thresholds needed to be met for maintaining the beneficial uses. Exceedance plots at an intake location or a location of interest show how often that intake has access to water below a given threshold or within a certain range. For example, a comparison of salinity exceedance plots at an intake would show how a storage project improves (or degrades) delivered water quality. An example of an exceedance plot is shown in Figure 4-8. Changes in X2 distances and salinity at locations near the intake of interest may also be used to assess the effects of the proposed project.

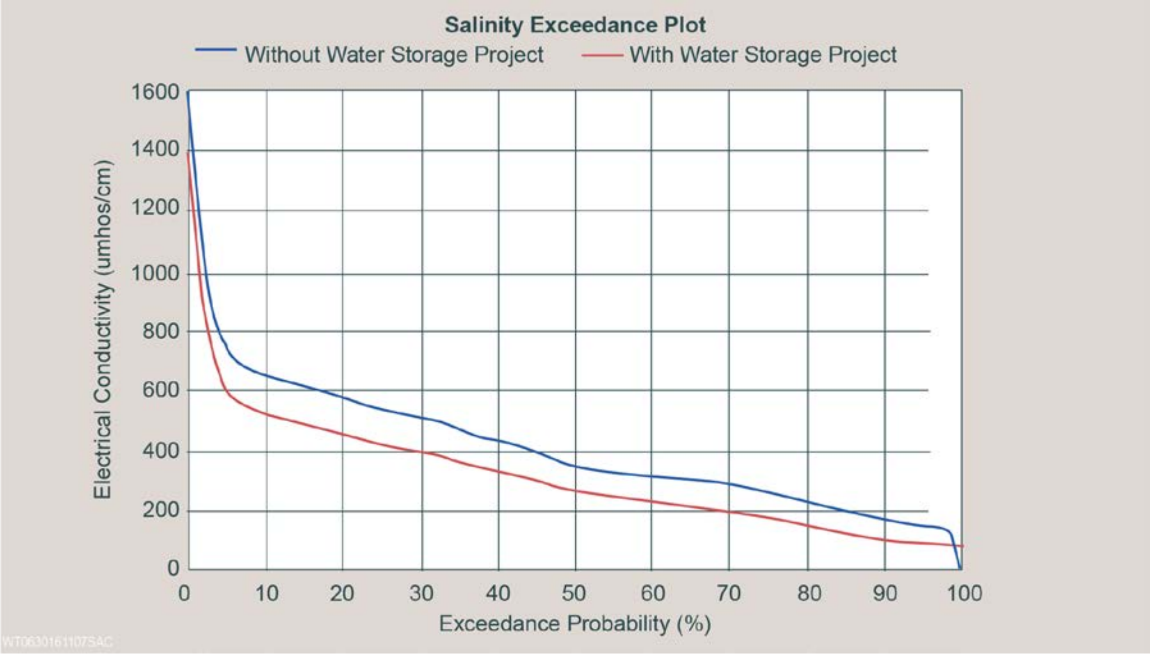

Figure 4-8. Example Exceedance Plot.

Salinity can be measured in a number of ways, including electrical conductivity (EC), total dissolved solids, or chloride concentration. Other constituents, such as bromide, can be estimated using known relationships to salinity. Salinity and other constituents related to salinity can be used to quantify water quality benefits and, in some cases, ecosystem benefits.

4.6.2.5 Fingerprinting

Fingerprinting is a procedure used in some hydrodynamic models to show how different water sources move through the Delta. Fingerprinting can show the ultimate fate of water from a given inflow location. For example, a fingerprinting analysis could determine the percentage of inflow that exits the system downstream, the percentage used by agricultural and municipal users within the Delta, and the percentage diverted from the Delta. Fingerprinting can also be used to determine the sources of water at a given location. For example, water exported through the SWP facility in the South Delta can be quantified by its source (e.g., 65 percent Sacramento River, 25 percent San Joaquin River, 3 percent ocean water, etc.). Fingerprinting can be used to assess how a project would affect water supply, water quality, or ecosystem resources in different parts of the Delta based on the location of the project.

4.6.2.6 Particle Tracking

Residence time, fates, and changes in flow paths can be quantified by processing results of particle tracking model simulations. Residence time is the average time a molecule of water remains in a given region. This could be the Delta as a whole, or a smaller localized region such as the South Delta. An incremental change in residence time at a specific location could be a water quality or ecosystem benefit or impact, depending on timing and location. An increase in residence time in nursery or spawning areas in Cache Slough could be beneficial to juvenile fish species, while an increase in residence time of water in the South Delta could lead to increased influence of agricultural runoff and a decrease in water quality.

Particle tracking can be used to determine the major pathways through which most flow occurs, by quantifying the proportion of particles that flow into one or more pathways from a given starting location. Changes in flow paths have the potential to benefit or impact water quality or the ecosystem. For example, particle tracking may be useful to indicate how a storage project would affect fish migration or transport, resulting in a benefit or an impact on a listed species. Particle tracking provides information useful for assessing ecosystem and water quality benefits.

4.6.2.7 Metrics

The physical changes detailed above provide a number of ways to understand how projects may affect the Delta. Metrics to quantify these physical changes and the associated benefits or impacts are tabulated in Table 4-8. Some of the listed metrics are standard ways of assessing Delta conditions for purposes of monitoring and regulatory compliance.

Table 4-8. Physical Changes, Example Metrics, and Their Potential Effects.

Physical Change	Output Type	Example Metric	Potential Benefit or Impact
Tidal flows	Flow	Tidally averaged flow (in cfs)	Ecosystem, Water Quality
Outflow	Flow	Net Delta Outflow Index (NDOI) Monthly averaged flow (cfs) Or monthly volumes of water (TAF or acre-feet [AF])	Ecosystem, Water Quality, Water Supply
Diversions	Flow	Monthly averaged flow (cfs) Or monthly volumes (TAF or AF)	Water Supply
Reverse Flows	Flow	Tidally averaged daily flow (cfs)	Ecosystem, Water Supply
Tidal prism	Flow	Volumes (TAF or AF)	Ecosystem, Water Quality (needs supporting metrics)
Access to water	Stage	Probability over a given extent of time	Water Supply

Table 4-8. Physical Changes, Example Metrics, and Their Potential Effects.

Physical Change	Output Type	Example Metric	Potential Benefit or Impact
Flood Frequency	Stage	Stage frequency curve	Ecosystem, Flood
Tidal Energy	Stage	Energy (kW or kW per foot of amplitude)	Ecosystem, Water Quality (needs supporting metrics)
Scour	Velocity	Velocity (feet per second [ft/s]) compared to a scour velocity threshold (ft/s)	Ecosystem, Flood, Water Quality
Tidal reversal	Velocity	Distance (in kilometers [km]) from a given reference point (e.g., Golden Gate Bridge)	Ecosystem, Water Quality, Water Supply
Freshening of Delta channels	Salinity	Daily averaged EC in micromhos per centimeter (μmhos/cm)	Water Quality
Position of X2	Salinity	Distance (in km) from a given reference point (e.g., Golden Gate Bridge)	Ecosystem, Water Quality
Water quality at intakes	Salinity	EC in μmhos/cm	Water Quality, Water Supply
Fate of a given input	Fingerprinting	Percent of input at each Delta output	Ecosystem, Water Quality, Water Supply
Source track at a given location	Fingerprinting	% of location for each input	Ecosystem, Water Quality
Residence time	Particle Tracking	Time (units depend on spatial magnitude; for tracking throughout the Delta, days)	Ecosystem, Water Quality
Changes in flow path	Particle Tracking	Percent of particles passing a given channel as compared to another	Ecosystem, Water Quality

4.6.3 Approaches and Methods/Models for Estimating the Nature and Magnitude of Physical Changes

A number of tools may be useful to estimate the magnitude and nature of physical changes in the Delta, including spreadsheets, CalSim II, one-dimensional (1D) hydrodynamic models, two-dimensional (2D) hydrodynamic models, and three-dimensional (3D) hydrodynamic models. Table 4-9 summarizes the modeling options and their general functions/limitations. The effort and resources required vary among the different options. The significance of Delta hydrodynamics to a proposed project's claimed benefits is an important driver for selecting the appropriate tool. In addition, applicants should consider the required inputs, computational resources, required time to complete a simulation, the duration of the desired simulation period, model complexity, and physical changes of interest before selecting a model. For further information regarding Delta modeling, refer to the white paper prepared by the Modeling Science Workgroup (State Water Board, 2016b).

Table 4-9. Summary of Model Approaches.

Model Type			
Spreadsheets	• Mass balance approaches	• Water quality • Velocity • Stage • Flow • Particle Tracking • Fingerprinting	Results should encompass large time steps (e.g. monthly). Relatively simple to set up and run.
CalSim II	• Mass balance approaches • Flow-salinity relationship at the monthly time step	• Velocity • Stage • Particle Tracking • Fingerprinting	Experience in CalSim II modeling is recommended
1D Hydrodynamic	• Stage • Velocity • Flow • Water Quality • Particle Tracking • Fingerprinting • Results at the sub-tidal time step	• All outputs are width and depth averaged • 1D models do not accurately model floodplain/marsh plain inundation	Experience with a 1D hydrodynamic model is recommended
2D Hydrodynamic	• Same as 1D above • Accurately models floodplain/marsh plain inundation	• All outputs are depth averaged	• Experience with a 2D model is recommended • Computational power begins to become a limitation of modeling scope
3D Hydrodynamic	• Same as 2D above	• Model outputs are only limited to grid resolution	• Experience with a 3D model is recommended • Computational power is significant.

4.6.3.1 Spreadsheets

Spreadsheet programs are useful for mass balance approaches in the Delta, for example, calculating monthly-averaged Delta outflow based on changes in inflow. Spreadsheets generally do not provide tidally averaged results. Detailed, short time step calculations needed to quantify changes in water quality, velocity, stage, flow, particle tracking, or fingerprinting are generally beyond the capability of spreadsheet models.

Spreadsheets do not require powerful computers, nor do they take a lot of time to prepare or compute (compared to the options below). However, this tool’s scope of physical changes is commonly limited to incremental changes in Delta outflow or inflow.

4.6.3.2 CalSim II

CalSim II, a publicly available model developed by DWR and Reclamation, is useful for mass balance calculations (e.g., Delta outflows) and flow-salinity relationships (e.g., X2 position or salinity at a location) at a monthly time step. Its artificial neural network, which is a set of equations and logic used to approximate the flow-salinity relationships of the more complex DSM2 model, relates flow conditions to salinity conditions, accounts for many small Delta diverters and aims to comply with salinity regulations. Outputs from

CalSim II studies are commonly used as inflow boundary conditions for extended DSM2 simulations. CalSim II is not a hydrodynamic model and does not account for any system hydraulics or tidal physics. For further information on CalSim II, read the CalSim II operations technical memorandum (DWR, 2003).

The use of CalSim II requires significantly greater effort than a spreadsheet. CalSim II does not provide results at the sub-tidal time step. Velocity, stage, particle tracking, and fingerprinting are not capabilities of CalSim II.

4.6.3.3 1D Hydrodynamic Models

1D hydrodynamic models calculate flow, stage, and velocity at every point on a model grid, at every time step during a model simulation. Some models, such as the publicly-available DWR's DSM2, provide additional capabilities including particle tracking, fingerprinting, and simple water quality (salinity). DSM2 is significantly more complex to use than spreadsheet models. The computation time required to complete model runs increases greatly from that of Microsoft Excel. Simulation periods in DSM2 have been extended to over 80 years to include a wide range of hydrologic conditions.

1D model outputs are not applicable for floodplain analysis (e.g., an inundation area). They only consider momentum in one direction, which works well in most Delta channels, but accurate floodplain or marsh plain inundation mapping requires the use of a 2D model. DSM2 is a 1D hydrodynamic model with a grid setup for the Delta (DWR, 2016).

4.6.3.4 2D Hydrodynamic Models

2D hydrodynamic models provide the same output variables as the 1D hydrodynamic models, with additional discrete outputs across the width of the channel. 2D models have more accurate floodplain or marsh plain inundation outputs. The increased complexity of 2D models (i.e., solving momentum in two directions) requires additional computational resources and time. Because of the significant computational resources and time required by 2D models, the length of simulations is generally a year or less.

2D hydrodynamic models require a similar setup as 1D hydrodynamic models. There are no publicly available 2D models of the Delta. Resource Management Associates (RMA) (RMA, 2016) developed a widely-used 2D proprietary model of the Delta.

4.6.3.5 3D Hydrodynamic Models

3D hydrodynamic models provide the same output variables as 1D and 2D hydrodynamic models, but with additional output resolving vertical variations in flow and velocity. There is no averaging with respect to channel depth or width in a 3D model. The 3D model requires even more computational time and power than a 2D model. Even with powerful computers or a cloud network, simulations of multiple years take a significant amount of time (e.g., on the order of days). The only spatial limitation of these models is the size of its computational units.

3D hydrodynamic models require a similar setup to the setup of 1D and 2D models. At present, there are proprietary 3D models of the Delta owned by Anchor QEA (previously Delta Modeling Associates), Dynamic Solutions, and RMA.

4.6.4 Selection of Approach to Quantify Delta Benefits

Selection of a method/model depends on available information, the expected physical changes and their importance, the area of interest (which could be the Delta itself), the temporal extent required to depict the physical changes, and the work effort required. The selected model must be capable of using (or of being adapted to use) available information, including results of other analysis or models used in the application. It must also produce results, either directly or through additional post-processing, that show the magnitude/nature of the physical changes needed to demonstrate benefits and impacts directly or that are required for subsequent analysis or models. Benefits or impacts are defined as changes relative to the without-project condition, so quantifying them usually requires at least two model runs (a with-project and a without-project run).

4.6.4.1 Geographic Scale

The study area for Delta analysis may simply be the entire Delta if one is observing large-scale physical changes like Delta outflows or X2 distances. However, some physical changes can be focused on a small specific area. Even when changes in specific channels are observed, those changes in one area of the Delta may easily cause changes in several other locations. So it may be necessary to provide analysis of specific locations in addition to analysis of the whole Delta (e.g., Delta outflow, X2 distances).

4.6.4.2 Temporal Scale

The temporal extent of the modeling analysis is the length of time covered by the inputs to and output of the model. It must be sufficiently long to provide a full description of the expected physical changes under representative hydrologic conditions. “Sufficiently long” may be different for different kinds of physical changes. For example, probability plots (exceedance curves) require very long time series that include as much variability (e.g., in water year types, storm events) as possible to provide a full description of benefits. For these plots, it is suggested to limit the computational requirements of modeling approach. To model specific years of interest (flood or drought) or even a specific event, higher order (2D and 3D) models are more accessible.

The time step of a model is also significant when modeling certain criteria. When modeling CVP/SWP deliveries with CalSim II, a monthly averaged flow or volume is sufficient. Physical changes like tidal flows or salinity require sub-tidal time steps (at most 15 minutes) to be accurately modeled.

The temporal resolution of the output data depends on the temporal resolution of the input data to the Delta model. If input data comes from CalSim II (which runs at a monthly time step), the output data must also be shown at a monthly time step, even if a model runs with a sub-tidal time step. Daily outputs could be used with simulations based on altered historic (to represent conditions with a new storage project) daily data. These simulations would need the operations of a new water storage project to meet the Delta regulations at the daily time step (State Water Board, 2016).

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4.7 Ecosystem Analysis

This section describes concepts and methods for quantifying ecosystem improvements (or impacts) that could result from water storage projects. First, desired ecosystem improvements are listed and briefly described. Next, relationships between physical changes and ecosystem improvements are described. Finally, methods and approaches, metrics, and models are described so that applicants can quantify the physical changes and assess the value of a project benefit and the project's ability to achieve ecosystem improvements. Applicants may propose and use other methods or tools not specifically included in this section. Any method used must be justified as scientifically sound and appropriate to the improvement being evaluated.

All concepts and methods discussed here apply to quantifying without-project conditions, and benefits and impacts of a water storage project, but for brevity, the narrative often refers only to benefits. Applicants must describe and quantify, where possible, without-project conditions and benefits and impacts of the proposed project. To be eligible for funding, the results of the selected methods must demonstrate that the project provides a net improvement in ecosystem conditions, considering both benefits and impacts, and measurable improvements to the Delta ecosystem or to Delta tributaries.

4.7.1 Ecosystem Improvements

Water Code Section 79750(b) states that funding is appropriated to "the commission for public benefits associated with water storage projects." Fundable public benefits must be associated with a water storage project, and fundable ecosystem improvements must "contribute to restoration of aquatic ecosystems and native fish and wildlife" [Water Code Section 79753(a)(1)]. Additionally, funds shall not be expended "for the costs of environmental mitigation measures or compliance obligations except for those associated with providing the public benefits" as described in Water Code Section 79753(b).

Water Code Section 79754 provides that "the commission shall develop and adopt, by regulation, methods for quantification and management of public benefits… The regulations shall include the priorities and REV of ecosystem improvements as provided by the Department of Fish and Wildlife and the priorities and REVs of water quality benefits as provided by the state board." The ecosystem priorities and REVs allow for a wide range of fundable ecosystem improvements. The priorities and the criteria used to determine the ecosystem REV, as developed by CDFW, are provided in the regulation and below for reference.

4.7.2 CDFW Priorities and Relative Environmental Value

CDFW has developed priorities to improve California's ecosystem resources for the benefit of people, fish and wildlife, and plants. The priorities address benefits that could be provided by water storage projects funded by the WSIP.

CDFW has jurisdiction over the conservation, protection, and management of fish, wildlife, native plants, and habitat necessary for biologically sustainable populations of those species and serves as the trustee for fish and wildlife resources. As such, CDFW manages California's fish and wildlife resources for their ecological values as well as for their use and enjoyment by the public. CDFW bases its ecosystem priorities for the WSIP on existing environmental laws and regulations, species recovery plans and strategies, initiatives, and conservation plans. These priorities address multiple levels of ecosystem organization and processes including biotic and abiotic components of the environment.

4.7.2.1 Rationale for Priorities

Impacts on native fish and wildlife species resulting from flow modifications and poor water quality are well documented and can include adverse chemical, physical, and biological changes to water and habitat. More specifically, flow and water quality are major determinants of fish species abundance, distribution, and overall viability. As a result of the construction of dams, levees, and water diversions on major waterways, the historical natural hydrograph has been altered such that the magnitude, timing, duration, and stability of flows are insufficient to support native fishes in habitats that exist across the state, and degraded water quality conditions have impaired both the movement and health of now imperiled fish and wildlife species. Projects that produce a more natural hydrograph and provide appropriate water quality conditions will help support native fish and wildlife populations.

Alteration of the Delta watershed has fundamentally changed the physical, chemical, and biological characteristics of ecosystems in which native species have evolved. Over 80 percent of the Central Valley's historical floodplains, riparian, and wetland habitats have been lost in the past 150 years, in part due to the construction of dams, levees, and water diversions as part of flood control and water delivery systems and due to the expansion of agricultural and urban land uses. These human activities have altered natural flow regimes, reduced access to spawning and rearing habitats of native fish species, and increased competition between native and non-native species for food, space, and other resources. These human activities have affected native fish and wildlife populations. Furthermore, loss of wetlands has reduced the quantity and quality of habitats for migratory birds and other species.

CDFW has organized its ecosystem priorities into two subcategories: (1) flow and water quality, and (2) physical processes and habitat.

4.7.2.2 CDFW Flow and Water Quality Priorities

CDFW's flow and water quality priorities are:

(1) Provide cold water at times and locations to increase the survival of salmonid eggs and fry.

(2) Provide flows to improve habitat conditions for in-river rearing and downstream migration of juvenile salmonids.

(3) Maintain flows and appropriate ramping rates at times and locations that will minimize dewatering of salmonid redds and prevent stranding of juvenile salmonids in side channel habitat.

(4) Improve ecosystem water quality.

(5) Provide flows that increase dissolved oxygen and lower water temperatures to support anadromous fish passage.

(6) Increase attraction flows during upstream migration to reduce straying of anadromous species into non-natal tributaries.

(7) Increase Delta outflow to provide low-salinity habitat for Delta smelt, longfin smelt, and other estuarine fishes in the Delta, Suisun Bay, and Suisun Marsh.

(8) Maintain or restore groundwater and surface water interconnections to support instream benefits and groundwater-dependent ecosystems.

4.7.2.3 CDFW Physical Processes and Habitat Priorities

CDFW’s physical processes and habitat priorities are:

(9) Enhance flow regimes or groundwater conditions to improve the quantity and quality of riparian and floodplain habitats for aquatic and terrestrial species.

(10) Enhance the frequency, magnitude, and duration of floodplain inundation to enhance primary and secondary productivity and the growth and survival of fish.

(11) Enhance the temporal and spatial distribution and diversity of habitats to support all life stages of fish and wildlife species.

(12) Enhance access to fish spawning, rearing, and holding habitat by eliminating barriers to migration.

(13) Remediate unscreened or poorly screened diversions to reduce entrainment of fish.

(14) Provide water to enhance seasonal wetlands, permanent wetlands, and riparian habitat for aquatic and terrestrial species on State and Federal wildlife refuges and on other public and private lands.

(15) Develop and implement invasive species management plans utilizing techniques that are supported by best available science to enhance habitat and increase the survival of native species.

(16) Enhance habitat for native species that have commercial, recreational, scientific, or educational uses.

4.7.2.4 CDFW Relative Environmental Values

CDFW has developed a list of criteria to be used to determine the REV for ecosystem improvements provided by a proposed project. These criteria are:

(1) Number of ecosystem priorities addressed by the project.

(2) Magnitude of ecosystem improvements.

(3) Spatial and temporal scale of ecosystem improvements.

(4) Inclusion of an adaptive management and monitoring program that includes measurable objectives, performance measures, thresholds, and triggers to achieve the ecosystem benefits.

(5) Immediacy of ecosystem improvement actions and realization of benefits.

(6) Duration of ecosystem improvements.

(7) Consistency with species recovery plans and strategies, initiatives, and conservation plans.

(8) Location of ecosystem improvements and connectivity to areas already being protected or managed for conservation values.

(9) Efficient use of water to achieve multiple ecosystem benefits.

(10) Resilience of ecosystem improvements to the effects of changing environmental conditions, including hydrologic variability and climate change.

While the ecosystem priorities stated above are not listed in rank order, the extent to which projects contribute to the desired ecosystem benefits may vary greatly. Project proposals should describe specific information such as number, magnitude, mix, location, duration, and timing of benefits. Project proposals should also include clearly stated goals and objectives for ecosystem improvements, including programs for monitoring and adaptive management and strategies for resilience to climate change. These REV criteria will be used by CDFW in its evaluation of the ecosystem improvements, so applicants should consider these criteria when selecting and implementing methods to quantify ecosystem improvements.

4.7.3 Ecosystem Impacts

A water storage project may also result in negative effects, or impacts, on ecosystem resources. Some impacts may be similar enough to an improvement that they can be subtracted to quantify the net improvement. In many cases, impacts will be different in physical nature, location, or timing such that they cannot be directly subtracted from an improvement. In either case, the impact must be quantified to the extent possible. If a project is fully mitigating an impact, such as the loss of terrestrial habitat caused by the footprint of a storage facility, and the cost of the mitigation is included in its project cost, no separate physical quantification is needed for quantifying net improvement.

4.7.3.1 High-Value Resources

CDFW's highest priority species for the WSIP are species listed under the CESA or ESA, as well as other sensitive or at-risk native species that depend on the Delta and its tributaries for their survival. Fish species that meet one or more of these criteria include winter-run, spring-run, fall-run, and late-fall run Chinook salmon; Central Valley steelhead and rainbow trout; green sturgeon; white sturgeon; Delta smelt; longfin smelt; Pacific lamprey; and Sacramento splittail. In addition, aquatic, riparian, and wetland habitats that support migratory birds of the Pacific Flyway, neo-tropical migratory birds, and native reptiles, amphibians, mammals, and plants are also priorities for CDFW.

4.7.4 Physical Changes Leading to Ecosystem Improvements

Water storage projects may influence ecosystem function by physically changing surface water flow, quantity, timing, water quality, and habitat for aquatic and terrestrial species. The relationship between physical changes and an ecosystem function and benefit may be direct, or it may involve a more complex set of cause-and-effect relationships. This section summarizes examples of physical changes from water storage project operations that may provide ecosystem improvements. Physical changes and the ecosystem improvements they could provide are organized into two broad categories: (1) changes in water quantity, timing, and quality, and (2) changes in physical habitat, which generally follows the organization of CDFW priorities. While these are described separately, ecosystem improvements may result from combinations and interrelated physical changes (e.g., increased flows create riparian habitat that cools water temperatures and in turn improves fish egg hatching success).

4.7.4.1 Changes in Water Quantity, Timing, and Quality

Water storage projects physically change the availability, flow, frequency, pattern, temperature, and duration of water resources. Ecosystem benefits are expected if physical changes are provided at locations and times, and of sufficient quality, where habitats and species would benefit from such changes. For example, project-related changes in surface water flows (a physical change) within a Sacramento River tributary may increase spring-run Chinook salmon egg survival (an ecosystem benefit) if surface flows are delivered at an active spawning area, at an appropriate magnitude, pattern, timing, and duration, and of sufficient water quality. Alternatively, delivering water that is too warm would be detrimental to incubating spring-run Chinook salmon eggs. Water that is too warm for salmonids (a cold water fish species) may in fact be optimal for warmer-water fishes such as Sacramento suckers. Species criteria (e.g., survival and condition) must be well understood and explained to achieve targeted ecosystem improvements, as species and habitats are likely to have unique, and sometimes precise, requirements for water quality, timing, and pattern of flow.

Pesticides and other Ecosystem Water Quality Stressors

Water quality constituents like pyrethroids, organophosphates, selenium, and contaminants of emerging concern can have a negative impact on the fish and wildlife as described in the sections below. Other water quality constituents (nutrients and mercury) and water quality parameters (temperature, dissolved oxygen, and salinity) are discussed in Section 4.8, Water Quality Analysis.

Pyrethroids

Pyrethroids are synthetically developed insecticides that are widely used in California. Pyrethroids have generally low toxicity to humans. However, they are highly toxic to fish, as well as to the invertebrates that make up their food web. The Surface Water Ambient Monitoring Program studies indicate that the replacement of organophosphate pesticides by pyrethroids has increased contribution of pyrethroids to ambient water and sediment toxicity (Anderson et al., 2011). Pyrethroids are found in wastewater effluent from secondary wastewater treatment plants, agricultural discharges, and stormwater runoff (Weston and Lydy, 2010).

Organophosphates

Organophosphates are man-made pesticides. Organophosphates, such as parathion, chlorpyrifos, malathion, and diazinon, can be acutely toxic and can affect the immune system of humans and wildlife (Galloway and Handy, 2003). Organophosphates have been used extensively in agricultural and residential applications. Diazinon and chlorpyrifos were banned from non-agricultural uses December 31, 2004, and December 2001, respectively (Central Valley Regional Water Quality Control Board, 2014). The reduction of organophosphate use has resulted in the increasing use of pyrethroids and carbamates as alternative pesticides in urban and agricultural areas. Diazinon was one of the most common insecticides in the United States for household use until all residential uses of diazinon were phased out, between 2002 and 2004 (EPA, 2004). Diazinon usage was prohibited for several agricultural uses in 2007, with only a few remaining agricultural uses permitted (EPA, 2007).

Selenium

Selenium is a nonmetal, chemical element that is found in sedimentary rock and is essential for a healthy diet (Presser and Piper, 1998; Presser, 1994). A selenium deficiency or excess in the diet can produce adverse responses, where the latter is particularly a concern for several beneficial uses (Agency for Toxic Substances and Disease Registry, 2003; Ohlendorf, 2003). Because of selenium bioconcentration from water to aquatic organisms and to higher trophic levels in the food chain, certain beneficial uses of water (i.e., fresh water, estuarine and wildlife habitat; spawning, reproduction, and/or early development; and rare, threatened, or endangered species) are very sensitive to selenium toxicity or selenosis. These conditions may result in death or deformities of fish embryos, fry, or larvae (Ohlendorf, 2003; Janz et al., 2010). In addition, the rate of selenium biomagnification is a function of the type of food web (e.g., benthic vs. pelagic). Selenium is mobilized from the soil by irrigation practices and transported to waterways receiving agricultural drainage (Presser and Ohlendorf, 1987). Other sources of selenium to the western Delta and San Francisco Bay include several oil refineries located in the vicinity of Carquinez Strait and San Pablo Bay (Presser and Luoma, 2013).

Contaminants of Emerging Concern

The term “contaminants of emerging concern” addresses the several potentially concerning unmonitored chemicals in water (EPA, 2015). The effect on public benefits and beneficial uses are unknown, but there is a potential for toxicity and health effects. Sources of contaminants of emerging concern may be from recycled water and could include persistent organics, pharmaceuticals and personal care products, veterinary medicines, endocrine-disrupting chemicals, and nanomaterials.

4.7.4.2 Changes in Physical Habitat Characteristics

Water storage facilities and project operations may create conditions at locations and times that are beneficial (or detrimental) to species and their habitats. For example:

- Altering flows in the Delta (a physical change) could affect the manner in which OMR flows are operationally managed (a physical change) and, consequently, reduce fish entrainment risk (an ecosystem improvement) at south Delta pumping facilities.
- Changing the pattern (magnitude and timing) of riverine flows (physical change) may contribute to the recruitment, establishment, and condition of riparian vegetation along stream margins (an ecosystem improvement), which in turn can reduce in-river water temperatures (an ecosystem and water quality improvement) and provide nesting habitat for rare birds (an ecosystem improvement).
- Increasing groundwater elevations (a physical change) can increase surface water flows (a physical change) and improve fish passage (an ecosystem improvement) through reaches of streams that would otherwise be dry and impassable. Physically changing instream features (e.g., retrofitting unscreened water diversions) may increase fish production and survival, particularly when combined with beneficial changes to instream flows and water quality improvements.
- Adding instream structures like logs or boulder clusters (a physical change) can slow flow velocity, elevate stream stage, and inundate side channel areas resulting in the creation of adjacent riparian and wetland habitat (an ecosystem improvement), which in turn may provide high-value rearing habitat for juvenile salmonids (an ecosystem improvement).

4.7.5 Assessing Physical Change and Ecosystem Improvements

This section describes metrics that may be used to assess targeted ecosystem improvements (benefits). Tools and approaches that can be used to quantify physical changes (e.g., groundwater and surface water resources and operations) are described in greater detail in other sections.

4.7.5.1 Assessment Metrics

Table 4-10 and Table 4-11 associate physical changes from project operations or contributions with targeted outcomes (i.e., ecosystem improvements) that are anticipated to be caused or influenced by the physical changes. Examples of metrics commonly used to report physical changes and ecosystem improvements are listed. Table 4-10 lists flow and water quality-related changes, and Table 4-11 lists physical processes and habitat-related changes to achieve ecosystem improvements.

Table 4-10. Ecosystem Priorities: Flow and Water Quality.

CDFW Priority Theme	Physical Changes and Their Metrics	Targeted Outcomes and their Metrics
Provide cold water at times and locations to increase the survival of salmonid eggs and frys.	Sufficient water flow (in cfs) and water temperature (in degrees) at appropriate locations (river system and stationing) and timing (within- and among-year).	Abundance and survival (#, % change) of eggs and fry.
Provide flows to improve habitat conditions for in-river rearing and downstream migration of juvenile salmonids.	Sufficient water flow (in cfs) at appropriate locations (river system and stationing) and timing (within- and among-year).	Abundance (#, % change) of rearing and out-migrating salmonids. Growth rates (size at time) of rearing fish. Out-migrant routing likelihood (based on particle tracking models).
Maintain flows and appropriate ramping rates at times and locations that will minimize dewatering of salmonid redds and prevent stranding of juvenile salmonids in side channel habitat.	Manage flow (in cfs) and ramping rates (% increase/decrease) at appropriate locations (river system and stationing) and timing (within- and among-year).	Abundance (#, % change) of redds and juvenile salmonids.
Improve ecosystem water quality.	Increase water flow (in cfs) at appropriate locations (river system and stationing) and timing (within- and among-year).	Water quality measures: salinity (ppt), temperature (degrees), nutrients (various units), dissolved oxygen (mg/l), mercury/methylmercury (ng/lL in water or mg/kg in tissue), selenium (ppb), pesticides (various units)
Provide flows that increase dissolved oxygen and lower water temperatures to support anadromous fish passage.	Increase water flow (in cfs) at appropriate locations (river system and stationing) and timing (within- and among-year) to increase dissolved oxygen (mg/l) and lower water temperature (in degrees).	Abundance (#, % change) of moving/migrating or holding anadromous fish life stages
Increase attraction flows during upstream migration to reduce straying of anadromous species into non-natal tributaries.	Increase water flow (in cfs) at appropriate locations (river system and stationing) and timing (within- and among-year).	Abundance (#, % change) or proportion of stray vs. indigenous adults
Increase Delta outflow to provide low-salinity habitat for Delta smelt, longfin smelt, and other estuarine fishes in the Delta, Suisun Bay, and Suisun Marsh.	Increase water flow (in cfs) at appropriate timing (within- and among-year).	Extent (in acres, % change) of low salinity habitat in the Delta, Suisun Bay, and Suisun Marsh
Maintain or restore groundwater and surface water interconnection to support instream benefits and groundwater-dependent ecosystems.	Maintain surface water flows (in cfs or acre-feet per unit time) and groundwater elevations (feet below ground surface) at appropriate locations (river system and stationing, groundwater basins) and timing (within- and among-year).	Numerous metrics for multiple instream benefits (e.g., see above in table). Extent (in acres, % change) of riparian habitat.

Table 4-11. CDFW Ecosystem Priorities: Physical Processes and Habitat.

CDFW Priority Theme	Physical Changes and Their Metrics	Targeted Outcomes and their Metrics
Enhance flow regimes to improve the quantity and quality of riparian and floodplain habitats for aquatic and terrestrial species.	Manage water flow (in cfs) at appropriate locations (river system and stationing), timing (within- and among-year), and release patterns (ramping rates).	Abundance (in acres) and distribution (locations/stationing along riverine systems) of riparian and floodplain habitat. Species distribution (location), abundance (#), specific species habitat components (distribution, abundance, diversity, condition, functional value).
Enhance the frequency, magnitude, and duration of floodplain inundation to enhance primary and secondary productivity and the growth and survival of fish.	Manage water flow (in cfs) to increase floodplain inundation frequency (recurrence frequency), extent (in acres and depth), and duration (days, weeks, months) at appropriate locations (river system and stationing), timing (within- and among-year), and release patterns (ramping rates).	Measures of primary productivity (plankton abundance and community composition; photosynthetic rate) and secondary productivity (zooplankton/insect abundance) on floodplains. Measures of fish growth (size at time, condition factors) and survival (#, % change) of floodplain fishes. Fish tissue methylmercury concentrations (mg/kg, minimize tissue concentrations to levels not deleterious to fish and wildlife)
Enhance the temporal and spatial distribution and diversity of habitats to support all life stages of fish and wildlife species.	Manage water flow (in cfs) and water temperature (in degrees) at appropriate locations (river system and stationing) and timing (within- and among-year) to mimic the natural variability of the system	Distribution (location), abundance (#), and condition (diversity indices, condition factors) of habitats and species life stages.
Enhance access to fish spawning, rearing, and holding habitat by eliminating barriers to movement/migration.	Use flow (in cfs) and water temperature (in degrees) at appropriate times (within- and among years) and locations (by river system, and stationing), and/or mechanical means (physical removal or modification of impediments), to eliminate fish movement barriers.	Fish life stage abundance (# by life stage, % change) at impeded locations (spawning, rearing, holding habitats).
Remediate unscreened or poorly screened diversions to reduce fish entrainment.	Ensure diversions are properly screened (# diversions, size of diversion).	Number of entrained fish at diversion (#, % change, proportion of population).
Provide water to enhance seasonal wetlands, permanent wetlands, and riparian habitat for aquatic and terrestrial species on State and Federal wildlife refuges and on other public and private lands.	Deliver flows (in cfs) at managed lands at appropriate times (within- and among-years). For managed lands entitled to receive Central Valley Project Level 2 refuge water, deliver Incremental Level 4 flows.	Measures of habitat enhancement: abundance (acres), distribution, species composition (diversity indices), condition, functional value (species served), etc. Aqueous and fish tissue methylmercury concentrations (mg/kg, to minimize deleterious impacts on fish and wildlife health). Species distribution (location), abundance (#), specific species habitat components (distribution, abundance, diversity, condition, functional value).
Develop and implement invasive species management plans utilizing techniques that are supported by best available science to enhance habitat and increase the survival of native species.	Implement management plans.	Measures of habitat enhancement (distribution, abundance, diversity, condition, functional value) and native species survival (#, % change).

Table 4-11. CDFW Ecosystem Priorities: Physical Processes and Habitat.

CDFW Priority Theme	Physical Changes and Their Metrics	Targeted Outcomes and their Metrics
Enhance habitat for native species that have commercial, recreational, scientific, or educational uses.	Provide, increase, or manage water flow (in cfs or acre feet) to enhance habitat for targeted species. Improve habitat parameters required by the targeted species (i.e. burrows, vegetation, cover, etc.)	Measures of habitat enhancement (distribution, abundance, diversity, condition, functional value). Species distribution (location), abundance (#), specific species habitat components (distribution, abundance, diversity, condition, functional value).

4.7.6 Assessment Methods and Approaches

This section summarizes methods and approaches that may be used by applicants to assess physical changes and ecosystem improvements that may be provided by a proposed water storage project.

As stated earlier in this document, applicants are required to identify all methods and approaches used in describing ecosystem improvements. Reference to a method in this Technical Reference does not, in itself, provide justification for its use in a specific case. The applicant must justify that the method used applies to the resource and project being evaluated. Datasets used and studies referenced in an application must be available to the Commission and public for review. Applications using models to estimate without-project conditions, impacts, and benefits must be accompanied by sufficient model documentation to facilitate the technical review process. Proprietary models, if used, must be made available for review by the Commission and experts conducting technical reviews.

It is important to note that the location of a project-related physical change is not the primary information of interest. Rather, it is the beneficial responses of species, habitats, and ecosystems to physical changes that are the targeted outcomes of interest. Therefore, a complete and meaningful assessment of ecosystem improvements requires a contextual understanding of where and when such benefits to ecosystems and species would accrue.

4.7.6.1 Identify Affected Resources

Applicants can identify the aquatic, semi-aquatic, and terrestrial species and habitats occurring within the geographic and temporal scope of a proposed project from the project's environmental documentation. Applicants can also identify species that might occur in a given area by querying one or more of several resource databases. These include the California Natural Diversity Database (available at: http://www.dfg.ca.gov/biogeodata/cnddb),
the Biogeographic Information and Observation System (BIOS) (available at: http://www.dfg.ca.gov/biogeodata/bios), and the USFWS species list generator (available at: http://www.fws.gov/sacramento/es_species/Lists/es_species_lists-overview.htm). However, these databases are based on positive occurrence records only and cannot be used to determine species absence at a specific location. In addition

to these databases, recent environmental documents prepared under CEQA or NEPA may be referenced to develop a list of resources present within a defined geography; most are available online at the website of the lead state or federal agency. Applicants may also conduct surveys to identify, describe, and quantify ecosystem condition within the proposed project's study area.

While the above references may allow an applicant to identify species and habitats present within a project's reach, the status of these resources (e.g., abundance, distribution, condition, absence) may not be readily determined. In these cases, an applicant may need to refer to the scientific literature, species-specific recovery or management plans, or plans prepared for management of resources at regional or watershed scales including Habitat Conservation Plans or Natural Community Conservation Plans. Commonly, existing habitat impairments (e.g., fish passage barriers, unscreened water diversions) can be identified within a project's geographic reach by reviewing the literature and noted management plans. Recovery plans prepared by NMFS or USFWS for species listed under the ESA typically include habitat- and species-specific actions to benefit listed species. However, recovery plans may be outdated and, if so, should be supplemented with more recent information such as personal communications with subject matter experts or by referencing other documents to understand changes in resource condition through time.

Applications should include a full list and description of species and habitats affected by a proposed project. The status of these resources (e.g., distribution, abundance, condition) in the without-project conditions should be clearly described by applicants so that benefits and impacts of physical changes can be determined. The description of existing conditions and analysis of project impacts is required by CEQA and should be included in the project's environmental documentation.

4.7.6.2 Evaluate the Magnitude of Change to Affected Resources

Ecosystem changes may be evaluated using a range of parameters, but such changes are typically tracked by quantifying changes in abundance, distribution (in time and space), and/or condition/function of resources of interest. In addition, the following standard approaches may be used to assess changes in these parameters: comparative analyses, index/classification procedures, and predictive modeling (EPA, 1997). Comparative analyses and index/classification procedures are described below, and predictive modeling is discussed in Section 4.7.6.3, under Species-Habitat (Predictive) Models.

Comparative assessment methods usually require collection and analysis of field data to understand without-project conditions at and near a project. Data may include numbers or individuals, condition or function of habitats, distribution of species or habitats, etc. These are then compared with values from control locations (i.e., a location not affected by the project or activity), and both locations (project and control) are monitored over time to track changes. In structuring an assessment this way, changes related to the project can be separated from changes that are not a result of the project. A challenge in using comparative analyses is that ecosystem changes may not be evident until some future time. As such, identification and quantification of ecosystem improvements may not be possible for some time. Comparative analyses are well suited for monitoring ecosystem responses during project implementation, but may not be appropriate for estimating future ecosystem improvements.

Index and classification procedures are similar to comparative analyses in that they track parameters between locations and through time to quantify changes related to actions (i.e., a project). Unlike simple comparative analyses, index and classification procedures aggregate raw data into groups or indices to track parameters like richness, diversity, or ecological health of a resource through time. While these are useful parameters to monitor through time to assess whether a project is delivering the types and magnitudes of improvements anticipated with project implementation, index and classification procedures may not be appropriate for estimating future project benefits.

Collectively, comparative analyses and index/classification procedures are often referred to as habitat assessments. Habitat assessments are the preferred approach for describing and quantifying existing conditions, and for assessing species or habitat conditions at locations through time to detect the nature and magnitude of change. Habitat assessments are also useful in detecting changes that may trigger adaptive management actions over a project's implementation period.

4.7.6.3 Define the Geographic Reach of Physical Changes and Potential Ecosystem Improvements

Water storage projects must demonstrate direct ecosystem improvements at a project's location, or adjacent to or downstream of a project, or demonstrate indirect improvements, as described in this section. In addition, Water Code Section 79752 requires that funded projects provide measureable improvements to the Delta ecosystem or tributaries to the Delta. Applicants must describe the ecosystem benefits with respect to the geographic scale, or reach, of project benefits. This section describes how the geographic reaches of a project's physical changes may influence ecosystem improvements.

For purposes of this section, direct ecosystem improvements are those that result from one or two cause-and-effect links between a project-related action and the resulting ecosystem improvement. Indirect improvements are those that involve a sequence or system of potentially complex cause-and-effect links between actions and improvements. The distinction is only for purposes of explaining different levels of possible analytical complexity; an applicant is not required to make such a distinction in its quantification of benefits.

Locations of Direct Ecosystem Improvements

Project applicants must describe the physical spaces and locations of proposed project facilities (e.g., reservoir footprints, groundwater wells, conveyance structures). Through water resources operations analyses, the geographic extent of physical changes to surface water resources must be defined in applications. Physical changes include changes to both water quantity and water quality, both of which may directly benefit aquatic biological resources.

Aquatic biological benefits may accrue at (and near) locations where improvements to surface water flows and water quality parameters are realized, as well as along and downstream of improvements. Applicants should therefore describe and map the geographic extent of flow and water quality improvements (i.e., with-project conditions relative to without-project conditions) to surface water resources. CDFW and State Water Board priorities identify flow and water quality objectives that may provide benefits to aquatic biological resources, but do not identify precise locations for implementing actions to achieve the stated objective.

Aquatic biological resources would be directly benefitted if they are exposed directly to improved flow or water quality conditions caused or created by the proposed project.

To assess the potential direct extent of aquatic biological benefits from a project, applicants should map and describe the geographic extent of changes to habitats and surface water quantity and quality. This information will likely be developed by applicants in the water resources and water quality sections of the project's environmental documentation.

Projects with larger geographic reaches may or may not provide greater benefit than projects with smaller geographic reaches. Improvements within smaller directly affected geographic reaches may be valued more than larger geographic reaches if project-related changes benefit biological resources of greater importance (e.g., fish species listed under the ESA or CESA) or if the magnitude of benefits is large. This assessment requires consideration of the types and importance of resources within a geographic reach, discussed later in this section.

Terrestrial and semi-aquatic ecosystem improvements may also be directly influenced by water storage projects. For example, seasonally inundated floodplains, wetlands, and riparian habitats may be created or enhanced by the delivery of stored water. Mechanical manipulations (e.g., topographic grading and contouring, plantings, installations of instream structures) may be conducted to accelerate achieving and/or increase the magnitude of consequent ecosystem improvements. Terrestrial and semi-aquatic habitats are important for sustaining and improving the condition of high-value aquatic and terrestrial species.

Locations of Indirect Ecosystem Improvements

The geographic reach of indirect improvements may be more difficult to identify. Indirect benefits to biological resources would include, for example, project-related changes that increase cover or food production for aquatic and/or terrestrial species. Such changes could be realized somewhat distant from the storage project footprint and area of direct benefits. An example would include a surface water storage or groundwater storage project that raises regional groundwater elevations and improves floodplain vegetation, which in turn reduces instream water temperature, increases the production of instream woody material, and increases the production of insects for fish and birds.

It is assumed that the geographic reach of indirect benefits to biological resources is larger than (and includes) the reach of direct benefits. Similar to direct effects, applicants should, if possible, map and describe the potential geographic reach of indirect benefits to biological resources, with benefits assessed in combination with the types and importance of resources in the geographic reach.

4.7.6.4 Define the Temporal Scale of Project Benefits

Project applicants must describe the temporal scales (i.e., shorter time periods vs. longer time periods, seasonal or year-round) over which project benefits will be realized. REVs will be calculated by comparing the number of days a project will provide benefits versus the number of days (of that benefit) that is needed for the species, life stage, or habitat to improve. Projects that provide benefits to aquatic biological resources for longer durations will generally be considered to provide greater value than projects that provide benefits for shorter periods. The temporal scale must be identified for each ecosystem benefit claimed.

Many of the aquatic species identified by CDFW as high-priority targets have life-history stage-specific needs that are critical to the survival and condition of the species. As such, demonstrating when project-related physical changes would occur (addressing, for example, seasonality, frequency, and duration of flows) is as critical as where the change will occur to understand and evaluate the benefit potential of the change. Applicants must present information to show the temporal reach of physical changes and should describe and quantify the benefits to aquatic biological resources resulting from project-related changes.

4.7.6.5 Species-Habitat (Predictive) Models

Depending on the types of biological resources in an assessment area, models may be available to estimate the project effects on the status of resources in the with-project conditions (i.e., ecosystem improvements). Ecological models, unlike comparative analyses and index/classification procedures, allow estimation of future conditions with the input of baseline ecological conditions and future physical changes (e.g., delivery of colder water in a stream reach). As such, models are well suited for predicting future project-related ecosystem changes.

Models by design attempt to simplify otherwise complex and sometimes uncertain relationships among various factors. Life-cycle modeling, for example, is a dynamic and quickly changing area of study. Applicants should use current versions of models, apply models to appropriate circumstances, and understand model limitations.

Some commonly used and publicly available species-habitat response models and their applications are described below. Table 4-12 summarizes these and other models, and includes citations and links for their access.

Table 4-12. Summary of Models, Methods, and Approaches for Assessing Ecosystem Improvements.

Resource Effects	Tools	Key Inputs and Assumptions	Outputs	Notes/Limitations/Links
Reservoir Effects				
Effects on reservoir fish spawning success	DFW regression model	Requires CalSim II flow inputs to estimate monthly and daily changes in water surface elevation.	Estimates bass nesting success	Coarse output. The DFW regression models and an example application are documented in Appendix 9F of the Long-Term Operation (LTO) Environmental Impact Statement (EIS) (Reclamation, 2015).
Surface water temperature in rivers and reservoirs	HEC-5Q and Reclamation Temperature Models Other temperature models listed in Deas & Lowney, 2000, including CE-QUAL-W2	Requires CalSim II inputs.	Estimates daily temperatures (HEC-5Q) and monthly temperatures (Reclamation Temperature Model) in riverine surface waters, and monthly temperatures in reservoirs (HEC5Q and Reclamation Temperature Model).	Only CVP and SWP reservoirs are modeled.
Riverine Effects				
Impacts/changes to salmon early life stages	Reclamation Salmon Mortality Model. Also referred to as Egg Mortality Model	Requires temperature inputs from HEC-5Q and Reclamation Temperature Model.	Estimates Chinook salmon egg and pre-emergent fry losses on Sacramento, Feather, American, Stanislaus rivers, annually.	May underestimate temperature related mortality and may not be sensitive enough to capture small differences in scenarios. DFW SOPs and OA/QC documents may be accessed here: https://www.wildlife.ca.gov/Conservation/Watersheds/Instream-Flow/SOP
In-river salmonid production	SALMOD	Requires temperature and flow inputs from HEC-5Q.	Estimates survival and mortality of Chinook salmon (all races, several life stages) in Sacramento River mainstem; specifically, from Keswick Dam to Red Bluff Pumping Plant.	Simulates annual growth, movement, mortality of various life stages based on an initial annual adult population that resets each biological year. Not a true life cycle model because it treats production results separately for each year rather than compounding outcomes over time. Without careful consideration of inputs this model may underestimate impacts and overestimate benefits.
In-river physical habitat	PHABSIM	WUA. Requires flow inputs (e.g., CalSim II) and established	Estimates habitat area and suitability for salmonids (by life stage) and other target fish species based on stream flows.	Flow/WUA relationships have not been developed for many species, life stages, and drainages. Monthly CalSim II time step may be too broad. The PHABSIM modeling tool is available at

Table 4-12. Summary of Models, Methods, and Approaches for Assessing Ecosystem Improvements.

Resource Effects	Tools	Key Inputs and Assumptions	Outputs	Notes/Limitations/Links
		flow-habitat relationships in IFIM.		https://www.fort.usgs.gov/publication/22800 Documented flow/WUA relationships for Clear Creek, Sacramento River, Lower Feather River, and Lower American River are found in Appendix 9E of the LTO EIS.
In-river winter-run Chinook salmon impacts	IOS	Requires DSM2, CalSim II, and HEC-5Q data as model inputs.	Estimates effects on all life-stages of winter-run Chinook salmon.	Surrogate species used when winter-run Chinook salmon data not available. The IOS tool was developed by Cramer Fish Sciences and is available at http://www.fishsciences.net/projects/ios.php
Temperature effects on fish	Temperature Threshold Analysis	Requires HEC-5Q and Reclamation Temperature Model inputs.	Estimates the percentage of time (by month) that temperature thresholds are exceeded over a period of record. For different fish species and life stages in the Sacramento, Feather, American, and Stanislaus rivers, and in Clear Creek.	Monthly averages may obscure important thresholds. Temperature thresholds and their source references for a variety of fish species can be found in Appendix 9N of the LTO EIS,
Flow and temperature effects on fish, birds, and riparian habitat	SacEFT	Requires consistency check with CalSim II and Reclamation Temperature Model.	Estimates extent of salmonid (steelhead and Chinook salmon) suitable spawning and rearing habitat, salmonid egg to fry survival rate, salmonid juvenile stranding index, and salmonid redd scouring and dewatering risk. Also estimates green sturgeon egg to larvae survival rate, bank swallow suitable habitat and risk of bank sloughing at flows, and riparian habitat establishment.	Green/Yellow/Red relative value output; dashboard summaries. Proprietary tool. Contact ESSA Technologies for information and use of the model. ESSA Technologies Limited (2010).
River and Floodplain habitat	HEC-EFM, HEC-RAS, HEC-GeoEFM	Requires daily input hydrology	Use statistical relationships to determine flow values that meet ecological criteria (i.e. 2-year flow that provides 30 days of floodplain inundation/year) in HEC-EFM, perform a hydraulic analysis of those flows in HEC-RAS, and then map those flows to calculate habitat area with HEC-GeoEFM.	Requires use of ArcGIS for habitat area calculations. All three modeling tools are available at http://www.hec.usace.army.mil/software/

Table 4-12. Summary of Models, Methods, and Approaches for Assessing Ecosystem Improvements.

Resource Effects	Tools	Key Inputs and Assumptions	Outputs	Notes/Limitations/Links
Geomorphic Function and Riparian Vegetation	SRH Modeling Package SRH-2D SRH-Capacity SRH-Meander RHEM SRH-1DV	Requires input hydrology, channel geometry information, sediment information, and vegetation growth information.	• SRH-2D gives a variety of hydraulic and sediment transport outputs such as stage, velocity, bed shear stress, erosion and deposition. • SRH-Capacity gives estimates of sediment loads • SRH-Meander gives river meandering tendencies • RHEM simulates cottonwood seedling growth • SRH-1DV simulates riparian vegetation establishment, growth, and mortality	All models were developed by Reclamation's Technical Service Center. Contact the Technical Service Center (http://www.usbr.gov/research/about/index.html) for further information about these modeling tools. See also Reclamation (2011, 2012).
Juvenile fall-run and spring-run Chinook salmon abundance and growth by habitat area.	ESHE			Cramer Fish Sciences. 2011. Estimating Rearing Salmonid Habitat Area Requirements: A demonstration of the Emigrating Salmonid Habitat Estimation (ESHE) Model for California Fall-run Chinook salmon, *Oncorhynchus tshawytscha*. Prepared for the Nature Conservancy. 48 pages
Potential of habitat to support salmonids.	EDT (Ecosystem Diagnosis and Treatment)	Water temperature and flow.	Spatially explicit estimates of density independent productivity, carrying capacity, and adult abundance.	Developed by ICF International. Available at: https://edt.codeplex.com/
Delta Effects				
In-river, Delta, and ocean survival of winter-run Chinook salmon	OBAN	Requires CalSim II flow and Delta Cross Channel inputs and HEC-5Q temperature inputs.	Estimates winter-run Chinook salmon escapement and ocean survival.	Proprietary model of R2 Resource Consultants. Model is limited to winter-run and spring-run Chinook salmon.
Delta smelt entrainment	USFWS regression model DSM2 PTM	Requires CalSim II OMR Flow inputs	Estimates proportional loss of both larval/juvenile Longfin and Delta smelt. Estimates adult Delta smelt entrainment losses.	The USFWS regression model and an example application are documented in Appendix 9G of LTO EIS. Relies only on OMR flows to explain loss/salvage, and does not incorporate adult distribution data.

Table 4-12. Summary of Models, Methods, and Approaches for Assessing Ecosystem Improvements.

Resource Effects	Tools	Key Inputs and Assumptions	Outputs	Notes/Limitations/Links
Delta passage/straying of Chinook salmon	DPM	Requires daily flows and Delta exports as inputs (CalSim II and DSM2).	Estimates Chinook salmon (most races) survival in the Delta.	Uses surrogate species data.
longfin smelt abundance	Regression model	Require X2 as inputs.	Estimates longfin smelt abundance as FMWT index value	The USFWS regression model and an example application are documented in Appendix 9G of the LTO EIS. An updated model by Mount et al (2013) accounts for the period of pelagic organism decline.
Juvenile anadromous fish migration through Delta	Delta Hydrodynamic Analysis	Requires DSM2 as input.	Estimates the likelihood of successful juvenile anadromous fish migration through the Delta.	An example analysis using DSM2 is found in Appendix 9K of the LTO EIS.
Delta passage/movement	Junction Entrainment Analysis	Requires DSM2 as input.	Estimates the probability of fish entrainment in the Delta.	An example analysis using DSM2 is found in Appendix 9L of the LTO EIS.
Juvenile Chinook salmon passage through Delta	Salmonid Salvage Analysis	Requires CalSim II and DSM2 inputs.	Estimates the proportion of juvenile Chinook salmon (all races) entrainment in the Delta. Sacramento River and SJR specific.	Model is applicable to all four races of Chinook, but spring-run were not used to construct the statistical model.
Juvenile Chinook salmon rearing	Emigrating Salmonid Habitat Estimation Tool	Requires input depths and velocities from a river hydraulics model	Estimates in-river suitable habitat for emigrating juvenile Chinook salmon.	Model has been applied on the San Joaquin for Spring-run and Fall-run chinook salmon.

Reclamation Salmon Mortality Model

The Reclamation Salmon Mortality Model simulates mortality of early life stage (pre-spawned and fertilized eggs and pre-emergent fry) Chinook salmon along specific reaches of the Sacramento, Feather, American, and Stanislaus rivers. The model sets an initial spawning distribution along the river reaches and uses water temperature data to simulate egg development and mortality based on temperature relationships specified in the model. Temperature model outputs are used as inputs to the Reclamation Salmon Mortality Model. The output of the Reclamation Salmon Mortality Model is the estimated annual percent mortality of Chinook salmon pre-spawned eggs. This model is useful for a long-term comparison among alternative projects.

SALMOD

The SALMOD model simulates the life-stage dynamics of fall-run, late fall-run, spring-run, and winter-run Chinook salmon populations. The model uses daily flow and temperature data from the HEC-5Q model to simulate the annual growth, movement, and mortality of the riverine life stages of the four Chinook salmon populations based on an initial annual adult population that resets each biological year. The dynamics simulated are based on assumptions and relationships specified in the model. The final output from SALMOD is annual production (number of surviving members of each life-stage) and annual mortality based on a variety of factors, including temperature and habitat (flow) based mortality. Appendix P of the 2008 Operations Criteria and Plan Biological Assessment provides a detailed description of the SALMOD model structure, assumptions, and processes (Reclamation, 2008).

Interactive Object-Oriented Salmon Simulation (IOS) Model

The IOS model simulates the entire life cycle of winter-run Chinook salmon through successive generations. This approach allows for the evaluation of individual life-stage effects on the long-term trajectory of the population. A description of this detailed model and a sensitivity analysis is provided in Zeug et al. (2012). The IOS model is composed of the following six model stages that are arranged sequentially to account for the entire life cycle of the winter run:

- Spawning (models the number and temporal distribution of eggs deposited in the gravel at the spawning grounds)
- Early development (models the impact of temperature on maturation timing and mortality of eggs at the spawning grounds)
- Fry rearing (models the relationship between temperature and mortality of salmon fry during the river-rearing period)
- River migration (estimates the mortality of migrating salmon smolts in the Sacramento River between the spawning and rearing grounds and the Delta)
- Delta passage (models the impact of flow, route selection, and water exports on the survival of salmon smolts migrating through the Delta to San Francisco Bay)
- Ocean survival (estimates the impact of natural mortality and ocean harvest to predict survival and escapement by age)

This model requires Sacramento River HEC-5Q daily temperature outputs and CalSim II monthly and DSM2 daily flow outputs as inputs to the model. This model is useful for a long-term comparison among alternatives, but is not particularly useful for estimating the absolute magnitudes of change.

Oncorhynchus Bayesian Analysis (OBAN) Model

Water operations in the Sacramento and San Joaquin rivers and Delta affect the hydrologic environment and therefore have the potential to affect the populations of fish that reside there. These effects may not be observed directly, however, and life-cycle models may be useful to evaluate the potential effects of water operations on fish population dynamics. The winter-run OBAN model was developed to understand how anthropogenic factors in the freshwater and marine portions of the life history may affect winter-run Chinook salmon. The OBAN model integrates sources of mortality across the life cycle by calculating escapement and calculates survival through the early life stages in the Sacramento River, survival through the Delta, and survival in the ocean. This model is more sensitive to water temperature during the incubation stage (July – September) and minimum flows during the fry rearing stage (August – November), and less sensitive to Delta Cross-Channel operations, exports, and Yolo operations. This model is useful for a long-term comparison among alternatives, but is not particularly useful for estimating the absolute magnitudes of change.

Instream Flow Incremental Methodology

To compare the operational flow regime and evaluate the potential effects of flows on habitat for anadromous species inhabiting streams, the relationships between streamflow and habitat availability can be estimated for each life stage of a fish species. The analytic variable provided by physical habitat simulation (PHABSIM) is total habitat, in units of weighted usable area (WUA), for each life stage (fry, juvenile, and spawning) of an evaluation species (or race as applied to Chinook salmon). Habitat WUA incorporates both macrohabitat and microhabitat features. Macrohabitat features include changes in flow, and microhabitat features include the hydraulic and structural conditions (depth, velocity, substrate, or cover) affected by flow, which define the actual living space of the organisms. The total habitat available to a species/life stage at any streamflow is the area of overlap between available microhabitat and macrohabitat conditions. Because the combination of depths, velocities, and substrates preferred by species and life stages varies, WUA values at a given flow differ substantially for the species and life stages evaluated. Using WUA to evaluate a project or compare among projects requires intensive site-specific studies. As such, WUA-flow relationships have been developed for only some of the rivers and creeks in the Central Valley. These include Clear Creek and the Sacramento, Feather, and American rivers.

Delta Smelt Adult Entrainment Model

The magnitude of entrainment of migrating and spawning adult Delta smelt into the CVP/SWP water export facilities is substantially affected by combined OMR flow in December through March. Water exported at the Banks and Jones pumping plants typically flows through the OMR channels. A positive OMR flow indicates a northward flow in the natural direction, toward the San Francisco Bay, and contributing to the Delta outflow. A negative OMR flow (also referred to as reverse flow) indicates a southward flow induced by pumping and away from the Delta outflow. To simulate Delta smelt entrainment as influenced by OMR flow, USFWS (2008) developed a regression model based on Kimmerer (2008).

The equation estimates the percentage of adult Delta smelt that may become entrained in the pumps based on the average December through March OMR flow (in cfs). The equation is:

> Adult entrainment loss [percentage] = 6.243 - 0.000957 * OMR Flow (average OMR from December through March)

This model does not incorporate distribution of fish, and so there is a considerable amount of uncertainty with using this model as a way to predict loss. However, it can be a useful tool in describing the proportional change in loss as it relates to a proposed water storage project.

Delta Smelt Larvae/Juvenile Entrainment Model

Larval and early juvenile Delta smelt are most prevalent in the Delta from March through June. USFWS developed a regression model based on Kimmerer (2008) to calculate the percentage entrainment of larval and early juvenile Delta smelt in South Delta pumping facilities (USFWS, 2008; Kimmerer, 2008). This regression depends on two variables: March through June average OMR flow, and March through June average X2. The equation is:

> Larvae and early juvenile entrainment loss [percentage] = [0.00933 * X2 (March through June) - 0.0000207 * OMR Flow (March through June) - 0.556] * 100

Juvenile Longfin Smelt Outflow-Recruitment Relationship

Kimmerer et al. (2009) correlated log-transformed longfin smelt abundance as indexed by Fall Midwater Trawl survey data (CDFW, 2016) with the preceding winter and spring location of X2. The correlation is based on the following regression equation:

> Longfin smelt abundance index value = 10 ^ [-0.05 * (January through June X2 average position) + 7]

The equation assumes that a lower (more seaward) X2 value would lead to increased juvenile longfin smelt recruitment. The mechanism behind this relationship is still unknown. The index value indicates the relative abundance of longfin smelt and not the calculated population. A more recent statistical analysis by Mount et al (2013) included an intercept shift to account for the spread of an invasive clam (1987-88) and for the pelagic organism decline beginning in 2003-04.

DSM2 Particle Tracking Model (PTM)

DSM2, a model identified elsewhere in this document, has a particle tracking component that has been widely used to better understand transport effects on larval and juvenile Delta smelt and longfin smelt. This model has been especially useful in water operation as it allows for a simulation of Delta hydrology based on certain metrics, such as Sacramento River flow.

Delta Passage Model (DPM)

The DPM analysis is used to quantify in-Delta survival of winter-run, fall-run, and late fall-run Chinook salmon. The DPM is based on a detailed accounting of migratory pathways and reach-specific mortality as Chinook salmon smolts travel through a simplified network of reaches and junctions. The biological functionality of the DPM is based upon the foundation provided by Perry et al. (2010) as well as other acoustic tagging based studies (Michel, 2010) and coded wire tag-based studies (Perry et al., 2010; Michel, 2010; Newman and Brandes, 2010; Newman, 2008). Uncertainty is explicitly modeled in the DPM by incorporating environmental stochasticity and estimation error whenever available. The DPM does not model fry migration and has limited ability to deal with uncertainties in rearing location and hydrologic variability. The major model outputs from the DPM are:

- Delta entry timing (models the temporal distribution of smolts entering the Delta for each race of Chinook salmon)
- Fish behavior at junctions (models fish movement as they approach river junctions)
- Migration speed (models reach-specific smolt migration speed and travel time)
- Reach-specific and flow-dependent survival
- Export-dependent survival (models survival response to water export levels in the interior Delta)
- North Delta intake predation (models mortality associated with predation at a north Delta intake water diversion)

Delta Smelt Abiotic Habitat Index

Feyrer et al. (2010) demonstrated that Delta smelt abiotic habitat suitability in the fall in the West Delta, Suisun Bay, and Suisun Marsh subregions, as well as smaller portions of the Cache Slough, South Delta, and North Delta subregions, is correlated with the location of X2. X2 was used as an indicator of the suitable salinity and water transparency for rearing older juvenile Delta smelt. X2 values simulated in the CalSim II model may be averaged over a given time period and compared for the expected changes in the with-project condition.

Delta Hydrodynamic Analysis

The Delta hydrodynamic analysis summarizes 15-minute water velocity output from DSM2 over a long-term simulation period. Results show the proportion of positive velocity for each condition (e.g., without-project vs. with-project), or as a comparison among projects. The key assumption in the Delta hydrodynamic analysis is that the proportion of positive velocities of a channel, measured at a monthly time step, is an indicator of the likelihood that juvenile anadromous fish will successfully migrate through that channel toward the ocean.

Junction Entrainment Analysis

The junction entrainment analysis uses the statistical relationship published in Cavallo et al. (2015) to predict the fish routing based on the proportion of flow moving through channel junctions in the Delta. Results are presented as the probability of fish entrainment at various junctions in the Delta. Flow outputs from DSM2 are inputs to this model. Using a proportion of flow entering a location (node) at a time step (e.g., 15 minutes) over a long-term simulation period, mean daily proportions of flow into a node location can be calculated and then used to predict the daily probability of fish entrainment. Cavallo et al. discuss the limited conditions in which this method may be used to predict fish routing or to influence it by managing flows or diversions.

Temperature Threshold Analysis

Monthly temperature data from any temperature model can be used to calculate the percentage of time (over a long-term simulation period) that monthly temperature thresholds for fish species and life stages may be exceeded on Central Valley rivers. Temperature thresholds, particularly for cold water species such as salmonids, are readily available in the scientific literature (e.g., EPA, 2003).

Sacramento River Ecological Flows Tool (SacEFT)

SacEFT (ESSA Technologies Limited, 2010) evaluates the ecological value of a proposed operations alternative from a multiple species point of view. SacEFT is a database-centered software system for linking flow management actions to changes in the physical habitats for several focal species of concern. This tool has been developed to link the river flow on the Sacramento River and ecological targets to improve conditions for the targets. SacEFT is designed to address the lack of information on the flow needs of valued ecosystem components of the Sacramento River. It provides the information to fill previously identified information gaps and link quantitative tools that can help water operations modelers and decision makers consider ecosystem needs in their planning. SacEFT provides estimates of ecological flow needs that are critical to maintaining or restoring river processes beneficial to fish, vegetation, and wildlife species of the Sacramento River ecosystem. The use of such information in decision making would help ensure that water flowing through the upper Sacramento River achieves more ecological benefits as it is routed to the Delta. It uses existing information synthesis, consultative and collaborative workshops, targeted field investigations, computer modeling, and a decision analysis tool to quantify selected linkages among the flow regime, channel characteristics, and specific valued ecosystem components. Focal species for SacEFT are Chinook salmon, steelhead, green sturgeon, Fremont cottonwood, western pond turtle, and bank swallows.

Sedimentation River Hydraulics (SRH) Model Package

The SRH Model Package (Reclamation, 2011, 2012) includes five numerical models that together simulate processes of flow hydraulics, sediment transport, river meandering, and the establishment and survival of riparian vegetation in the Sacramento River corridor. The SRH-Capacity Model estimates the contribution of tributary sediment to the main stem of the Sacramento River, which is important in estimating sustainability and future trends of river processes including riparian vegetation growth. The SRH-Meander Model is used to simulate future meander tendencies of the river and to estimate areas of erosion and changes to flood plain topography. SRH-2D relates sediment transport and flow and can estimate locations of point bar scour and suitable hydraulic habitat for fish and other aquatic species. The Riparian Habitat Establishment Model (RHEM) simulates individual cottonwood seedling growth while incorporating the effects of sediment texture and hydraulic properties, water table depth, and atmospheric conditions.

The fifth model of the SRH Model Package, SRH-1DV, pulls together aspects and outcomes of modeling from the SRH-Capacity Model, SRH One-Dimensional Sediment Transport Dynamics Model (SRH-1D), and RHEM for a construction of flow, sediment transport, and vegetation growth and removal river processes. SRH-1DV may be used to assess the survivability of cottonwoods and other riparian vegetation, including invasive plants, for river and reservoir operational conditions.

Emigrating Salmonid Habitat Estimation (ESHE) Model

The ESHE model simulates rearing and emigration of individual daily groups (cohorts) of juvenile spring-run and fall-run Chinook salmon. The model tracks their abundance, average migration speed, size, territory size, and ultimately the amount of suitable rearing and emigration habitat required to sustain the number of juvenile salmon present within a model reach. The model assumes a 274-day model year that ranges from November 1 through July 31 of the following year. These dates are the combined rearing and emigration period for Central Valley fall-run and spring-run Chinook salmon. Model outputs provide daily estimates of the number of juvenile spring-run and fall-run Chinook salmon present in each model reach and the required available suitable habitat needed to support them throughout the rearing and emigration period. The ESHE model could potentially be used to estimate increases in fish abundance or growth as a result of increased floodplain habitat.

Ecosystem Diagnosis and Treatment (EDT)

The EDT model is a fish life-cycle habitat model designed to help managers identify priorities for habitat restoration investments and to understand how habitat conditions control fish abundance and distribution. EDT assesses the potential of aquatic habitat to support fish populations using the population performance metrics embodied in the NMFS Viable Salmonid Population (VSP) concept: fish abundance, productivity, biological diversity and spatial structure (McElhany et al. 2000). While EDT is most frequently applied to habitat for salmonids it has been applied to other fish species such as Delta Smelt (ICF International 2013). The model outputs metrics for fish survival (density independent productivity), habitat carrying capacity, and adult abundance that can develop under various flow and water temperature regimes.

Species Conceptual Models

In circumstances where there is no existing or accepted resource response model available to assess ecosystem improvements resulting from physical change, conceptual models may be useful in developing an assessment approach. Conceptual models are typically developed to illustrate, in simplistic, meaningful terms, sometimes-complex ecosystem relationships (e.g., food web showing trophic cycling of food from primary-producing plankton to humans, as ultimate consumers). Conceptual models can be used to develop, refine, and document a common understanding of ecosystems, including assumptions about intended outcomes from potential actions, such as restoration. Conceptual models also illustrate cause-and-effect relationships in systems.

CDFW has developed several conceptual models in association with the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP), a component of the multi-agency Ecosystem Restoration Program. The DRERIP conceptual models describe linkages and causal relationships within systems and attempt to predict how actions such as restoration may result in various outcomes. Two categories of DRERIP conceptual models have thus far been developed: species life history models, and ecosystem models (processes, habitats, and stressors). Applicants are encouraged to refer to publicly available conceptual models (including the DRERIP models) to understand how physical changes may result in ecosystem improvements and to assist in developing approaches for benefit assessment. A good example is the updated and comprehensive conceptual model prepared by the Interagency Ecological Program’s (IEP) Management Analysis and Synthesis Team (MAST) for Delta smelt (IEP, 2015). Based on the MAST model, the State of California developed a Delta Smelt Resiliency Strategy to improve the status of Delta smelt, both in the near-term and in the future (Resources Agency, 2016). This strategy document identifies specific actions to benefit Delta smelt and other species.

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4.8 Water Quality Analysis

This section describes concepts and methods for quantifying water quality benefits (or impacts) that could result from water storage projects. This section focuses on methods for quantifying surface water quality. For a discussion of groundwater quality analysis methods, see Section 4.4, Groundwater Analysis.

This section describes water quality improvements for which WSIP funding may be provided. Funding is available for water quality improvements specified by the State Water Board priorities. Funding for other water quality improvements may be provided if they contribute to ecosystem benefits. Following the description of water quality improvements, the pathways by which a water storage project could lead to water quality improvements are discussed. Relationships between State Water Board priorities and water quality improvements are discussed. Finally, methods for quantification of water quality improvement benefits are presented, including metrics (i.e., how parameters or constituents are measured) used to evaluate benefits and applicable water quality models.

Applicants are not limited to using the specific water quality constituents, benefits, and quantification methods and models discussed in this section. Applicants are required to quantify all physical changes of a project and may choose from among the methods described in this Technical Reference or use other methods as appropriate. Regardless of the methods chosen, applicants must clearly describe and support the data, methods, and assumptions used to quantify physical changes leading to water quality benefits.

4.8.1 What are Water Quality Improvements?

Water Code Section 79753 (a)(2) defines water quality improvements as providing “significant public trust resources, or that clean up and restore groundwater resources.” Public trust resources related to water quality improvements, for the purposes of this program and quantifying public benefits, are fishery protection, fish and wildlife conservation, preservation of waterways in their natural state, and recreation. Water quality improvements in the Delta, or in other river systems, that provide these public trust resources are public benefits (as are improvements for human health).

4.8.2 State Water Board Water Quality Priorities

The State Water Board has developed priorities for the improvement of California’s water quality for the benefit of people, fish, and wildlife that could be realized by water storage projects. The State Water Board water quality priorities are to:

1. Improve water temperature conditions in surface water bodies that are not meeting water quality standards for temperature.
2. Improve dissolved oxygen conditions in surface water bodies that are not meeting water quality standards for dissolved oxygen.

3. Improve nutrient conditions in surface water bodies that are not meeting water quality standards for nutrients.
4. Improve mercury conditions in surface water bodies that are not meeting water quality standards for mercury.
5. Improve salinity conditions in surface water bodies that are not meeting water quality standards for sodium, total dissolved solids, chloride, or specific conductance/electrical conductivity.
6. Protect, clean up, or restore groundwater resources in high- and medium-priority basins designated by the Department.
7. Achieve Delta tributary stream flows that resemble natural hydrograph patterns or other flow regimes that have been demonstrated to improve conditions for aquatic life.
8. Reduce current or future water demand on the Delta watershed by developing local water supplies and improving regional water self-reliance.
9. Provide water for basic human needs, such as drinking, cooking, and bathing, in disadvantaged communities, where those needs are not being met.

4.8.3 State Water Board Relative Environmental Value

The State Water Board developed a list of criteria to be used to determine the REV for water quality improvement benefits provided by the proposed project. These criteria are:

1. Number of water quality priorities addressed by the project.
2. Magnitude of water quality improvements.
3. Spatial scale of water quality improvements.
4. Temporal scale of water quality improvements.
5. Inclusion of an adaptive management and monitoring program that includes measurable objectives, performance measures, thresholds, and triggers for managing water quality benefits.
6. Immediacy of water quality improvement actions.
7. Immediacy of the realization of water quality benefits.
8. Duration of water quality improvements.
9. Consistency with water quality control plans, water quality control policies, and the Sustainable Groundwater Management Act (2014).
10. Connectivity of water quality improvements to areas that support beneficial uses of water or are being managed for water quality.
11. Resilience of water quality improvements to the effects of climate change and extended droughts.
12. Extent to which undesirable groundwater results that are caused by extractions are corrected.

These criteria will be used to evaluate a proposed water storage project's contributions to achieving State Water Board water quality priorities.

4.8.4 Other Water Quality Improvements

Some water quality improvements other than those included in the State Water Board water quality priorities may be fundable under the WSIP, but the improvements must support other purposes and be allocated to other public benefit categories, such as ecosystem improvements. Examples include water quality improvements not associated with the parameters and/or constituents identified in the State Water Board's priorities 1-5. In such cases, applicants must identify the water quality issue being addressed, the improvement potentially realized, and the analyses supporting the project's contribution to water quality improvements.

Water quality improvements that may be allocated to ecosystem improvement benefits would support the following CDFW priorities:

- Provide cold water at times and locations to increase the survival of salmonid eggs and fry.
- Improve ecosystem water quality.
- Provide flows that increase dissolved oxygen and lower water temperatures to support anadromous fish passage.
- Increase Delta outflow to provide low-salinity habitat for Delta smelt, longfin smelt, and other estuarine fishes in the Delta, Suisun Bay, and Suisun Marsh.

Public benefits associated with achieving these priorities as they relate to ecosystems (e.g., fish, habitat) are explained in greater detail in Section 4.7, Ecosystem Analysis. Water quality-related characteristics (e.g., dissolved oxygen, water temperature, salinity) are discussed further in this section.

4.8.5 Relationships Between Project Implementation and Water Quality Improvements

Water quality improvements that could be provided by a water storage project are described below. Fundable water quality improvements are not limited to those included in the State Water Board priorities. If water quality improvements do not meet a State Water Board priority but do provide an ecosystem improvement that meets a CDFW priority, or provide another benefit (e.g., recreation), the benefit may still be fundable. If, for example, a project would reduce mercury levels in a waterway that currently has less than dangerous levels of mercury, a reduction in this constituent provides little to no ecosystem benefit. If, however, a project would remove selenium from a contaminated wetland, the ecosystem benefits to fish and wildlife are much more defensible and clear. More information regarding ecosystem-related water quality improvements are provided in Section 4.7.

Table 4-13 shows the relationship between priorities, physical changes that could be provided by storage projects, and targeted benefits.

Table 4-13. Relationship Between Water Quality Priorities, Physical Change that Could be Recognized by Storage Projects, and Targeted Benefits.

State Water Board Priority	Physical Change	Targeted Benefits
1. Improve water temperature conditions in surface water bodies that are not meeting water quality standards for temperature.	Effective temperature improvements involve the design and operation of reservoirs so the manner of releasing water, both physically and temporally, as well as other actions (e.g., vegetative cover), results in meeting water quality objectives.	Physical changes can result in achieving water quality objectives for temperature by regulating releases through temperature stratification in a reservoir.
2. Improve dissolved oxygen conditions in surface water bodies that are not meeting water quality standards for dissolved oxygen.	Effective dissolved oxygen improvements involve the design and operation of reservoirs so the manner of releasing water, both physically and seasonally, as well as other actions that lower biochemical oxygen demand concentrations, results in meeting water quality objectives.	Physical changes, such as high or turbulent flows, can result in achieving water quality objectives for dissolved oxygen by aerating the water body. Also, regulated flows and operations that reduce residence times and temperatures may allow greater saturation.
3. Improve nutrient conditions in surface water bodies that are not meeting water quality standards for nutrients.	Effective management strategies to control nutrient levels may involve managing nutrient loading, sediment, recycled wastewater, and biological communities; restoring wetlands; regulating quantity and timing of freshwater flow (including from the Delta); aerating bottom waters; capping or dredging bottom sediments; increasing flushing or circulation rates; harvesting aquatic plants; and inactivating nutrients; biological control results in achieving water quality objectives for nutrients	Physical changes, such as reducing residence time, can result in achieving water quality objectives for nutrients and may reduce the negative effects of high concentrations of nutrients. However, nutrient levels may not be the primary drivers in macrophyte density nor cyanobacteria bloom initiation.
4. Improve mercury conditions in surface water bodies that are not meeting water quality standards for mercury.	Effective management strategies to control or mitigate mercury accumulation in reservoirs may involve preventing or cleaning up contamination from mine sites (e.g., acid mine drainage), aerating anoxic bottom sediment and waters, managing water levels, nutrients, dissolved oxygen, and other factors that affect production of methylmercury in reservoirs and bioaccumulation of methylmercury in fish, changing the timing and location of reservoir discharges, managing fisheries to control bioaccumulation (e.g., restoring native fishes and increasing numbers of lower trophic level fishes), reducing the source of mercury before flooding, limiting the extent of flooded areas, communicating health risks associated with fish consumption (e.g., signage, educational materials), and capping or dredging bottom sediment.	Less conversion to methylmercury. Physical changes can result in achieving water quality objectives for mercury by reducing the conversion of mercury to methlymercury. Achieve water quality objectives for mercury.

Table 4-13. Relationship Between Water Quality Priorities, Physical Change that Could be Recognized by Storage Projects, and Targeted Benefits.

State Water Board Priority	Physical Change	Targeted Benefits
5. Improve salinity conditions in surface water bodies that are not meeting water quality standards for sodium, total dissolved solids, chloride, or specific conductance/electrical conductivity.	Effective salinity improvements may involve releasing stored water to meet salinity objectives, operational or physical changes at the Delta export pumps, operational or physical changes to Delta channels, treating or reusing agricultural drainage, and re-operation of agricultural drainage (e.g., real-time salinity management).	Physical changes can result in achieving water quality objectives for salinity by dilution or repulsion. Higher flows could reduce salinity intrusion. Restoring the natural variability of saltwater intrusion could reduce invasive species (e.g., macrophytes).
6. Protect, clean up, or restore groundwater resources in high- and medium-priority basin designated by the Department.	The State Water Board's specific priorities related to groundwater protection and remediation efforts include: increasing storm water capture, infiltration, and reuse projects; emphasizing the use of low impact development and green infrastructure technologies, that provide multiple benefits (e.g., water quality, supply, habitat, flood control); increasing the percolation of low-nitrate/low-salt waters; developing and implementing Salt and Nutrient Management Plans as specified in the State Water Board's Recycled Water Policy 6 (2009); establishing or enhancing local groundwater management efforts; including Integrated Regional Water Management planning, that include performance standards for maintaining groundwater quality and quantity; using recycled water to improve or protect groundwater quality in a manner that also offsets groundwater overdraft or increases surface water storage; providing large-scale groundwater cleanup where there is no readily identifiable or viable responsible party; constructing and using barrier wells to prevent or reduce seawater intrusion; preventing contamination in groundwater from spreading, especially to groundwater sources used as drinking water.	Physical changes can prevent groundwater contamination, clean up groundwater contamination that already exists, and restore groundwater levels that result in water quality improvements.
7. Achieve Delta tributary stream flows that resemble natural hydrograph patterns or other flow regimes that have been demonstrated to improve conditions for aquatic life.	Regulate flow pattern with operations to resemble natural hydrograph patterns or other flow regimes that have been demonstrated to improve conditions for aquatic life	Flows resembling natural unimpaired hydrographs may benefit native species and their habitats. For example, pulse flows can be incorporated into reservoir operating regimes to maintain channel function, enhance outmigration, or trigger ocean entry of fishes.
8. Reduce current or future water demand on the Delta watershed by developing local water supplies and improving regional water self-reliance.	Increase available and reliable regional water supply in areas that rely on Delta water supply, through surface water or groundwater storage, and water quality improvements.	More water can be available to distribute throughout the Delta for other purposes, such as ecosystem or water quality benefits

Table 4-13. Relationship Between Water Quality Priorities, Physical Change that Could be Recognized by Storage Projects, and Targeted Benefits.

State Water Board Priority	Physical Change	Targeted Benefits
9. Provide water for basic human needs, such as drinking, cooking, and bathing, in disadvantaged communities, where those needs are not being met.	Increase available and reliable water supply of sufficient quality to support human health beneficial uses, through surface water or groundwater storage, and groundwater remediation.	Improved water supply reliability for disadvantaged communities

4.8.5.1 State Water Board Water Quality Priorities 1 Through 5

The State Water Board developed priorities for the WSIP that aim to improve water quality for the health of aquatic species and humans. Water quality constituents and parameters can occur in reservoirs, rivers, and the Delta at levels that cause one or more state and/or federal water quality standards to not be met (i.e., one or more beneficial uses of the water body are inhibited).

State Water Board Priorities 1 through 5 address pollutants and parameters that (1) are of a high concern to the State Water Board, (2) can be improved through water storage projects, and (3) may be on the federal CWA Section 303(d) list. The 303(d) list identifies water bodies that do not meet federal standards for specific pollutants/parameters. Applicants should consult the 303(d) list for water bodies within the geographic reach of the proposed project that may be relevant to the State Water Board water quality priorities (the geographic reach includes the project area, benefit area, or impact area). In addition, applicants should consult water quality control plans (e.g., Basin Plans), and other sources, to identify water quality standards for appropriate pollutants/parameters and geographic reach.

The 303(d) list is provided on the State Water Board website. The Final 2012 California Integrated Report [CWA Section 303(d) List/305(b) Report] satisfies 303(d) requirements by providing a fact sheet for each listed water body and each de-listed water body. The fact sheets include the listing decision, evidence for the decision, potential sources of the pollutants, affected beneficial uses as defined by water quality control plans, expected date for issuing the total maximum daily load (TMDL), data used to quantify the water quality, and the water quality criterion.

In accordance with CWA Sections 303(d) and 303(e), approved TMDLs and their implementation regulations are required to be incorporated into Basin Plans. Basin Plans describe existing and potential beneficial uses, water quality objectives that include TMDLs and waste discharge requirements, implementation plans to meet objectives, and programs for monitoring beneficial uses. Basin Plans are provided on Regional Water Quality Control Board websites, which can be accessed from the State Water Board website.

The discussions below for State Water Board Priorities 1 through 5 explain the significance of the water quality parameters (i.e., temperature, dissolved oxygen, and salinity) and the chemical constituents (e.g., nitrogen, phosphorus, mercury), and how they can vary.

Priority 1 — Temperature

Water temperature influences physical, chemical, and biological processes of an aquatic ecosystem. Changes in water temperature can affect warm and cold freshwater habitats and can be significant for threatened and endangered aquatic species. Temperature thresholds vary by species and life stage and, if exceeded, can impair growth, reproduction, or cause mortality. Water temperatures are also a factor in how other parameters and constituents affect water quality. Water temperatures in a river or stream can vary based on channel geometry, vegetative cover, climate, water discharges, and reservoir releases.

Priority 2 — Dissolved Oxygen

Low dissolved oxygen concentrations can cause mortality, reduced swimming performance, reduced growth, impaired development, reduced spawning success, reduced fecundity and fertility, and altered behavior. As a result of these effects, other impairments can arise, such as increased susceptibility to predation, parasites, pathogens, and contaminants. Oxygen can be reintroduced to water by diffusion between the atmosphere and the water surface and through photosynthesis by aquatic plants (e.g., algae). Dissolved oxygen also varies with temperature and salinity. High temperatures and higher salinity, among other factors, decrease dissolved oxygen.

The amount and timing of water released from a proposed storage project can help to achieve water quality objectives for dissolved oxygen. Many of the design and operation factors that address dissolved oxygen impairment will also improve temperature levels.

Priority 3 — Nutrients

High concentrations of nutrients, such as nitrogen and phosphorus, can contribute to eutrophication, a process where there is excessive primary productivity (e.g., growth of macrophytes, phytoplankton, or cyanobacteria). Eutrophication can result in blooms of algae or cyanobacteria that can produce toxins. These toxins can cause illness in people who consume the contaminated water or tainted fish or shellfish. Algae, as the base of the food web, provide food for zooplankton and fish; however, excessive algae can settle to the bottom and decompose, resulting in dissolved oxygen concentrations below thresholds for some aquatic species (Wetzel, 2001). Nitrogen and ammonia concentrations in the Delta are primarily from point source urban discharges (i.e., WWTPs) (Ballard, et al, 2009; CVRWQCB, 2010a). Removal of these nutrients may occur through uptake by algae or other aquatic vegetation and conversion to gas by nitrification and volatilization.. It is generally recognized that nutrient levels are high in the Delta and do not limit ecosystem productivity (Jassby et al., 2002).

Insufficient nutrients in a system can be a concern. Salmon fisheries in Alaska, Canada, and Northern California have found that anthropogenic causes of reduced nutrients (cultural oligotrophication) have reduced salmon production. In addition, the State Water Board's Statewide Mercury Program has determined that cultural oligotrophication likely has exacerbated mercury contamination in reservoirs.

Priority 4 — Mercury

Mercury in water is a significant health concern. Mercury concentrations in fish exceeding the human health criteria can cause significant adverse health effects (EPA, 2001). Recent research on mercury has found that fish species are as sensitive to mercury toxicity as humans (National Wildlife Federation, 2012). Mercury is introduced into water bodies by atmospheric deposition, but most of Delta mercury comes from runoff from legacy mercury and gold mining activities entering the Delta from streams (CVRWQCB, 2010b). Other sources of mercury include urban runoff, municipal wastewater treatment plants, wetlands and open water sediment flux, and agricultural return flows. Methylmercury, a more toxic form of mercury, can be formed naturally in aquatic environments in the presence of anaerobic organisms and can be removed through demethylation. Bioaccumulation is a major concern with methylmercury because it causes significant adverse health impacts on humans, fish, and wildlife.

Particle-bound inorganic mercury settles out in reservoirs and other depositional areas where anaerobic bacteria in the sediment convert it to methylmercury, the form that is biologically available and can bioaccumulate in higher trophic level organisms. Reservoirs, therefore, have the potential to amplify the adverse effects of mercury in the aquatic environment. Furthermore, the rate of methylation and the toxicity of mercury to aquatic life are affected by water temperature, dissolved oxygen, and salinity, among other factors.

Priority 5 — Salinity

Salinity indicates the water's salt concentration and is measured as the concentration of total dissolved solids, specific conductance or electrical conductivity, or the concentration of sodium or chloride. Excessive salinity can affect aquatic life directly and indirectly (e.g., changing the chemistry of other constituents) and can impair the use and effects of water for domestic, agricultural, and industrial water supply. Most of the salts in the Delta and in tributaries of the Delta come from tidal action when freshwater flows from tributaries are low and from agricultural runoff from salt-rich soils draining into the San Joaquin River (CALFED, 2007).

In addition, implementation of salinity standards to protect Delta agriculture has reduced the natural variability of saltwater intrusion into the Delta. This affects habitat conditions for species native to the Delta and may create conditions that are beneficial to invasive or other undesirable species (e.g., macrophytes, cyanobacteria).

Some salinity impairment is caused or exacerbated by flow regulation/modification and can be mitigated by the pattern, volume, and timing of reservoir releases. Effective salinity improvements may involve releasing stored water to meet salinity objectives;

operational or physical changes at the Delta export pumps; operational or physical changes to Delta channels; treating or reusing agricultural drainage; and re-operation of agricultural drainage (e.g., real-time salinity management).

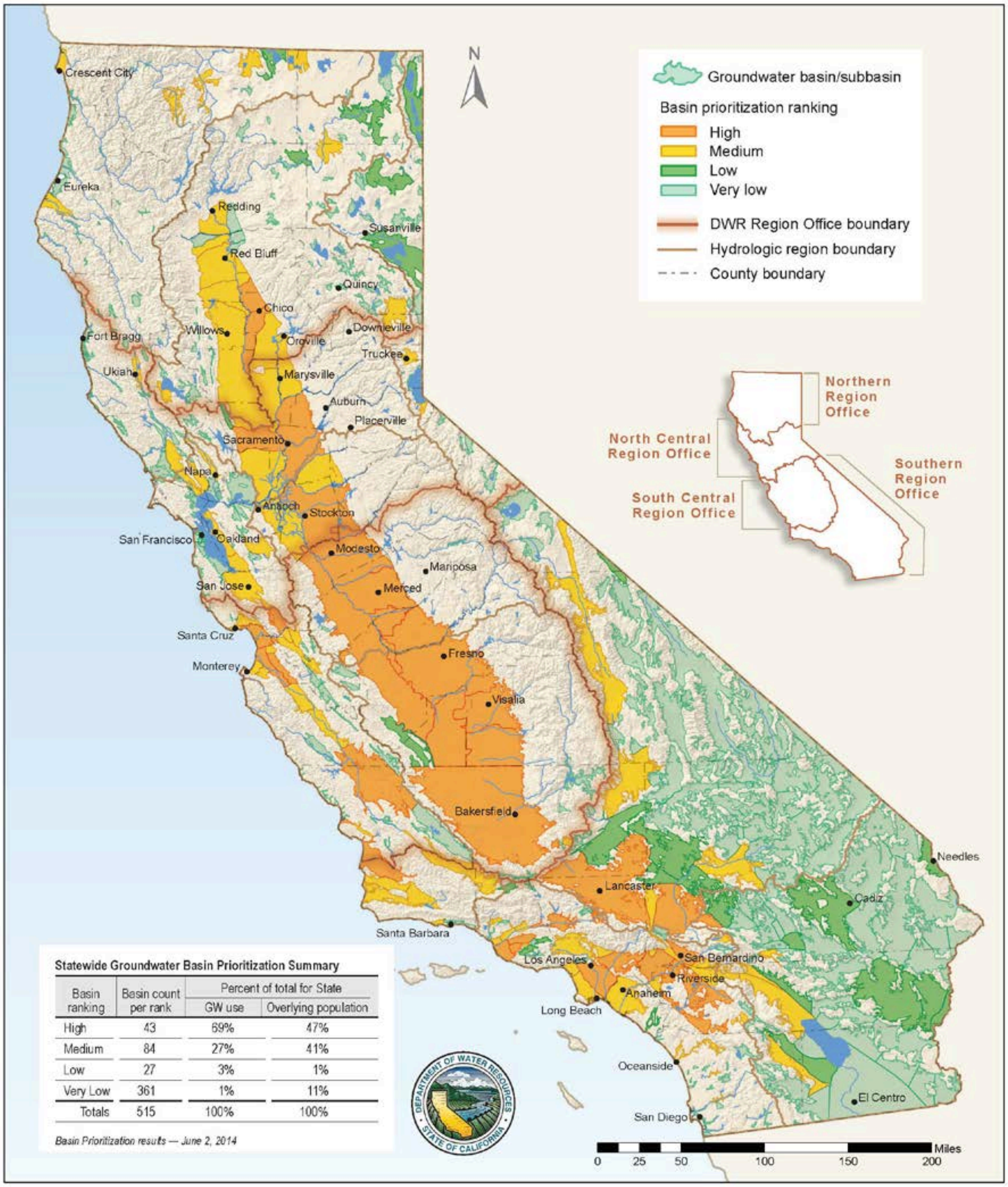
4.8.5.2 State Water Board Water Quality Priorities 6 Through 9

The State Water Board's Priorities 6 through 9 are discussed below.

Priority 6 — Groundwater

In many parts of the state, groundwater is being depleted, especially during prolonged drought conditions when demand exceeds recharge. In addition, some aquifers are contaminated with pollutants and are not currently useable as a source of supply. Proposed projects that would protect, clean up, and restore groundwater in high- and medium-priority basins may address this State Water Board priority. Protecting groundwater from contaminants can be achieved by preventing releases to groundwater from point source discharges (e.g., leaking underground tanks, industrial activities that discharge chemical waste) and non-point source discharges (primarily agricultural operations), and by containing existing aquifer contamination to protect clean groundwater nearby. To clean up or reduce contaminant concentrations in groundwater for beneficial uses, aquifer remediation techniques can be implemented or good quality water from surface reservoirs can be used for blending with groundwater of lesser quality prior to use to increase the available usable storage. Restoration of groundwater levels can improve water quality, depending on source water. Protecting, cleaning up, and restoring groundwater resources can also improve surface water quality when streams are connected to underlying shallow aquifers.

DWR has prioritized groundwater basins to identify, evaluate, and determine the need for additional groundwater level monitoring. The Statewide Groundwater Basin Prioritization is a ranking of groundwater basin and subbasin importance that incorporates groundwater reliance and focuses on basins producing greater than 90 percent of California's annual groundwater. Basins have been ranked as high, medium, or low priority based on criteria specified in the California Water Code (Section 10933). A map of groundwater basin priorities has been developed and is shown as Figure 4-9.



Statewide Groundwater Basin Prioritization Summary

Basin ranking	Basin count per rank	Percent of total for State	
		GW use	Overlying population
High	43	69%	47%
Medium	84	27%	41%
Low	27	3%	1%
Very Low	361	1%	11%
Totals	515	100%	100%

Basin Prioritization results — June 2, 2014

Figure 4-9. Statewide Groundwater Basin Prioritization.

Source: DWR, 2015a

Priority 7 — Delta Tributary Flow

Hydrology of the Delta watershed has been regulated by water diversion, storage, and use; as a result, flows have become more homogenous. Native aquatic species, which have evolved to take advantage of flow and habitat variability, have been adversely affected by physical and flow-related habitat simplification, which often favors exotic species over native species. This concept, and the supporting science, is described and incorporated in the report Development of Flow Criteria for the Sacramento-San Joaquin Delta Ecosystem (State Water Board, 2010a), which includes flow criteria expressed as a percentage of the unimpaired hydrograph rather than as fixed values. The report indicates that Delta "inflows should generally be provided from tributaries to the Delta watershed in proportion to their contribution to unimpaired flow unless otherwise indicated."

Water storage projects typically result in net decreases to instream flows due to consumptive use, but new and existing projects can be operated in a manner that results in flows that resemble natural unimpaired hydrographs to the benefit of native species and their habitats. For example, pulse flows can be incorporated into reservoir operating regimes to maintain channel function, enhance outmigration, or trigger ocean entry of fishes.

The Bay-Delta Plan (State Water Board, 2006) includes water quality objectives to protect fish and wildlife beneficial uses through inflows to the Delta from the Sacramento River and San Joaquin River and Delta outflows, in addition to water quality objectives for salinity and dissolved oxygen. In December 2010, the State Water Board completed a prioritized schedule and cost estimate to complete instream studies for Delta tributaries (State Water Board, 2010b). The report includes a detailed list (Schedule 1) of Sacramento River and Delta tributaries that are high priorities for conducting instream flow analyses and developing instream flow criteria. Some water storage projects can implement instream flow criteria that have been established for rivers and streams identified in Schedule 1.

Projects that result in Delta tributary stream flows that resemble natural hydrograph patterns or other flow regimes that improve conditions for aquatic life may include those designed to divert and store (in surface impoundments or groundwater basins) high flows that exceed established instream flow criteria caps or other levels demonstrated to exceed flows needed for aquatic habitat or to cause human or environmental harm.

Priority 8 — Demand on Delta Watershed

As stated above, water storage projects are typically associated with a net depletion of instream flow. Incremental improvement to instream flow conditions and water quality can potentially be achieved in the Delta watershed by increasing local water supplies. Developing local water supplies in southern California, for example, could reduce reliance on imported Delta water and/or create additional flexibility in the timing of diversions from the Delta or its tributaries. Developing additional water supply capacity south of the Delta would also result in a more diverse and potentially more reliable source of supply considering the regulatory uncertainty associated with diverting water from the Delta and predictions of future reductions in the Sierra snowpack due to climate change. Types of water storage projects that could both increase reliable local water supplies south of the Delta and have water quality benefits include storm water capture, infiltration, and reuse projects and conjunctive use or other groundwater storage projects that result in measurable improvements to Delta flows or flow variability conducive to enhancing conditions for aquatic life.

Priority 9 — Basic Human Needs

In 2012, California became the first state in the nation to recognize legislatively the human right to water. Specifically, Water Code Section 106.3 states “every human being has the right to safe, clean, affordable, and accessible water adequate for human consumption, cooking, and sanitary purposes.” On February 16, 2016, the State Water Board adopted a resolution that established the human right to water as a core value and directed its implementation in State Water Board programs and activities (State Water Board, 2016).

Over 21 million Californians rely on contaminated groundwater as a source of drinking water (State Water Board, 2013). Their water system draws water from one or more contaminated groundwater wells prior to treatment or blending.

State Water Board Priority 9 for the WSIP focuses on those elements of the policy declared in Water Code Section 106.3 that relate to water quality by prioritizing safe and clean water for disadvantaged communities (DACs). Water storage projects can have the potential to address surface water and groundwater contamination so that safe and clean water is available for DACs. Types of water storage projects that may provide water for basic human needs include surface water and groundwater storage and groundwater remediation.

Applicants can identify DACs using DWR’s web-based Disadvantaged Communities Mapping Tool (DWR, 2015b).

4.8.5.3 Other Benefits

Potentially fundable water quality improvements are not limited to the State Water Board priorities. Other water quality improvements resulting from a proposed project that do not benefit a State Water Board priority can be considered for funding if the improvement can be allocated to another benefit (e.g., ecosystem) as specified in Water Code Section 79753. Other water quality benefits that result in ecosystem improvements are discussed in Section 4.7, Ecosystem Analysis.

4.8.6 Assessing Physical Change and Water Quality Improvements

This section describes metrics, modeling concepts, and tools that may be used to assess water quality improvements. Tools and approaches that are used to simulate physical changes (e.g., groundwater and surface water resources and operations), and quantify changes in water quality parameters and constituents, are described in greater detail in other analyses in Section 4. Groundwater quality modeling techniques are described in Section 4.4, Groundwater Analysis.

4.8.6.1 Methods and Metrics to Evaluate Water Quality Improvements

Water quality improvements can be measured by changes in temperature, dissolved oxygen, salinity, and concentrations of specific constituents (e.g., nitrogen, phosphorus, mercury) and by changes in groundwater, Delta tributary flows, demand on the Delta, and water for basic human needs. These shall be evaluated quantitatively for the without-project and with-project conditions, with the change representing the improvement or adverse impact. Table 4-14 associates physical changes from project operations or contributions with targeted outcomes (i.e., water quality improvements) that are anticipated to be caused or influenced by physical changes.

Methods to assess water quality improvements include both formal models and simpler approaches that may be appropriate in some cases. Regardless of approach, the method must have the geographic and temporal extent, duration, and level of detail needed to quantify the improvement.

Define the Spatial Extent of Water Quality Improvements

Project applicants must demonstrate that water storage projects provide water quality improvements at a project's location, adjacent to the project, and/or downstream of a project. Applicants must describe the physical spaces and locations of proposed project facilities (e.g., reservoir footprints, groundwater wells, conveyance structures). The spatial extent of physical changes to water resources must be defined in applications. Physical changes include changes to water quantity and flow patterns, which are determined through water resources operations analyses. Physical changes may improve water quality by changing constituent concentrations or other water quality parameters downstream. Applicants must also describe and map the spatial extent of water quality improvements (with-project conditions relative to without-project conditions), especially surface water reaches where water quality standards are not being met (e.g., on the 303(d) list) and improvements are expected. An applicant must also demonstrate water quality improvements to the Delta ecosystem or its tributaries.

Water storage projects may benefit other resources (e.g., agriculture, fish habitat, recreation areas) as a result of improved water quality. Such changes could be realized somewhat distant from the project.

Define the Temporal Scale of Water Quality Improvements

Project applicants shall describe the temporal scale (i.e., shorter time periods vs. longer time periods, seasonal or year-round) of water quality improvements that will be realized by the proposed project. All else equal, projects that provide water quality improvements sooner will generally provide greater improvements than projects that provide improvements later. Applicants must present information to show the temporal scale and describe and quantify the water quality improvements resulting from project-related changes. Demonstrating when project-related physical changes would occur (e.g., season, frequency, duration of flows) is as critical as where it will occur when quantifying water quality changes.

Similar to the spatial extent, the temporal scale of water quality improvements may benefit other resources (e.g., water supply, ecosystem, recreation).

4.8.6.2 Water Quality Modeling Concepts

Water quality parameters and constituents can be analyzed with quantitative physical and empirical models. Physical models use governing equations for calculating heat exchange and diffusion and are able to model conditions that may not be present in the existing system. Empirical models use a statistical relationship between two or more observed characteristics and are unable to model situations that did not occur during the observed data collection period. A combination of physical and empirical modeling methods can be used.

An alternative to quantitative models are qualitative models, such as conceptual models. Conceptual models can be developed to determine an outcome evaluated by identifying sources or factors of water quality parameters and constituents and processes that may affect a change in magnitude.

Modeling concepts are discussed below for water quality parameters and constituents.

Table 4-14 provides general information about water quality models. It should be noted that this is only a partial list of models that have been used to simulate water quality. For parameters and constituents that do not have qualitative models, conceptual models could be created to identify qualitative changes in water quality.

Table 4-14. Partial List of Water Quality Models applicable in Water Bodies in California

Model	Version	Geographical Scope	Model Time Step	Model Objective/Output Parameters	Comments	More Information
DSM2 –Qual	8.1.2	Delta	15 minutes	Models salinity (EC), organic carbon, and temperature. Long-term water quality changes in the Delta. Calculates the proportion of water from different sources at specific locations in Delta (fingerprinting).	This 1-dimensinoal model is recommended for running 82 years, is flexible for the evaluation of project-specific details. The ocean-side boundary at Martinez is too close to the study area for accurately simulating salinity transport under certain conditions. DSM2-Hydro is needed to generate the hydrodynamic inputs to DSM2-Qual.	http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm
DSM2-PTM	8.1.2	Delta	Monthly	Models flow-salinity relationship. Model provides an indication of particle fate and transport that can be used to infer effects of Delta hydrodynamics on Delta residence time.	This Quasi-3D (simplified representation of 3D hydrodynamics) model assists in visualizing changes in hydrodynamics and simulates short term periods. DSM2-Hydro is needed to generate the hydrodynamic inputs to DSM2-PTM.	http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm
Artificial Neural Networks (ANNs)	Bay-Delta Conservation Plan ANNs for no tidal marsh habitat, new ANNs to be developed for tidal marsh habitat	Delta	Monthly	Models flow-salinity relationship. ANNs are trained to mimic DSM2 salinity results for use in CalSim II	This model is dynamically linked to CalSim II.	http://baydeltaconservationplan.com/Libraries/Dynamic_Document_Library/Public_Draft_BDCP_EIR-EIS_Appendix_5A_-_EIR-EIS_Modeling_Technical_Appendix_-_Sections_A_B.sflb.ashx
Selenium Exposure of Sturgeon (clam-based food web)	DRERIP (Presser and Luoma, 2013)	Western Delta and Suisun Bay.	Monthly	Estimate whole-body selenium concentrations under “low-flow” and “average” conditions.	This model is the best available tool for detailed evaluation and screening, and compares to 5 and 8 mg/kg potential effect concentrations. This model is dynamically linked to DSM2 and uses DSM2-QUAL outputs (source water finger printing). Modeling for water in Suisun Bay is less certain than for the Delta.	http://www.usbr.gov/mp/nepa/documentShow.cfm?Doc_ID=23711
Selenium Exposure of Diving Ducks (clam-based food web)	DRERIP (Presser and Luoma, 2013)	Western Delta and Suisun Bay	Monthly	Estimate selenium concentrations in eggs under “low-flow” and “average” conditions.	This model is the best available tool for detailed evaluation and screening and compare to 7.7, 12.5, and 16.5 mg/kg potential effect concentrations. This model is dynamically linked to DSM2 and DSM2-QUAL (source water finger printing) outputs. Modeling for water in Suisun Bay less certain than for the Delta.	http://www.usbr.gov/mp/nepa/documentShow.cfm?Doc_ID=23711
Selenium Exposure of Largemouth Bass (insect-based food web)	DRERIP (Presser and Luoma, 2013)	Delta	Monthly	Estimate whole-body selenium concentrations in “average” conditions.	This model is the best available tool for detailed evaluation and screening and compare to 5 and 8 mg/kg potential effect concentrations. This model is dynamically linked to DSM2 and uses DSM2-QUAL (source water finger printing) outputs.	http://www.usbr.gov/mp/nepa/documentShow.cfm?Doc_ID=23711
Selenium Exposure of Insectivorous (insect-based food web)	DRERIP (Presser and Luoma, 2013)	Delta	Monthly	Estimate selenium concentrations in eggs under “average” conditions.	This model is the best available tool for detailed evaluation and screening and compare to 7.7, 12.5, and 16.5 mg/kg potential effect concentrations. This model is dynamically linked to DSM2 and uses DSM2-QUAL (source water finger printing) outputs.	http://www.usbr.gov/mp/nepa/documentShow.cfm?Doc_ID=23711
Selenium Exposure of Largemouth Bass (insect-based food web)	DRERIP (Presser and Luoma, 2013)	San Joaquin River (main stem at Vernalis)	Monthly	Estimate whole-body selenium concentrations in “average” conditions.	This model is the best available tool for detailed evaluation and screening and compare to 5 and 8 mg/kg potential effect concentrations. This model is dynamically linked to DSM2 and uses DSM2-QUAL (source water finger printing) outputs.	http://www.usbr.gov/mp/nepa/documentShow.cfm?Doc_ID=23711
Methylmercury Regional Water Quality Control Board Model for the Delta	2015 version used for LTO EIS	Delta	Period average or seasonal	Models standardized size largemouth bass fillet concentrations of mercury. Estimates fillet mercury concentrations of fish under long term average conditions.	This model is a locally accepted method for translating between waterborne methylmercury and fish tissue mercury. This model is dynamically linked to DSM2 and uses DSM2-QUAL (source water finger printing) outputs.	http://www.waterboards.ca.gov/centralvalley/water_issues/tmdl/central_valley_projects/delta_hg/april_2010_hg_tmdl_hearing/apr2010_tmdl_staffrpt_final.pdf; https://www.usbr.gov/mp/nepa/documentShow.cfm?Doc_ID=22417

Table 4-14. Partial List of Water Quality Models applicable in Water Bodies in California

Model	Version	Geographical Scope	Model Time Step	Model Objective/Output Parameters	Comments	More Information
HEC-5Q	May 2015	Rivers and reservoirs	Daily	Simulates the effects of operations on water temperature in the Sacramento River American River, Stanislaus River, and the lower San Joaquin River as well as the major CVP reservoirs. Capable of simulating temperature control device operations on Shasta and Folsom. Provides temperature output.	This model simulates mean daily (based on 6-hour meteorology) reservoir and river water temperatures. The CALSM25Q model completes a simplistic temporal downscaling on the CalSim II monthly average tributary flows to convert them to daily inputs to the HEC-5Q model. The model has been used in several studies including the LTO EIS where temperatures were simulated for the Trinity River, Trinity Lake, Lewiston Reservoir, Shasta Lake, Keswick Reservoir, Black Butte Reservoir, American River, Folsom Lake, Lake Natoma, Stanislaus River, the lower San Joaquin River, and New Melones Reservoir.	http://www.hec.usace.army.mil/publications/TechnicalPapers/TP-111.pdf, https://www.usbr.gov/mp/nepa/documentShow.cfm?Doc_ID=22422
RMA Trinity River Temperature Model	RMA 11 latest version	Trinity River	Hourly/Sub-hourly	RMA-11 is a general purpose water quality model that simulates temperature and constituent concentration along a river reach.	Information from “Trinity River Flow and Temperature Modeling Project” report.’ The report states that this suite of models is used as a complimentary tool to SNTEMP for screening purposes where sub-daily time step may be necessary. This model provides a better representation of physics and is computationally intensive. The RMA suite includes RMA-2 and RMA-11. The RMA-2 model produces time series of velocities, water levels, and discharges.	http://www.rmanet.com/projects/modeling/bdcp/; http://odp.trrp.net/Data/Documents/Details.aspx?document=338
Stream Network Temperature (SNTEMP) model	January 12 2010	Any stream network	Time steps ranging from 1 month to 1 day	SNTEMP (Stream Network Temperature model) predicts the daily mean and maximum water temperatures as a function of stream distance and environmental heat flux.	Mechanistic, one-dimensional heat transport model. Accounts for streamside shading vegetation and groundwater influx, Unable to deal with rapidly fluctuating flows.	https://www.fort.usgs.gov/sites/default/files/products/publications/2767/2767.pdf;
Reclamation Temperature Model (RECTEMP)	LTO EIS Version	Trinity Lake, Whiskeytown Reservoir, Shasta Lake, Oroville Reservoir, Folsom Lake, New Melones Reservoir, and Tulloch Reservoir, Lewiston, Keswick, and Goodwin reservoirs; Lake Natoma), and five main river systems (Trinity, Sacramento, Feather, American, and Stanislaus rivers)	Monthly	Calculates temperature changes in the regulating reservoirs, below the main reservoirs, and computes temperatures at several locations along the rivers.	This model is one-dimensional in the longitudinal direction and assumes fully mixed river cross sections. Calculations are based on regulating reservoir release temperatures, river flows, and climatic data.	https://www.usbr.gov/mp/nepa/documentShow.cfm?Doc_ID=22422
River Assessment for Forecasting Temperature (RAFT)	Unknown	Rivers	Sub-hourly	Couples river heat budget models and spatially explicit weather forecasting models to produce accurate river temperature forecasts at mesoscales (sub-hourly intervals for every 1 km of river). Used on the Sacramento River.	The River Assessment for Forecasting Temperature (RAFT) is a collaborative project between NOAA and NASA (funded by NASA Applied Sciences Grant # NNX08AK72G). The goal of the project is to improve decision support systems for river temperature management in the western U.S. The project focuses on managed rivers where discharged from reservoirs (both discharge flow and temperature) can have significant impact on downstream temperature regimes. These water temperature models can inform water managers of the predicted impacts on the thermal regimes of downstream waters under current operations, and allow them to quantitatively evaluate a range of alternative operating scenarios.	http://oceanview.pfeg.noaa.gov/RAFT/

Table 4-14. Partial List of Water Quality Models applicable in Water Bodies in California

Model	Version	Geographical Scope	Model Time Step	Model Objective/Output Parameters	Comments	More Information
CE-QUAL-W2	Version 4.0	Rivers, estuaries lakes, reservoirs, river basin systems	Varies	Temperature-nutrient-algae-dissolved oxygen-organic matter and sediment relationships	Can simulate reservoirs in 2-D. There is a calibrated and validated CE-Qual-W2 (W2) model of Millerton Lake and Temperance Flat Reservoir. The period simulated in the model is 1977 to 2003, on a 1-hour time step. CE-Qual-W2 model output of Friant Dam release temperatures are used as input for the HEC-5Q model used for predicting San Joaquin River temperatures. The model was used in: -San Joaquin River Restoration Program Programmatic EIS/EIR -Upper San Joaquin River Basin Storage Investigation EIS/EIR	http://www.ce.pdx.edu/w2/
QUAL 2K/ QUAL 2E	Version 2.12	River and stream	Daily	Conductivity, inorganic suspended solids, dissolved oxygen, CBOD, nitrogen, phosphorus, phytoplankton, detritus, pathogen, alkalinity, total inorganic carbon, algae, total suspended solids	This one dimensional assumes channels are well-mixed vertically and laterally and non-uniform, steady flow is simulated. The heat budget and temperature are simulated as a function of meteorology. Point and non-point loads and abstractions are simulated.	http://www.qual2k.com/; QUAL2K documentation
WARMF	Version 6.5b	Rivers and lakes	Daily	Nutrients, bacteria, dissolved oxygen, acid mine drainage, loading from onsite wastewater systems, mercury loading, fate, and transport including bioaccumulation in fish tissue, sediment transport, periphyton in rivers, algae in stratified reservoirs	WARMF does not rigorously simulate groundwater processes; does not model deep groundwater aquifers (all sub-watersheds are assumed to be closed, storage effects are not considered, and deep groundwater quality is not tracked).	http://gator4201.hostgator.com/~systechwater/warmf_intro/
HEC-RAS	Version 5.0.1	Rivers		Flow sediment transport, and water temperature	The model allows the user to perform one and two-dimensional unsteady flow calculations, sediment transport/mobile bed computations, and water temperature/water quality modeling.	http://www.hec.usace.army.mil/software/hec-ras/whats_new.aspx
CALSIM II	May 2015	Rivers and reservoirs	Monthly	CalSim II model is used frequently to approximate the changes in storage, flow, salinity, and reservoir system reoperation.	CalSim II uses the ANN to determine releases from upstream reservoirs to meet Delta salinity and X2 requirements.	http://baydeltaoffice.water.ca.gov/modeling/hydrology/CalSim/index.cfm
CALSIM III	Not yet released	Rivers and Reservoirs	Monthly	CalSim III model is used to approximate the changes in storage, flow, salinity, and reservoir system reoperation.	Compared to CALSIM II, CALSIM III has greater spatial resolution, enhanced groundwater integration with C2VSIM, new input hydrology, demands are broken down by user (instead of demands being handled by large DSAs [Depletion Study Areas]), calculation demands and return flows differently, stream gains and surface runoffs are local, and inflows are separated out more.	http://www.cwemf.org/Asilomar/CWEMF_ADraper.pdf

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Water Temperature

Water temperature is generally simulated as a heat exchange process within a river or a lake. Various factors are considered, including air temperature, solar radiation, long-wave radiation, heat conduction between the river bed and the water, convection between layers in a water body, and evaporation at the air-water interface. These factors and their interaction create gains and losses in heat that result in changes in water temperatures. The change in water temperature is directly affected by the volume of water within which the heat exchange occurs, which is a function of flow in the river or storage in a reservoir. In addition, inflow temperatures to a river reach or reservoir dictate the initial temperature conditions. Inflow from stream tributaries, agriculture return flows, and water diversions also affect flow temperature conditions. The temperature in river reaches downstream of reservoirs will be affected by reservoir outflow and the release temperatures. Higher storage levels can create and protect thermal stratification, thereby preserving cold water in the reservoir. The temperature of water released to the river depends on the reservoir outlet elevation. Temperature control devices on dams, such as those at Shasta and Folsom dams, control the release temperatures to help meet downstream temperature requirements.

Typically, water temperature in rivers is modeled using a one-dimensional plug flow assumption. However, resolution beyond one-dimension may be required depending on the geometry of the water body, the question that the model is addressing, and the level of resolution required for that particular question. Inputs to water temperature models are typically observed or modeled flow and/or storage data, inflow temperature boundary conditions, bathymetric data, and climatic parameters (sunlight, wind, shading, etc.). Outputs are simulated time series of temperature by location. Reservoir models may produce temperature contour plots as an additional output. Timescales are typically less than one day to represent diurnal response to temperature. In 2000, the California Water and Environmental Modeling Forum released a Water Temperature Modeling Review (Deas and Lowney, 2000) that discussed input and output parameters, available water temperature models, and some water temperature studies.

Dissolved Oxygen

Dissolved oxygen in a water body depends on air temperature, water temperature, organic matter, salinity, season, time of day, and groundwater discharge into streams (USGS, 2014; NOAA, 2008a, 2008b). Processes that introduce oxygen into the water include diffusion at the water surface and photosynthesis of aquatic plants. Eutrophication and nitrification also reduce dissolved oxygen in the water.

The Streeter-Phelps model evaluates dissolved oxygen in a stream or a river based on two factors: reaeration and carbonaceous oxygen demand. The model assumes that the stream acts as a plug flow in steady state. Several models are available that account for most of the water quality processes that affect dissolved oxygen, such as photosynthesis, carbonaceous oxygen demand, oxidation, nitrification, plant respiration, and reaeration. Input variables considered in these models include initial constituent concentrations, water temperature, salinity, and hydraulic characteristics. Typical model outputs include simulated time series of dissolved oxygen at given locations. Models that estimate dissolved oxygen include CE-QUAL-W2, QUAL 2K, and WARMF (Table 4-14).

Nutrients

Nutrients of greatest importance are nitrogen (in the forms of ammonium and nitrate) and phosphorus. A significant amount of these nutrients come from fertilizers and human and animal waste (Chapra, 1997), and they can enter the water from erosion, agricultural runoff, urban runoff, and disposal of treated effluent. Nitrates and ammonium can be removed from water through uptake by plants (algae or other aquatic vegetation) or through denitrification/volatilization. Phosphorus can attach to suspended particles and settle out of the water column. Decaying plants return nutrients to the water and sediment, which can affect the water quality downstream. The movement and effects of nutrients depend on flow and other factors such as temperature and turbidity.

Models can be used to assess the effects of nitrogen and phosphorus on dissolved oxygen depletion through nitrification and eutrophication. Eutrophication models can assess scenarios where phosphorus is limiting (i.e., controls plant growth) or nitrogen is limiting. Outputs include simulated time series of nutrient concentrations and dissolved oxygen concentrations at given locations. Models that simulate nutrients include CE-QUAL-W2, QUAL 2K, and WARMF (Table 4-14).

Mercury

Sources of mercury include current and past mining operations (especially in the Coast Ranges and the Sierra Nevada), atmospheric deposition, and wastewater treatment plant discharge. Processes that may affect the concentration of mercury in water include volatilization and settling. When mercury is methylated (inorganic mercury is converted to methylmercury) through the action of microbes in aquatic systems, it is more toxic in the food chain. Factors that can affect methylation and the bioaccumulation of methylmercury in the food chain are growth rates, pH, the length of the aquatic food chain, water temperature, and dissolved oxygen (EPA, 2001).

Mercury exposure to humans and wildlife is primarily through the consumption of fish, so metrics to measure ecological benefits will include reduced mercury concentrations in fish tissue. Mercury impacts also need to be considered in surface reservoirs. Reservoir creation or enlargement can exacerbate mercury contamination and exposure in the lentic environment, and biogeochemical processes within reservoirs can result in water quality impacts downstream. Applicants should consider these potential effects in the analysis if applicable.

Mercury can be modeled as it is transported through waterways and as it bioaccumulates in the food chain. A report by the Sacramento River Watershed Program described important concepts for modeling mercury’s transport and interactions within waterways (Delta Tributary Mercury Council, 2002). Although the report was created for the Sacramento River Watershed, the concepts apply to other watersheds. Typical input requirements for models include time series of various parameters, such as hydrologic and hydraulic variables, and constituent concentration data. Some mercury bioaccumulation models use observed relationships between concentrations in water and concentrations in fish tissue as inputs. Model outputs include mercury and methylmercury concentrations in water and fish tissue. In addition to the models described in the Sacramento River Watershed Program report, WARMF has the capability to model mercury, and the Central Valley Regional Water Quality Control Board developed a methylmercury model for the Delta (Table 4-14). Some studies have used DSM2 to model the mercury concentration in water.

Salinity

Salinity is measured as the concentration of total dissolved solids, specific conductance or electrical conductivity, or the concentration of sodium or chloride, and can come from human sources, such as municipal, industrial, and agricultural discharges, and from natural sources like the ocean (State Water Board, 2006). Water treatment technologies, farming practices, CVP and SWP operations, and regulatory processes affect the levels of and changes in salinity in water bodies.

Models of salinity in surface water generally use mass balance calculations and can be modeled as electrical conductivity or total dissolved solids. QUAL2K is a one-dimensional model of stream water quality (i.e., it assumes the stream is well mixed) that simulates salinity concentration, measured as electrical conductivity. A model specific to the Delta is DSM2, a one-dimensional hydrodynamic and water quality simulation model that models salinity, with output also in units of electrical conductivity. The ANN module in CALSIM II and III also models salinity in the Delta. More information regarding the models is provided in Table 4-14.

Groundwater

Groundwater contamination can occur as a result of changes in land use, point and non-point source discharges, discharges to an unsaturated zone that seep into groundwater over time, or flushing of salts that have been concentrated in the soil profile due to agricultural irrigation. The water quality of contaminated aquifers can be improved through remediation projects. Groundwater modeling tools are available for aquifer remediation analysis by either using a groundwater flow model with particle tracking or using a groundwater flow and contaminant transport model. Contaminant transport models assess the potential migration of existing contaminant plumes due to storage project implementation and estimate the resulting groundwater quality over time after a remediation project is implemented. MODFLOW-Surfact, MT3D, RT3D, and SEAWAT are publicly-available groundwater transport models. Because these models are integrated with groundwater flow models, these models are discussed in further detail in Section 4.4.6.

4.8.6.3 Models

Water quality models have been developed for reservoirs and streams throughout California by several agencies such as DWR, Reclamation, and USACE and by private and academic researchers. Documents and websites are available that list water quality models, and many documents evaluate water quality models.

Typically, surface water quality models are one-dimensional, but more complex models are also available for evaluating water quality in streams, rivers, reservoirs, or a combination. Water quality models are primarily dynamic and can simulate water quality at a fine time scale. Most models are capable of simulating multiple parameters and constituents selected by the user. Water quality models vary in the way they account for hydrology, time scale (time step, time frame, season, water year type), and initial conditions (concentrations, temperature, pH). Some models have separate modules to simulate hydrology and assess the effect of varying hydrologic regimes on water quality. Initial concentrations and other initial conditions can be gathered from studies, monitoring reports, or agency websites as raw data. Raw data should be reviewed prior to use. Results are generally presented as a time series in tables or graphs.

Below is a partial list of agencies that have posted water quality models on their websites:

- DWR: http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/deltaevaluation.cfm
- USACE: http://el.erdc.usace.army.mil/products.cfm?Topic=model&Type=watqual
- EPA: https://www.epa.gov/exposure-assessment-models/surface-water-models
- USGS: http://water.usgs.gov/nawqa/modeling/

Below is a partial list of modeling literature and model evaluations that describe simulating parameters or constituents, or describe water quality models:

- Surface Water-Quality Modeling (Chapra, 1997)
- Compendium of Tools for Watershed Assessment and TMDL Development (EPA,1997)
- TMDL Model Evaluation and Research Needs: https://www.epa.gov/sites/production/files/2015-07/documents/600r05149.pdf (EPA, 2005)
- Water Temperature Modeling Review: http://cwemf.org/Pubs/BDMFTempReview.pdf (Deas and Lowney, 2000)
- Pesticide and threatened and endangered species co-occurrence model in the Central Valley (Hoogeweg et al., 2012)

4.9 Flood Risk Reduction Analysis

This section describes concepts and methods for quantifying physical flood control benefits (or impacts) that could result from water storage projects. A definition of flood control benefits is presented below, followed by a description of the two main ways new, expanded, or re-operated water storage projects can achieve flood control benefits. Then, methods and models for evaluating and quantifying flood control benefits are described.

Relative to other public benefit categories, flood control benefits and methods are generally well-established. In particular, DWR and USACE have developed a series of hydrologic and damage assessment methods and models that provide standardized approaches (see, for example, DWR, 2014; USACE, 2006). These methods and models are described in this and other sections, although applicants are not required to use those models. For a complete overview of methods for assessing flood control benefits, applicants should review this section, economic methods described in Section 5 and Appendix F.

4.9.1 Definition of Flood Control Benefits

The WSIP regulations define a flood control benefit as follows:

> *"Flood control benefit" means a public benefit that reduces or prevents the extent or magnitude of the expected detrimental effects of flooding as a result of new, expanded, or reoperated storage projects. Per Water Code section 79753(a)(3), flood control benefits include, but are not limited to, increases in flood reservation space in existing reservoirs by exchange for existing or increased water storage capacity in response to the effects of changing hydrology and decreasing snow pack on California's water and flood management system.*

Based on the definition above, there are three main ways water storage projects can provide flood control benefits:

- The water storage project can provide a direct flood control benefit by reducing the expected detrimental effects of flooding under with-project future conditions as compared to without-project future conditions through a combination of new or expanded flood control storage capacity and reservoir operations.
- The water storage project can provide indirect flood control benefits by offsetting the loss of water storage capacity due to increases in flood control reservation space at existing reservoirs that may be required due to climate change.
- Water storage projects can modify operations at existing reservoirs to incorporate forecasting into flood operations to maximize the use of the flood storage space in a reservoir during a flood event.

Typically, flood benefits and impacts are described in terms of projected changes to physical characteristics such as peak flow, river stage (water surface elevation), inundated area, or inundation depth. Monetary damages are damages to property, emergency response costs, cleanup costs, and related economic losses such as lost business due to flood events. A reduction in expected loss of life is another important measure of the benefits of flood control.

Flood events are probabilistic, so flood control benefits or impacts must consider not only each physical characteristic of the hydrologic system but its probability of occurrence, expressed either as an exceedance probability or a recurrence interval. The primary purpose of flood control is to reduce the probability of damage and loss of life by changing the relationships between hydrologic inflows (importantly, storm events), storage releases, river flows, overbank flows, flood inundation areas and depths, and affected lives and property. Therefore, an analysis of flood control benefits or impacts evaluates these relationships in sequence.

The metric or metrics at each step can be expressed as values for specific design events, such as the 100-year peak flow event, or as an exceedance curve based on the range of possible events with probabilities driven by the underlying hydrology and operational controls. The benefit or impact resulting from a proposed project can be expressed as a change in the value of a metric at a specific design event. For example, a project that reduces the 100-year peak flow may reduce or eliminate the associated inundated area and flood depths, which in turn may reduce or eliminate monetary damages and loss of life.

4.9.2 Relationship Between Water Storage Projects and Flood Control Benefits and Impacts

This section summarizes the primary ways water storage projects may provide flood control benefits and the potential flood control impacts resulting from new storage projects.

4.9.2.1 Direct Flood Control Benefits

A water storage project can include flood control as one of the direct public benefits of the project. The project would accomplish this by creating a physical change (based on a comparison of without-project and with-project future conditions) in the magnitude and duration of flood flows and stages, and a resulting reduction in potential flood damages. Demonstrating flood control benefits requires a project operations plan that includes flood operations. Providing local flood control benefits could potentially cause flood control impacts at the system-wide level, and vice versa. Applicants must address whether flood control benefits are realized locally and/or throughout the larger flood control system, and address and mitigate potential negative impacts, as necessary.

4.9.2.2 Indirect Flood Control Benefits

Potential changes in hydrology due to climate change may result in an increase in the frequency and magnitude of flood events. To address this potential increase in the frequency and magnitude of flood events, existing reservoirs that are operated for flood control purposes may have to allocate additional storage to flood control. Increasing flood control storage would require existing reservoirs to reduce storage dedicated for other purposes, such as water supply, environmental, hydropower, and recreation. A new, expanded, or reoperated water storage project could provide flood control benefits by offsetting the loss of that additional water storage allocated to flood control at existing reservoirs. As a result, there would be a net increase in flood control storage, and no net loss in water storage capacity.

For example, an existing 300,000-acre-foot reservoir dedicates 200,000 acre-feet of storage capacity to water supply and 100,000 acre-feet to flood control (Figure 4-10). Under climate change conditions, that existing reservoir may have to dedicate 150,000 acre-feet of storage to flood control by reducing water supply storage to 150,000 acre-feet. A new, expanded, or reoperated water storage project could provide 50,000 acre-feet of storage for water supply, resulting in a net increase in flood control storage of 50,000 acre-feet with no net loss in water supply storage.

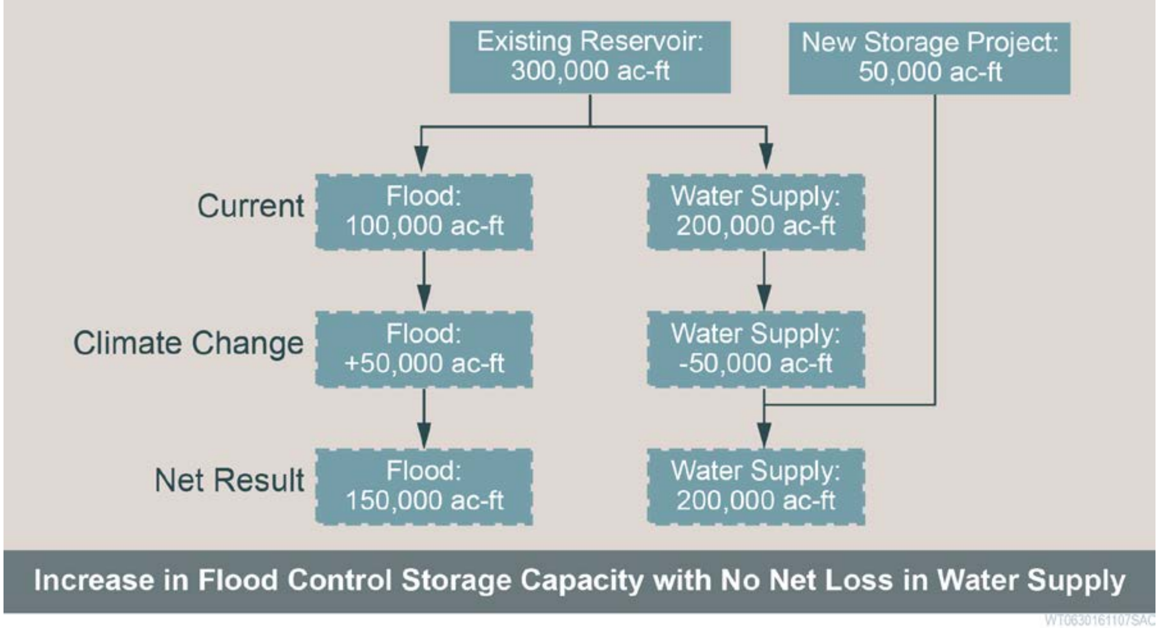

Figure 4-10. Example of a New Storage Project with Net Flood Control Storage Increase.

Under this scenario, a new, expanded, or reoperated storage project could not also claim a water supply benefit for the 50,000 acre-feet because there is no overall net increase in water supply. If the new project provided 100,000 acre-feet of storage dedicated to water supply, then half of that storage could be claimed as flood control benefits and half of that storage could be claimed as water supply benefits. This type of flood control benefit would require coordination, and agreements, between the existing reservoir and the new storage project, and perhaps with other existing projects.

4.9.2.3 Existing Operations Modification

A proposed project could incorporate operational changes at existing reservoirs, such as incorporating weather forecasting into operations. This would allow a reservoir to potentially maintain a smaller flood pool, and as a result, increase water supply conservation storage. If a high flow event is forecast, the reservoir can make pre-releases from the conservation storage to make room for the high flow event.

4.9.2.4 Flood Control Impacts

Negative effects, or impacts, of a water storage project on flood control must be considered and quantified where applicable. Flood control impacts of a water storage project would be primarily driven by the purpose and operations of a reservoir. For example, if the purpose of a reservoir is for water supply storage, and the reservoir is operated so that the reservoir stays full, the reservoir may be required to make large releases in advance of a large storm to ensure major flood impacts do not occur. This could result in localized flooding downstream, impacting downstream communities.

4.9.3 Assessing Physical Change and Flood Control Benefits and Impacts

As described above, a project can provide a direct flood control benefit by creating a physical change (based on a comparison of without-project and with-project future conditions) in the magnitude and duration of flood flows and stages. An applicant would calculate benefits by quantifying physical changes (i.e., benefits or impacts) in expected flows and stages and the resulting change in flood damages and loss of life. This section describes methods, models, and metrics of quantifying physical changes and flood control benefits for projects that provide flood control as a direct project benefit. The methods are limited to those relevant for riverine and estuarine floodplain flooding that could be affected by a water storage project. Coastal flooding and pluvial flooding (i.e., ponding caused when the overland runoff into an area exceeds the rate of drainage) are not addressed.

Historical floods can provide important empirical information to improve flood damage estimates and should be documented wherever possible. It may be possible in some cases to use historical flood information to quantify physical benefits of flood control from a proposed water storage project. The disadvantage of this method is that it is almost always incomplete. Only flood events that occurred are counted, but not others that are possible but have not occurred. It relies on historical records of the hydrologic and hydraulic conditions that occurred and estimates of the resulting flood damage. Finally, conditions such as riverine features, levee conditions, and development in the floodplain are likely to have changed since the historical flood.

4.9.4 Quantifying Physical Changes

Quantifying flood control benefits or impacts involves a series of steps linking hydrologic flows to operations, riverine conditions, floodplain inundation, damage to properties, and loss of life. The following steps summarize the analysis for the with-project condition.

- Hydrologic records or predictions are used to develop inflows for the proposed storage reservoir, typically for a selected set of potential high-inflow events.
- The operation of the proposed storage reservoir determines the relationship between inflows and releases.
- Riverine hydraulics assesses the relationship between reservoir releases and flow/stage at points downstream.
- Characteristics of flood control structures, such as levee fragility curves, are used to assess the probability of structural failure at different flow/stage conditions.
- Further hydraulic modeling is used to determine flows into the floodplain and the inundation areas and depths resulting from the flows.

These steps are also done for the without-project condition, so that failure probabilities, inundation area, and other physical metrics of flood risk can be compared between the without-project and with-project conditions. Finally, an inventory of affected residents, land uses, buildings, and infrastructure is used to estimate expected damage and loss of life due to inundation under the without-project and with-project conditions (see Section 5.4.3 for further discussion of monetary flood damage analysis).

In the sections below, hydrologic analyses refer to the unregulated hydrology development and reservoir operations. Hydraulic analyses refer to riverine hydraulics, flood control structure characteristics and flood hydraulics. The State of California has used this approach for its CVFPP for the Sacramento and San Joaquin basins. Figure 4-11 shows a schematic of the CVFPP analyses and models. Applicants with projects within the Sacramento and San Joaquin basins that could affect Central Valley flooding may use these methods and models.

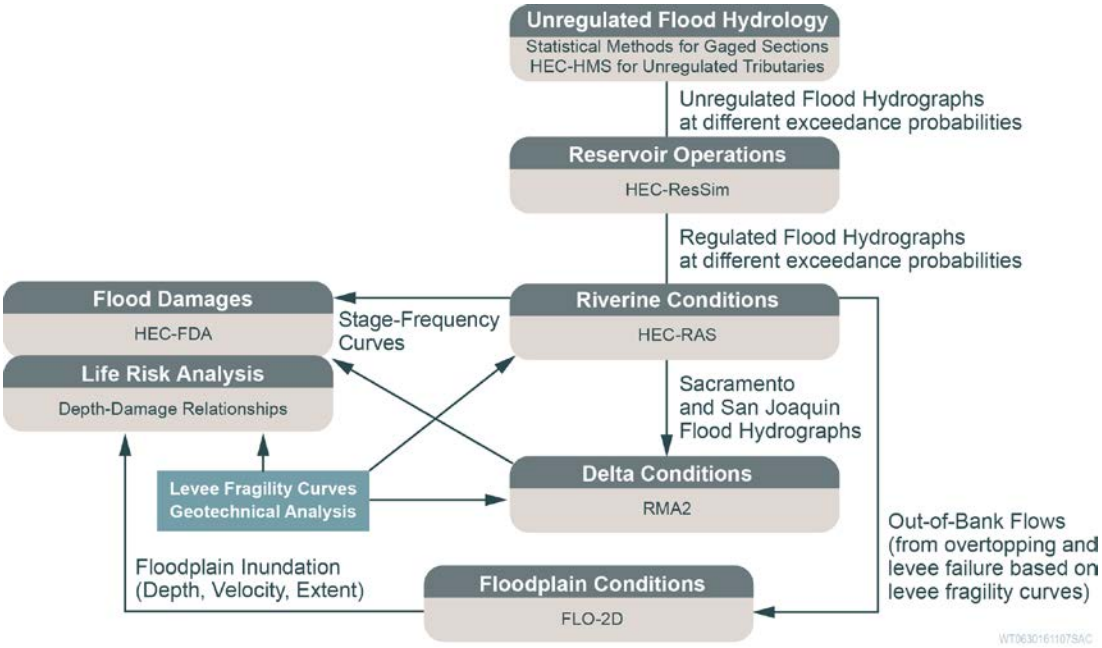

Figure 4-11. Schematic of CVFPP Process and Tools for Calculating Flood Damages.

4.9.4.1 Hydrologic Analyses

Hydrologic models and historical data can be used to develop unregulated flood hydrology; reservoir operations analysis help to transform unregulated flows into regulated flood hydrographs. Hydrologic and operations analyses are conducted to quantify regulated flows for different events characterized by their exceedance probability or recurrence interval (e.g., a 100-year flow event). Typically, at least three such events are needed to construct exceedance curves that can support the monetary damage and loss-of-life analysis. Applicants must determine the appropriate number and recurrence interval of events needed to demonstrate benefits or impacts.

Unregulated Flood Hydrology

Unregulated flood hydrology refers to synthetic hydrographs developed from a range of approaches, including using different hydrologic models and historical data. The unregulated hydrographs reflect the flows within the system that would occur if no flood control operations were in place. The method used to develop the unregulated flow hydrographs depends on the duration and time scale resolution of potential flood events, and on the availability and quality of historical flow data.

For areas without historical flow data, rainfall runoff hydrologic models and statistical approaches are common methods for developing unregulated flood hydrographs. Rainfall runoff models generate flow-time series based on the precipitation that falls on a drainage basin. These models generally require large amounts of input data, including precipitation and drainage basin characteristics such as land-use. USACE’s Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) is a commonly used rainfall-runoff modeling tool for natural river systems. Statistical methods to estimate unregulated hydrographs generally involve the use of historical data from nearby rivers or watersheds. There are many documented statistical approaches that have been used to develop unregulated flood hydrographs, such as regression analysis and dimensionless hydrographs. If a statistical method is deemed necessary for the project, applicants should determine what method is most appropriate and justify that method.

For areas with historical flow data, hydrologic routing models are often used to generate unregulated flood hydrographs. The hydrologic models use historical reservoir inflows upstream of a reservoir that are routed downstream to quantify the attenuation and combined effects of multiple time series. However, even with historical data available, statistical methods are often required to estimate local inflows. HEC-HMS and Hydrologic Engineering Center's Reservoir Simulation Model (HEC-ResSim) are two commonly used hydrologic routing models. An example of unregulated flood hydrology development is the Central Valley Hydrology Study (CVHS). The CVHS developed hourly flood hydrographs at different frequencies (e.g., 100-year) at different locations on the Sacramento and San Joaquin rivers (USACE and Ford, 2015). Historical data upstream of the major flood control reservoirs were used to determine annual maximum flow events. These flow events were then routed through a hydrologic model to generate unregulated hydrographs at different points on the Sacramento and San Joaquin rivers. Local flows were estimated using either local historical data or HEC-HMS models. The unregulated hydrographs were then translated into unregulated flow-frequency curves.

The CVHS unregulated hydrology is the current accepted hydrology for the major flood planning efforts in the Sacramento and San Joaquin basins, including DWR's CVFPP.

Projects in the Sacramento and San Joaquin basins may use CVHS hydrology methods when quantifying system-wide flood benefits, as this hydrology has been accepted and used by DWR and USACE for flood planning. Local flood benefits analysis and projects outside of the Sacramento and San Joaquin basins that do not have publicly-available flood hydrographs may use any of the described methods as long as proper justification and documentation are provided. Table 4-15 lists the commonly used hydrologic models that can be used for flood analyses.

Table 4-15. List of Common Hydraulic Models used for Flood Analyses.

Model Code or Application	Description	Download and Documentation	Maintained By	Other Considerations
HEC-RAS	1D hydraulic model; simulates flows, stage and velocities based on input flow/stage	• http://www.hec.usace.army.mil/software/hec-ras/downloads.aspx • http://www.hec.usace.army.mil/software/hec-ras/documentation.aspx	HEC	• Open source • Provides temperature and sediment transport capabilities

Table 4-15. List of Common Hydraulic Models used for Flood Analyses.

Model Code or Application	Description	Download and Documentation	Maintained By	Other Considerations
MIKE HYDRO RIVER	1D hydraulic model; simulates flows, stage and velocities based on input flow/stage	• https://www.mikepoweredbydhi.com/download/mike-2016/mike-hydro-river?ref={181C63FF-2342-4C41-9F84-F93884595EF3} • Software comes with user guide	DHI	• Free • Provides water quality, sediment transport, and long term geomorphic modeling capabilities
DSM2	1D hydraulic model; simulates flows, stage and velocities based on input flow/stage	• http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm	DWR	• Open source • Provides temperature and water quality modeling capabilities
HEC-RAS 2D	2D hydraulic model; simulates flows, stage and velocities based on input flow/stage	• http://www.hec.usace.army.mil/software/hec-ras/downloads.aspx • http://www.hec.usace.army.mil/software/hec-ras/documentation.aspx	HEC	• Open source • Option to run 2D Saint Venant equations or 2D Diffusion Wave equations • Implicit finite volume solver •
SRH	Package of models including: hydraulic (1D/2D) model, river meander model	• Contact information at: http://www.usbr.gov/tsc/tscorganization/8200.html • User manual is attainable through contact	Reclamation	• Open source • 1D and 2D hydraulic, vegetation, and river meander models available • Cannot be used to simulate channel aggradation or degradation
MIKE 21	2D hydrodynamic model; simulates flows, stage and velocities based on input flow/stage	• https://www.mikepoweredbydhi.com/download/mike-2016/mike-21?ref={181C63FF-2342-4C41-9F84-F93884595EF3} • Software comes with user guide	DHI	• Free • Salinity and temperature modeling capabilities • Transport of bed load (ST), erosion/deposition (MT), and suspended sediment (PT) modules are available
FLO-2D	2D hydraulic model	• http://www.flo-2d.com/ • http://www.flo-2d.com/download/	FLO-2D Software, Inc.	• Proprietary

Table 4-15. List of Common Hydraulic Models used for Flood Analyses.

Model Code or Application	Description	Download and Documentation	Maintained By	Other Considerations
RMA2	2D hydrodynamic model; simulates flows, stage and velocities based on input flow/stage	• http://chl.erdc.usace.army.mil/rma2 • http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=ARTICLES;480	Coastal Hydraulics Laboratory (CHL)	• Free • Time step is not limited by model structure
Nays2DH	2D hydraulic model and sediment transport model	• Contact information at: • http://i-ric.org/en/contact • User manual is attainable through contact	iRIC	• Proprietary • Models bank erosion, bed load, suspended load

Reservoir Operations

Reservoir operations models use the unregulated inflow hydrology to simulate storage and releases. Commonly used reservoir operations modeling software capable of simulating flood operations are HEC-ResSim and RiverWare. Section 4.3, Surface Water Operations Analysis, describes the commonly used water resources operations models. Table 4-15 lists the commonly used reservoir operations models used for flood analyses.

The CVHS developed HEC-ResSim models for the Sacramento and San Joaquin basins to simulate flood system responses to unregulated inflow time series described previously (USACE and Ford, 2015). The HEC-ResSim model simulates flood operations and the resulting outflows based on rule curves and other specified operating constraints. The model then routes outflows to downstream nodes based on different user-specified routing procedures.

Projects in the Sacramento and San Joaquin basins may use these HEC-ResSim models to quantify system-wide responses to flood operations proposed for storage projects, as these models have been accepted and used by DWR and USACE for flood planning. Local flood control benefit analysis and projects outside of those basins may use any publicly-available reservoir simulation models.

4.9.4.2 Hydraulic Analyses

Hydraulic analyses quantify the resulting physical changes in stage, velocity, and floodplain inundation of the flow quantified in the hydraulic analyses. A simple hydraulic analysis is the use of a rating curve to convert flow into stage at specific location. However, flood analyses require more complex hydraulic analyses which generally require the use of river hydraulics models. These models often require an inventory of flood control structures.

River Hydraulics Models

River hydraulic models calculate resulting river stage and potential floodplain inundation using flow outputs of the reservoir operations model. The stage and floodplain inundation that is calculated can then be used as inputs to flood damage assessment and flood risk models to ultimately calculate monetary flood control benefits. USACE's HEC-RAS is a commonly used river hydraulic model for calculating riverine hydraulic responses. FLO-2D is commonly used for floodplain hydraulic responses. Section 4.5, Riverine Hydrologic/Hydraulic Analysis, provides more descriptions of hydraulic models and parameters. HEC-RAS and FLO-2D models were developed as part of the DWR's Central Valley Floodplain Evaluation and Delineation Program (CVFED) to quantify the river stage, velocity, and depth and the floodplain depth and inundation extent respectively for the Sacramento and San Joaquin basins as part of the CVFPP.

For projects in the Sacramento and San Joaquin basins, applicants should use the CVFED data and models. Projects outside of those basins may use other hydraulic modeling tools. Table 4-16 lists the commonly used river hydraulics models.

Table 4-16. List of Common Reservoir Operations Models used for Flood Analyses.

Model Code or Application	Description	Download and Documentation	Maintained By	Other Considerations
HEC-ResSim	Hydrologic routing and reservoir operations model. Performs rule based simulations of operations. Has built in flood operating rules such as downstream control points and reservoir drawdown rules. Users can also script custom rules.	http://www.hec.usace.army.mil/software/hec-ressim/downloads.aspx http://www.hec.usace.army.mil/software/hec-ressim/documentation.aspx	HEC	• Open source • Reservoir based planning and management tool
RiverWare	Hydrologic routing and reservoir operations model. Can perform rule based simulations. Users can create custom rules such as downstream control points.	Contact information at: http://cadswes.colorado.edu/home-page	CADSWES	• Not open source; free • Reservoir based planning and management tool

Downstream Flood Control Structures

Many areas within the floodplain are protected by existing levees, floodwalls, retention basins, and other kinds of structures. An appropriate flood risk analysis must consider the effect of these structures on flooding, including the risk of structural failure. Depending on the flood damage model used, either a point estimate or a probability distribution of structural failure may be needed. These are often generated through geotechnical analyses. Refer to the flood damage assessment models described in

Section 5.4.3 and in Appendix F for more information about incorporating structural failure into the overall flood control benefits analysis.

4.9.4.3 Physical Resources at Risk

Operations, hydraulics, and structural failure analyses provide results indicating the extent, depth, and duration of flood events with and without the proposed project. As a next step, an applicant must determine the kinds of valuable resources and activities at risk and quantify those to support the economic analysis of flood control benefits. Section 5.4.3 and Appendix F describe models and databases that can be used for this step.

4.9.4.4 Physical Change Metrics

Metrics for quantifying physical changes that result in flood benefits usually involve quantifying the changes in flow and stage of different frequency events. Lower frequency events (e.g., a 100-year event) can cause substantially more flood damage than higher frequency events (e.g., a 5-year event). Large physical changes in the flows and stages of higher frequency events may not provide the same level of flood control benefit as smaller physical changes of lower frequency events. In general, a project may provide no benefit (i.e., avoided damage) during high-frequency, low-flow events where there is no damage even in the without-project future conditions. Also, some very high-flow but rare events may be so large that a devastating flood would occur with or without the proposed project. As a result, the benefits of a project tend to occur at the intermediate frequency events. Therefore, if design events are developed to construct flow-frequency or stage-frequency relationships, a minimum of three design flood events must be used, and providing more design events may be better.

4.9.5 Quantifying Flood Control Benefits

Flood benefits are ultimately quantified in terms of reductions in economic damages and life loss, which are analyzed using changes in physical metrics described above. DWR's *Handbook for Assessing Value of State Flood Management Investments* (HAV) (DWR, 2014) describes three different categories of flood risk benefits: inundation-reduction benefits, intensification benefits, and location benefits. Inundation-reduction benefits are the reduction in damages due to a flood management action(s). Intensification and location benefits are the changes in land use that result from a flood management action(s).

Inundation-reduction benefits are generally measured in economic terms and the metric, as specified in the HAV, is the reduction in the expected annual damage (EAD). The HAV discusses the method approved by USACE for quantifying inundation-reduction benefits associated with a project. It requires prior analysis of the physical changes of flow and stage, as well as present land use and predicted changes in land use over the planning horizon. An applicant must determine the kinds of valuable resources and activities at risk and quantify those to support the economic analysis of flood control benefits. Appendix F describes models and databases that can be used for this step.

The HAV focuses on a specific model for an inundation-reductions benefits analysis, the Hydrologic Engineering Center's Flood Damage Reduction Analysis (HEC-FDA) model. HEC-FDA requires input of hydrologic, hydraulic, geotechnical and relevant economic information to compute EAD. HEC-FDA is one of the commonly acceptable models for quantifying flood control benefits. The CVFPP uses HEC-FDA as the primary model for quantifying flood control benefits. See Section 5.4.3 and Appendix F for a more complete description of EAD and for more discussion of HEC-FDA and other acceptable models.

In addition to the flood control benefit, additional storage may benefit downstream areas by reducing the vulnerability and exposure of people and property to flooding. For example, regardless of the impact of storage on peak flood stage downstream of the reservoir, its control of water may delay the time of arrival of the stage. This delay can permit the public to evacuate soon-to-be-inundated areas or to raise damageable property in the area. These actions reduce vulnerability and exposure, leading to reduction of damage and life risk.

The Corps and DWR refined and applied a method for accounting for the emergency response benefit of storage and other actions, and that method should be used here to assess any flood emergency response benefit. The method is described broadly in (Carsell, Pingel, and Ford, 2004) and (Cowdin, et al., 2014). DWR's application of the method to the Central Valley Flood Protection Plan is documented in (DWR, 2012).

The method requires the applicant to estimate the increase in mitigation time attributable to storage; this time is a function of the time delay of arrival of peak stages downstream of the reservoir. Functions that predict damage or life loss at specified stages then are adjusted to account for the increased mitigation time. For benefit assessment here, estimates of increased delay attributable to storage must be supported by reservoir operation studies that route a full range of historical or design storm flood hydrographs through the proposed reservoir-river system to demonstrate the delay attributable to the new storage. With the delay, stage-damage or stage-life loss functions can be adjusted and expected annual damage or life risk assessed with methods described in this section and in Section 5.4.3 to compute benefit as the cost or life loss avoided.

4.10 Recreation Analysis

This section describes concepts and methods for quantifying recreation benefits (or impacts) that could result from water storage projects. A definition of recreation benefits is presented below, followed by a description of the different means by which water storage projects can provide qualified recreation benefits. Then, methods for evaluating recreation benefits are described. This section focuses on the physical and hydrologic changes that can provide recreation benefits; that is, changes to the physical environment that provide for or enhance recreation use. Recreation use is typically measured as visitation, and methods, models, and data for quantifying and monetizing visitation are described in the corresponding section on economic benefits of recreation (see Section 5).

4.10.1 Definition of Recreation Benefits

Recreational purposes of a water storage project may be eligible for funding by the WSIP. The WSIP regulations define a recreational purpose as “a public benefit that provides recreation activities typically associated with water bodies (such as rivers, streams, lakes, wetlands, and the ocean) and wildlife refuges that are accessible to the public. Recreational benefits must be directly affected by the proposed project and be open to the public, and may provide interpretive, educational, or intrinsic value.”

4.10.1.1 Relationship between Water Storage Projects and Recreation Benefits

This section summarizes the kinds of recreation benefits and impacts potentially produced by water storage projects. A proposed water storage project can provide various kinds of recreational benefits or impacts based on its facilities, features, and operations. The applicant must determine and demonstrate which kinds of benefits or impacts apply.

Reservoir Lake Recreation

Surface storage reservoirs that have some shoreline open to the public provide shore-based recreation, and if boating is allowed and accommodated, boat-based recreation.

Most lake recreation can only be provided if appropriate facilities are also provided. Recreational facilities and operations that are part of a proposed project must be described in the project application and a feasibility study should be provided. Nearby lakes can provide a source of the types of recreation that may occur, and can also provide information on the types of facilities most sought after and used. Many facilities, such as boat ramps, campgrounds, swimming beaches, visitor centers, day use areas, trails, fishing piers/docks, and similar facilities, will generally not require a model or other analytical method to quantify, but they should be listed if they are important for quantifying and monetizing recreation benefits.

Lakes that do not allow power boating or water contact recreation may provide much less recreational use than those that do. However, numerous types of recreation can occur at these lakes. Land-based facilities such as trails, picnic areas, and fishing piers/docks support recreation. Lakes that allow water contact but not power boats can provide launches for kayaks and other non-motorized craft.

Water Storage Operations Affecting Recreation

For surface storage projects, most recreation benefits are likely to occur at the lake itself. These recreation benefits typically will be affected by the operations of the storage project. Operations will affect water surface area available for boating, and lake levels affect the accessibility of boat launches, campsites, beaches, and fish and wildlife. Recreation operations plans should consider the range of water years and lake conditions. If recreation benefits are claimed, applicants should discuss how operations will affect the quantity and quality of recreation available.

Impacts on Without-Project Recreation

Negative impacts caused by operations of the project that adversely affect existing recreation must also be considered. If a project impairs or eliminates use of an existing recreational site, such as a whitewater rafting area, those impacts must also be described and quantified. An applicant must identify the extent to which any new recreation facilities replace (i.e., mitigate for) other facilities affected versus providing a net increase in available facilities.

Surface Water Recreation on Other Facilities

Other surface storage facilities may be affected by 1) coordinated operations and by 2) potential changes in visitation caused by substitution with the proposed project. Coordinated operations mean that the surface area of other reservoirs may be affected. The effect may be to provide more or less surface area on other reservoirs. If surface area is increased, then visitation may increase (recreation benefits at reservoirs are often correlated with pool level during the recreation season).). Negative impacts caused by operations of the proposed project, if any, must also be considered. Visitors may simply shift location of their recreation from an existing site to the new site.

Recreational Fishing

Reservoir visitation estimates normally include reservoir fishing visits. However, recreational fishing benefits may occur outside of the reservoir. Important tailwater fisheries supported by cold water releases might provide economic benefits. If improved water quality or ecosystem conditions in streams will increase sport fish populations, then recreational fishing will usually increase. Recreation benefits from increased populations of native sport fish can be counted as ecosystem benefits (as these benefits support ecosystem priorities identified by CDFW), but recreational use estimates will be required. Additional fish result in better quality fishing, which could be expressed as increased benefit per day of fishing, and more fishing time – increasing catch rates attract and retain more fishing days. If applicants can support estimates of increased benefit per day based on increased catch rates, this approach is acceptable. If not, if there are estimates of catch per unit effort then it can be assumed that catch increases proportionately to fish populations and catch per unit effort remains constant. This approach results in an estimate of increased fishing days which may be valued using the recreation unit day values.

Riverine Recreation

Other upstream or downstream recreation use may be affected by a proposed water storage project. Riverine recreation that may be affected includes whitewater rafting and kayaking, canoeing, and floating. Riverbank recreation use may be affected if flow and water quality are improved. Quality of a downstream fishery can be improved or altered depending on water temperature and volume released. Generally, a project claiming important riverine recreation benefits should demonstrate improved riverine conditions during periods of recreational use, especially weekends and peak summer recreation periods.

Wildlife Refuges

A proposed project may provide water supply for wildlife refuges or other wetlands where wildlife-watching and photography, hunting, fishing, hiking trails, environmental education, interpretation, boating, swimming, and picnicking are important economic activities. The applicant should support visitation based on improved wetland conditions. If not, visitation can potentially increase proportionately with the total quantity of water supplied to the wetlands. If no visitation data are available, some form of sampling and estimation may be required to support visitation estimates.

Open Land/Public Access

A proposed project may provide open land or public access where hunting, hiking trails, biking trails, horse trails, environmental education, and picnicking may occur

Recreation Losses Due to Inundation

Reservoirs may inundate an area of land or stretch of stream that was being used for recreation or some other purpose. If the land must be acquired from private owners, the price of land for the proposed project which must be included in project costs may account for a portion of the value of recreation lost. In some cases, access for recreation use within the inundated lands is no controlled or priced. In this case, the value of recreation lost due to inundation would not be fully included in the cost of land and must be evaluated as an additional economic cost of the project. For example, persons who own land next to whitewater often cannot control or benefit from the whitewater activity. In this case, the value of lost recreation caused by the inundated area should be counted separately from the land value.

4.10.1.2 Assessing Recreation Benefits

This section describes the methods, models, and metrics for quantifying physical recreation benefits. The focus here is on describing the physical facilities and conditions associated with or affected by the proposed project that would, in turn, affect recreational use and enjoyment. The applicant planning to quantify recreation benefits should consider both the available physical information and the available methods for quantifying recreational use in order to determine the most supportable overall analysis.

Benefits can be counted if the water storage project will be open for public use. For large facilities, applicants should provide a recreation facilities plan and a market study. Future visitation estimates should be based on similar local facilities. Section 5 describes ways to quantify expected changes in recreation use, or visitation, provided by the proposed project and to quantify the economic value of the visitation. Some methods may estimate total visitation of all activities, perhaps including boating, camping, and other day use activities. Other methods may be specific to one kind of activity.

The minimum information that should be provided to support recreation use estimates are:

- The size of the facility;
- Recreation activities allowed;
- Recreation facilities associated with activities and their capacities
- Seasonal closures and conditions in which facilities are not usable or activities cannot occur.

Size of the Facility

The size of a lake recreation facility is usually measured in acres. Length of available shoreline can be important for some facility estimates such as beaches.

Activities, Closures and Conditions

Recreation use estimates must account for seasons available for use and types of activities allowed. Lakes that do not allow power boating or water contact recreation will generally provide much less recreational use than those that do. The types and amounts of recreational use must account for all of these factors, uses allowed, operations, and times and seasons of available use. The relationship between expected storage operations and recreation use should be documented.

Facilities Provided by the Project

Facilities provided by or affected by the proposed project will be an important part of an analysis of recreation visitation or impacts. Examples of such facilities could include, depending on the project:

- Boat launch lanes and marina slips
- Full service marinas
- Campsites and picnic tables
- Parking spaces, restrooms, handicap-accessible facilities
- Trails for hiking and other uses
- Educational or interpretive facilities
- Fish stocking operations
- Swimming beaches
- Fishing piers/docks
- Launches for small non-motorized craft (kayaks, canoes)

All of the facility information must be consistent with the project description and analysis provided in the applicant's feasibility study and environmental documentation.

Depending on the methods the applicant uses to quantify recreational use, it may also be necessary to provide an inventory of existing recreational facilities in the area surrounding the proposed project and the distance to those facilities, in order to assess the net regional change in recreational use. For example, if the proposed project would provide new boat launches, the visitation rate at launches in existing, nearby lakes could decline, and the net change is the desired measure of quantified benefit of the proposed project.

Potential Metrics for Quantifying Physical Recreation Changes

The methods and models the applicant selects to quantify and monetize visitation and the types of recreational opportunities provided by the project will determine appropriate metrics. Metrics could include numbers and kinds of facilities and other physical metrics of the recreational site. The following list is not comprehensive, but indicates the kinds of input information an applicant may need to develop for its selected quantification methods:

- A list of activities supported and season of use
- A list of recreation facilities
- Maximum and average lake surface area
- Lake elevation when full
- Reservoir average percent full, and percent full in the late summer of dry years

- A list of nearby existing recreation sites that provide substitute recreation opportunity, and their qualities

The method selected to quantify visitation will determine the appropriate units for these metrics. For example, a statistical model relating annual visitor-days of boating to lake surface area may require the input value to be average acres of boatable surface during the boating season.

Section 5.4.5 provides a recreation visitation model based on recent State Parks visitation data for reservoirs in California. If this model is used as part of the market study, the following input data are required.

1. Maximum surface acreage.
2. Average storage in each month as a percent of capacity (0 < percent < 100).
3. 2010 population within 60 miles, in thousands.
4. Maximum (when full) surface acreage of substitute reservoirs within 30 miles.
5. Number of campsites.
6. Number of boat launch lanes.

4.11 Emergency Response Analysis

This section describes concepts and methods for quantifying physical emergency response benefits (or impacts) that could result from water storage projects. A definition of emergency response benefits is presented followed by a description of the different means by which water storage projects can provide emergency response benefits. Then, methods for evaluating emergency response benefits are described. This section focuses on the physical and hydrologic resource changes that can provide emergency response benefits, that is, changes to the physical environment that provide for or enhance emergency response use.

4.11.1 Definition of Emergency Response Benefits

Emergency response purposes of a water storage project provide benefits that may be eligible for funding by the WSIP. Water Code section 79753(a)(4) defines emergency response's purpose as "including, but not limited to, securing emergency water supplies and flows for dilution and salinity repulsion following a natural disaster or act of terrorism." The main intent of the emergency response public benefit is to provide public funding for water supply that can be used to repel seawater from the Delta following a Delta levee failure event. However, water storage facilities could provide a variety of benefits following natural disasters including earthquakes, floods, wildfire, landslides, or any event that is capable of disrupting water supply. Water supply for wildfire fighting, and additional firefighting reliability for fire following earthquake, can qualify for funding.

4.11.2 Relationship between Water Storage Projects and Emergency Response Benefits

A storage project may provide various kinds of emergency response benefits or impacts based on its water supply capabilities and operations. The applicant is responsible for determining and demonstrating which kinds of benefits apply.

Conditions that might result in an emergency response benefit are discussed below. In any case, an applicant will need to define and commit to the conditions under which water would be made available, and the amount or share of water to be provided.

4.11.2.1 Delta Levee Failures, Accidents, or Terrorism that Impact Delta Water Supply Operations

This benefit applies if project stored water will be made available following a Delta levee failure event, or an accident such as a chemical spill, or an act of terrorism, that disrupts water supply operations in the Delta. To qualify, the project must be able to make the stored water available to benefit the Delta, or to the affected service area, following the event. In the discussion below, any event that would impact operations in the Delta and trigger use of storage is called a Delta event.

Following Delta levee failures, Delta water quality may be degraded by seawater intrusion. For other types of Delta events, degraded water will flow downstream. An emergency response benefit can be claimed for an upstream project that can disperse, dilute, or repel the seawater intrusion or unwanted chemical. Additionally, an emergency response benefit can be claimed for a project that can serve demands in an affected service area in a different way. To claim this type of emergency response benefit, the proposed project must provide an alternative water source to meet demands in an affected service area.

Any proposed water storage project demonstrating the benefits above can claim a Delta emergency response benefit, but only to the extent that the proposed project will be operated to provide the benefit. There must be a commitment that defines the amount or share of available stored water to be provided. This does not mean that water supply must be dedicated or reserved in storage for emergency supply. For example, the commitment could state that half of the stored supply at the time of the Delta event will be made available.

The physical effects of a relevant Delta event are a combination of degraded quality of the water supply and interruption or reduction in amount of Delta supply. Following a levee failure event, Delta source water might be too saline to use at all. If Delta supply is impaired, other supplies may be available to replace it on a short term basis. If an applicant quantifies an emergency response benefit, they must consider in its without-project condition the availability of these other replacement supplies.

A proposed project emergency response benefits could include reduced water supply interruption and better quality water. These physical effects must be quantified. Water supply interruptions will impose physical adjustments on water suppliers and their customers, which could include imposing shortages or securing alternative supplies. The analysis to quantify emergency response benefits must also consider the physical metrics associated with the water supplier responses.

The probability and magnitude of all Delta events cannot be known. For Delta levee failure events, potential causes are floods, earthquake (seismic failure), and a variety of natural or human causes including burrowing animals and shipping accidents. Considerable effort to quantify levee risks has been expended in recent years (URS and Jack R. Benjamin & Associates, Inc., 2008; Suddeth et al., 2008; Business Forecasting Center et. al., 2012; DWR, 2013; Delta Stewardship Council, 2015). There are currently no probability functions for Delta levee failure that include sea-level rise, planned levee improvements, and probabilities of earthquake and flood events. Furthermore, there are no plans that show how much of the total emergency water might be provided by other projects.

Therefore, unless the applicant can defend an alternative set of events and their probabilities, the simplifying assumptions provided below should be used. To claim a Delta event economic benefit, applicants must:

- Define the committed quantities of water and conditions under which stored water will be made available by the proposed project following a Delta event
- Assume a Delta event occurs that would require all of the water made available by the commitment

- Assume that the need for this amount of water occurs once within the hydrologic analysis, during average hydrologic conditions
- In the planning horizon analysis, assume that the Delta event and its use of project water occurs once, 30 years into the project operation period
- Show how the emergency response operation affects the project's normal operations and benefits in the years following the event

4.11.2.2 Earthquake Events that Impact Local or Regional Water Supply Operations

This benefit applies if stored water will be made available following an earthquake event that disrupts water supply, and the stored water can be made available to the affected area following the earthquake. The main differences between this type of benefit and Delta events are that water quality is not likely to be involved, and the delivery reliability of all supplies, both from the proposed project and from other supply, must be considered.

Earthquake events might disrupt water supply due to damaged water delivery systems. New water storage projects might include new delivery systems that are expected to be more reliable, or if there are already multiple delivery systems, the new project might be able to provide more water supply compared to the without-project condition.

Three types of earthquake emergency benefits that may be provided by water storage projects:

- If some areas would have no water supply immediately following the earthquake, but the proposed project would provide supply, then a fire-fighting benefit can be claimed. This situation may be rare if damages to street-level delivery facilities are likely to be the limiting factor, because they would be affected either with or without the proposed project.
- If the proposed project allows water service to be restored faster than under the without-project future conditions, or if use of costly alternative supplies is avoided, then an emergency response benefit can be claimed.
- Water provided for other health and safety purposes during the emergency, beyond those itemized just above, can be claimed as a benefit.

To claim an earthquake emergency water supply benefit, applicants must:

- Define the committed quantities of water and conditions under which stored water will be made available by the proposed project following an earthquake event
- Include the earthquake event and proposed commitment once within the hydrologic analysis, during average hydrologic conditions
- Define and justify the area that will benefit; this is the service area that will lose service or require costly alternative supplies following an earthquake, and show why

the area of benefit will lose service or require costly alternative supplies following an earthquake, and how the project will be able to provide water service

- Define and justify the duration of service outage or amount of use of costly alternative supply to be reduced by the project
- In the planning horizon analysis, assume that the benefits are obtained once, 50 years into the project operation period
- Show how the emergency response operation affects the project's normal operations and benefits in the years following the event

4.11.2.3 Drought Emergencies

Water supply provided in a declared drought emergency, above that provided in the without-project condition, and up to a minimum per capita per day needed for public health and safety, is eligible for emergency response funding. The applicant must document the minimum per capita per day requirement for a public health emergency. As with the other emergency categories, the applicant must define the committed quantities and conditions under which stored water will be made available for a drought emergency. The amount of water provided must be accounted for in the project's operations analysis.

Drought emergencies can be assumed to occur during a critical year if it is the third or later year of any multi-year drought period that occurs in the hydrologic dataset used in the project's operations analysis. For local drought emergencies that are not also general statewide drought emergencies, applicants must provide evidence of the frequency of formally-declared drought emergencies as the basis for quantifying the benefits. Frequency of drought emergency must be based upon the available historical record for the portion of the study area provided emergency supply.

4.11.2.4 Wildland Fire Emergencies

A water storage project provides a wildland fire emergency response benefit if the project or its facilities will provide water for fighting wildfires. The water might be provided through the project distribution system, or it might be collected by trucks or aircraft from the water storage facility.

The physical benefit is the volume of water used for firefighting. Emergency response benefits may include the reduced cost of fighting the fire, and avoided fire damage (see Section 5.4.6, Emergency Response). If an applicant wants to claim avoided fire damage, models are available that estimate fire behavior in a variety of natural and urban environments. However, reduced firefighting cost is likely to be more practical for most applicants. Applicants must define the committed quantities of water and conditions under which stored water will be made available by the proposed project for firefighting and show how the project will contribute to reduced firefighting costs by providing more or more accessible water supply. An estimate of the quantity of water provided during a typical event must be included.

4.11.2.5 Emergency Response and Facilities

The types and amounts of emergency response activities allowed may be limited by facilities. The emergency response analysis must consider any capacity limitations imposed by facilities including outlet and conveyance capacities, distribution systems, hydrants, and access.

4.11.2.6 Conditions Affecting Emergency Response Benefits

Emergency response benefits typically will be affected by the hydrologic conditions occurring at the time of the emergency. For Delta levee failure and earthquake emergencies, benefits will be strongly affected by the hydrologic conditions in which the event occurs. Delta levee failures due to high river flow events may result in a smaller effect on water supply if significant flow is available to prevent or mitigate salinity intrusion.

The timing of other Delta levee failure events and earthquake events are random relative to hydrologic conditions. Therefore, simulations should assume average hydrologic conditions including average project water storage and average storage recovery conditions. Applicants must not design their analysis so that emergency response events occur when storage can be easily replenished, or when the avoided costs of events would be unusually large. Benefits related to wildfire suppression should assume average summer conditions.

4.11.3 Assessing Emergency Response Physical Benefits

This section describes the methods, models, and metrics for quantifying emergency response physical benefits.

4.11.3.1 Facilities Provided by the Project

Facilities provided by or affected by the proposed project and that are related to the emergency response benefit must be listed. Examples of such facilities could include, depending on the project:

- Outlet capacity
- Water delivery facilities and interconnections
- Firefighting facilities and capacities

All of the facility information must be consistent with the project description, cost, and analysis provided in the applicant’s feasibility study and environmental documentation.

4.11.3.2 Analysis of Conditions Affecting Emergency Response

Applicants must quantify physical conditions affecting emergency response in coordination with methods and information used for other benefits. The water operations model (see Section 4.3, Surface Water Operations Analysis, or Section 4.4, Groundwater Analysis) must be used to estimate the amount of water in storage and available for emergency response, and it must be used to asses impacts on storage in the years following an emergency event. With-project emergency response must be compared to without-project conditions regarding other available water supplies that could be used for emergency response. The emergency conditions resulting from a Delta event and the result of emergency water releases by the proposed project must be analyzed using, or at least consistent with, hydrodynamic models used to quantify other benefits (see Section 4.5, Riverine Hydrologic/Hydraulic Analysis, and Section 4.6, Delta Hydrodynamics/Hydraulic Analysis).

Potential Metrics for Quantifying Emergency Response Benefits

The metrics for quantifying the emergency response benefits include:

- The amount and frequency of water provided by the emergency response commitment
- Water quality with and without this amount of water
- The amount and costs of other source(s) of water supply made available for the event
- The duration and severity of water shortage (volume of supply relative to demand at the time of the event) with and without the project

Methods to Estimate the Emergency Response Benefits

In general, the project’s description, operations plan, and operations modeling should be the starting points for any analysis needed to estimate emergency response benefits. The commitment to provide water supply for emergency response will alter the operating rules in the months and years following an event. Operations modeling must account for emergency water released from storage, either within the operations model, or if that is not feasible, using post-processing of operations model results (see Section 4.5, Riverine Hydrologic/Hydraulic Analysis). Hydrodynamics and water quality analysis is required to demonstrate benefits for Delta events if the applicant is quantifying water supply and water quality changes (see Section 4.6). Operating rules related to water quality and use of alternative supplies might be required to estimate the amount of alternative supplies and the amount of water shortage avoided by the emergency response water provided by the project.

4.12 Water Supply Analysis

Most benefits provided by a water storage project result from water supplied for beneficial uses. These include water provided for human uses such as municipal and agricultural use, water provided to improve aquatic and related ecosystems, and water provided to improve water quality conditions. Benefits that do not depend directly on water supply include flood control and lake recreation benefits, which depend on other aspects of a water storage project and its operation.

This section provides information on evaluating and quantifying the amount of water supply effectively available from a surface water storage or groundwater storage project for beneficial use. This section addresses the important concepts of water accounting, timing, and location of water, and how to assess delivery system losses, inefficiencies, and impacts on other water supplies. These are concepts that apply to all benefits related to water supply. However, the focus in this section is on water supply for non-public benefits, that is, human uses. Quantification of benefits (and impacts) of water supplied for public benefits, such as ecosystem flows, flow to improve water quality, or delivery to wildlife refuges, are described in other sections that follow.

This section does not describe specific models, but rather focuses on concepts of how to use the models described in other sections to quantify water supply benefits or impacts. Following this section are sections on how to use models of water storage operations and the related hydrologic system to quantify all public and non-public benefits, including water supply.

4.12.1 Water Supply Benefits

The physical water supply benefits are increases in the volume, and potentially changes in timing and location, of water provided by a proposed water storage project for human uses. Human uses of water include agricultural, residential, commercial, public, industrial and institutional uses. This also includes delivery of water for groundwater recharge that provides a usable supply for future extraction and human use. Non-public water supply benefits must be accurately assessed to ensure a fair cost allocation between public benefit and non-public benefit categories.

A key concept for measuring a physical water supply benefit is that the use, location, and timing of the quantified water supply must match the use, location, and timing used for quantifying its monetary value. Results of water storage operations analysis, whether for a surface water or a groundwater storage project, will include water supply as a quantified physical benefit. The location and timing of the benefit provided from the operations analysis may require further adjustments.

Another important concept is that new water storage projects might have impacts on existing or planned without-project beneficial uses, including other water supplies. Any impacts on other beneficial uses must be quantified and disclosed.

4.12.2 Storage Projects and Water Supply

Water supply quantification uses the output from a storage project's operations analysis and applies conversions and other adjustments to calculate the resulting change in water delivered to users at the times and locations those users want it and are willing to pay for it. Calculations of water supply from a water storage project must be consistent with the specific type of project and its operation. Units of volume, time scale, and location of the water provided as output from the operations analysis must match the same information used to monetize the value of the water supply, or be adjusted to match. Projects that deliver water on demand and to users very near the storage facility may require relatively minor adjustments to calculate resulting water supply. Water storage projects that transport water many miles for delivery can require a more complex set of calculations to account for conveyance losses and operational spills, or to account for regulating reservoirs or other facilities needed to match the timing of water delivered to the timing of water demanded.

Some water storage projects may require water exchange agreements to provide the projects' water to the targeted users, resulting in more potential adjustments for losses or other contractual terms among parties to the exchange. An example of an exchange agreement could be a project that releases water to meet another party's existing water rights obligation, allowing that party to increase water supply to its other water users. An exchange agreement may include adjustment factors to account for losses, time-of-year differences, or other agreed-upon adjustments. Exchange agreements might also involve exchange of storage space, conveyance arrangements, and considerations for timing, water quality, or other attributes.

Each proposed project will need appropriate conveyance and distribution systems to provide the water supply to users. Projects may include construction of new conveyance and distribution facilities, or they may rely on existing facilities, or both. Applicants must demonstrate that the project is physically capable of providing the water supply to the users, whether using existing facilities, new facilities that are part of the project, or exchange agreements.

4.12.3 Location at Which Supply is Measured

Applicants must identify the area or areas that will receive water supply from the proposed project. In addition, applicants must match the location of the quantified water supply to the location of its monetized value. Note that the monetized location need not be the location of final use. For example, if the water's monetized value is based on water available for use at a generally-described geographic location, such as the Sacramento Valley or south of the Delta, then the physical quantity of water must be measured at that same location. Alternatively, if the water's value is monetized based on its delivery to a farm gate or to a city's water treatment plant, then water supply must be measured there, including applicable conveyance or other losses to transport the water to that location (and costs of that conveyance must be either included in project costs or subtracted from the monetized value of the water at that location).

4.12.4 Timing

Timing of water supply relative to demands and to availability of other supplies is often important for calculating the value of water supply. Water delivered in dry and critical years often has greater monetary value than water delivered in wetter years. In some cases, time of year is also important. For example, water may have little value as supply if available for diversion only in winter months and the recipient has no way to store it for later use. Applicants must account for these timing considerations in order to match the quantified water supply with an appropriate monetized value.

4.12.5 Assessing Water Supply Benefits

The following outlines the steps to quantify water supply for human uses:

- Use surface water or groundwater operations analysis to determine the quantity, location, and timing of water produced by the proposed project (i.e., released from the reservoir, diverted from a stream or the Delta, or pumped from groundwater) for purposes of water supply. Methods to generate this information are described in Section 4.3, Surface Water Operations Analysis, and Section 4.4, Groundwater Analysis.
- If water supply is monetized at the output location of the operations model, it is not required to make further adjustments for conveyance losses to transport water to the point of use. If the applicant wants to adjust for conveyance losses to the point of use, the effective price per acre-foot of water received must be correspondingly adjusted (resulting in the same total monetized water supply benefit as calculated without adjusting for conveyance loss).
- If water supply is monetized at the location of use, conveyance losses must be included. Applicants may also need to account for any other operational or capacity constraints not included in the operations analysis. This could include conveyance capacity between the output location of the operations analysis and the entity receiving the water supply.
- For each future condition year, summarize the physical water supply benefit (the difference between with-project and without-project water supply). This can include a full time series or an exceedance curve covering the hydrologic period, but must also be summarized according to the time frame for which water supply is monetized. For example, if all water supply is monetized using a single unit value regardless of the year type in which it is delivered, then an overall average annual delivery is sufficient and appropriate. But if water supply is monetized by water year type, for example, dry years, critical years, etc., then annual supply averaged for each of those year types is needed at each of the future condition years.
- If the project causes any impacts on existing beneficial uses of water, these negative effects must be disclosed. The physical water supply impact must be calculated using the same methods and standards as applied to the physical water supply benefit.

Conveyance losses and reuse fractions are calculated using standard methods found in hydraulics and engineering textbooks. Some system operations models have these adjustment factors built or available in post-processing tools. For example, an output conversion tool for CalSim II adjusts deliveries at model nodes to an equivalent supply delivered to final users. It uses adjustment factors developed by hydrologists and water use specialists as part of regional water balance calculations, and these can be used for water supply delivered by existing conveyance facilities in regions covered by the CalSim II model. Some economic models used for estimating the benefits of water supply also incorporate conveyance losses and reuse. Each applicant must examine the models it intends to use to quantify water supply benefits to determine if and how they account for losses and reuse. If the models do not, an applicant must develop its own estimates and adjustment factors as needed.

4.12.6 Calculating Potential Losses

Conveyance losses from transporting water from the location at which water supply is measured by the operations model output to the point at which its value is monetized must be calculated. Losses include evaporation from water surface, transpiration by canal-side vegetation, seepage, and spills. Conveyance may include gravity-fed or pressurized pipe and lined or unlined canals. Intermediate storage or regulating reservoirs also have losses that must be included.

Applicants shall calculate conveyance losses using best engineering practice, considering the conveyance materials and condition, lengths, water surface area, and operations. Water supply delivered using existing conveyance facilities must calculate losses using information provided in existing studies and reports applicable to those existing facilities. For example, applicants proposing to deliver water through SWP facilities must calculate losses using information provided by SWP (DWR, 2015). Note that system operations models including CalSim II and CalLite, and perhaps others, will already account for losses occurring within the scope of the models. Each applicant must determine what losses are or are not included within its operations analysis in order to properly account for losses. Local water supplier management plans and operations plans may also provide estimates of losses.

If the applicant intends to use an existing surface or groundwater storage facility that is not part of the proposed project (for example, as temporary storage to facilitate delivery of the water supply), it must also consider potential storage losses at that existing facility. Water supply provided through exchange must be adjusted to account for any storage or conveyance losses needed to make the water available to the location where its value is monetized.

Percolation losses to usable groundwater need not be counted as permanent losses. An applicant can account for percolation from water supply as increased groundwater storage that is available for use as water supply in the planning horizon. Reduced pumping lift benefits may also be quantifiable, if applicable (these are non-public benefits). The cost of pumping the recharged water must be subtracted from the monetized value of the water supply provided from the groundwater storage.

An applicant may also calculate losses between the location of monetized value and the location of final use, but this is not required. Once the appropriate total loss fraction is calculated, considering all losses between operations analysis point of measurement and the point of delivery, it is used to calculate the delivered water. For example, if the operations analysis calculates 10,000 acre-feet of water supply at the project, and the applicant estimates 8 percent total losses until ultimate delivery, then delivered water is 9,200 acre-feet (10,000 x (1 - 0.08)

4.12.7 Accounting for Potential Reuse

Depending on characteristics of the water users and the method used to monetize, applicants may also count the fraction of delivered water that is reused - that is, that becomes available to others after its initial delivery and use. For example, if irrigation water is delivered to a service area that typically reuses tailwater from one field to irrigate other fields, the reuse fraction may be counted in the total new water supply, but only if its value is monetized at the field level. For example, if the value of water supply is estimated as a dollar value per acre-foot applied to the field, and reuse within the irrigated area results in 1.2 acre-feet applied for every acre-foot delivered to the area, then 5,000 acre-feet delivered to the area results in 6,000 acre-feet (5,000 x 1.2) applied to fields. Reuse of water for other benefits such as ecosystem or water quality improvement should also be accounted for in the analysis, though they would be quantified and counted as public benefits, not non-public water supply benefits.

Monetization of water supply at a more aggregate level, for example using unit values paid by large water districts for water delivered south of Delta, already accounts for its total net value to the buyer, including potential reuse and losses. Applicants must carefully justify and account for the quantity and monetized value of reused water in order to avoid double-counting benefits.

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4.13 Hydropower Analysis

This section describes concepts and methods for quantifying hydropower benefits (or impacts) that could result from water storage projects. A definition of hydropower benefits is presented followed by a description of the different ways new water storage projects can provide hydropower benefits. Then, methods for evaluating and quantifying hydropower benefits are described.

4.13.1 Definition of Hydropower Benefits

Hydropower benefits of a new, expanded, or reoperated water storage project can be generally described in two general categories: benefits associated with energy generation and benefits from integration with renewable energy. Within the category of energy generation benefits, capacity value is the ability of the proposed hydropower facility to replace the highest-cost generation, usually from thermal generating plants, during peak demand periods. Net energy generation is the net increase in electricity available to the overall electrical grid after accounting for operating energy requirements of a project. Integration with renewable energy is the ability to increase the effectiveness of other renewable resources, such as wind and solar power, within the overall electrical grid to reduce fossil fuel-based electrical energy generation. Hydropower is a non-public benefit and is not funded by the WSIP.

Hydropower benefits are measured in physical terms as the net energy generation from a hydropower facility, either on an annual basis or broken out into different load conditions such as time of year, time of day, or peak/nonpeak periods. Typically, energy production is measured in kilowatt-hours. The different load periods indicate different demands and/or alternative costs for energy during those load conditions, and may be needed to derive a good estimate of the economic value of hydropower production. Energy production is the primary and most important way to quantify hydropower benefits.

Other ways of quantifying benefits may be appropriate for a particular project, and the applicant must determine this. Generating capacity, measured in kilowatts or megawatts, can be used to quantify the rate at which a hydropower facility can produce during peak periods. Hydropower generation can also provide an indirect secondary benefit by displacing emissions of air pollutants and greenhouse gases that would otherwise be generated by a fossil fuel plant. Finally, hydropower may be operated in a way that can enhance the overall production efficiency of the regional production grid.

Some water storage projects also use energy to operate, such as diverting water from a stream/river and pumping it into the reservoir, for pump-storage, or injection and extraction from groundwater storage. Generally, these uses of energy will be included in project costs, so they would not need to be subtracted from the produced hydropower to get the net hydropower generation. However, if a hydropower project's use of energy is not included in the project's cost estimate, then it should be subtracted from any produced energy to get the net hydropower generation.

4.13.2 Relationship between Water Storage Projects and Hydropower Benefits

This section summarizes the kinds of hydropower benefits potentially produced by water storage projects. Only water storage projects with hydropower generation facilities can claim hydropower benefits. The following benefits do not necessarily apply to all hydropower projects. The applicant is responsible for determining and demonstrating which kinds of benefits apply.

4.13.2.1 Energy Generation

A new, expanded, or re-operated water storage project can provide hydropower benefits by providing an overall net increase in electricity available to the grid. This is the primary approach to estimate benefits of hydropower generation. This applies to projects that include hydropower generation facilities as part of the project operations and energy generation that exceeds the power requirements for the project to operate.

4.13.2.2 Integration with Renewable Energy

A new, expanded, or re-operated water storage project with a pump-storage component or a re-regulating reservoir can provide hydropower benefits by integrating with renewable energy sources (mainly wind and solar) to increase their overall effectiveness within the electrical grid and reduce reliance on fossil fuel-based electrical energy generation. Renewable energy resources are intermittent sources of electrical energy and often produce more electricity than the electrical grid requires at a particular moment. A hydropower project might be flexible enough to adjust its generation to offset such peaks. If the hydropower project has pump storage, it can use excess electricity during off-peak hours, effectively storing that excess electricity for on-peak periods, increasing the efficiency of the overall regional electricity production system. With a re-regulating reservoir, a hydropower plant can meet variable power needs while still providing constant downstream flows. This reduces the necessity of fossil fuel power plants to provide on-peak power generation.

4.13.3 Assessing Hydropower Benefits

This section describes the methods, models, and metrics for quantifying hydropower generation benefits. Applicants are not required to perform an exhaustive analysis of integration with renewable energy; therefore, it is not included in the methods description below. However, the applicants should qualitatively discuss how their proposed project will integrate with renewable energy, if that is applicable to the project.

4.13.3.1 Energy Generation

The overall approach to quantifying energy generation is to:

1. Quantify the hydropower generation (and power consumption requirements if not included in project costs) of a proposed project, either at the daily or monthly level, over a sequence of years representing the hydrologic conditions
2. Calculate the expected hydropower generation per year, broken out by load conditions if desired
3. Display results over the planning horizon, showing how hydropower generation ramps up after project construction

This kind of analysis is based on input hydrology and reservoir operations information, where energy generation capability will be based on the storage in the reservoir and flow through the turbines and operating energy consumption will be based on pumping requirements to meet the operating criteria of the project. In reality, hydropower generation is based on a variety of complex factors, including electricity markets, which are difficult to simulate over the long-term planning horizon of the proposed project. Therefore, an applicant is not required to perform complex electricity market analyses when quantifying hydropower benefits.

LTGEN and SWP_Power are two commonly used, publicly available models developed by the Reclamation and DWR. These models calculate a facility’s long-term power generation capacity and pumping energy consumption for CVP and SWP facilities (Reclamation, 2015). To calculate long-term power generation, the models use reservoir storage and release data from the CalSim II model along with user-specified generation characteristics, such as the number of units and transmission loss, to calculate a monthly average energy generation at all CVP and SWP reservoirs with power plants. For calculating pumping energy requirements, these models use flow data from CalSim II (described in Section 4.3, Surface Water Operations Analysis) along with user-specified characteristics, such as percentage of on-peak and off-peak pumping and transmission losses to calculate the monthly average energy consumption of all CVP and SWP pumping plants under the assumed CalSim II scenarios. While these two spreadsheet models are specific to the CVP and SWP, the models’ general methods are transferable to other projects.

In addition, HEC-ResSim and RiverWare are two commonly used simulation models that simulate hydropower generation and pumping energy use. The models use input flow data at a variety of time steps and user-defined reservoir, power plant, pumping characteristics, and operating logic to quantify the power generated based on reservoir releases. The models differ in their overall modeling logic but both have been applied in a variety of settings, and would be useful for calculating long-term energy generation and pumping energy requirements. See Section 4.5 Riverine Hydrologic/Hydraulic Analysis for more information on HEC-ResSim and Riverware.

Metrics for quantifying hydropower generation can simply be output in terms of energy units generated (such as megawatts). Calculating energy generation annually, monthly, and/or by water year type can help demonstrate the overall hydropower benefit of a project under a variety of energy demand and hydrologic conditions.

Power utilities or private consultants may have their own models that may apply to quantifying hydropower benefits. Some may be publicly available and some may be proprietary. If an applicant uses such a model, they should provide technical documentation describing methodology and results.

4.13.3.2 Integration With Renewable Energy

Applicants are not required to quantify system integration benefits for hydropower. An applicant wanting to demonstrate system integration benefits resulting from its hydropower production should compare with-project and without-project conditions to demonstrate such benefits. There must be some ability to adjust hydropower production according to the amount of electricity being produced by renewable power. The appropriate method will be specific to the project.

SECTION 5

Monetizing the Value of Project Benefits

The applicant shall estimate the monetary value of physical net benefits of the proposed project over the entire planning horizon. Net benefits are defined as benefits (desirable changes) minus unmitigated impacts (undesirable changes). If benefits and unmitigated impacts are measured in the same physical units at the same location and time, they may be directly comparable, and a simple subtraction calculates net benefits. However, in most cases, physical benefits and impacts are not measured in the same units or at the same time and location and, thus, are not directly comparable. In these cases, quantification of net benefits requires that the physical benefits and impacts be converted to comparable units. Monetizing is not the only way to bring disparate measures of physical changes into a common metric, but it is the most common way.

Economic, or monetized, benefits estimates are required to comply with WSIP requirements and to support ranking criteria, including the following:

- The share of project costs that can be funded depends on the share of project benefits that are public benefits.
- Ecosystem benefits must be at least half of funded public benefits.
- The project must provide benefits cost-effectively in comparison to other feasible means of providing the same benefits.
- A project must be economically feasible; that is, the project’s economic benefit must exceed the project cost.

The appropriate level of analysis for monetizing each public benefit depends on the size of the proposed project and the magnitude of that public benefit compared to all public benefits. The larger the project measured as total WSIP funding request, and the larger a monetized public benefit as a share of all public benefits, the more analysis is justified.

If physical benefits cannot be monetized, the applicant shall provide justification why and include a qualitative description of the importance of the benefits, who is affected, how, and how often, and other evidence to show how the physical change is beneficial and important to Californians.

This section is composed of four sections. Section 5.1 provides background on monetizing the value of physical benefits. Section 5.2 provides economic assumptions related to the planning horizon, monetary benefits, prices, and inflation. Section 5.3 describes monetary benefits methods generally, and Section 5.4 describes monetary benefits tools and methods by public benefits type, with emphasis on appropriate level of analysis.

Additional detail is provided in five appendixes. Appendix C provides a summary of reference and guidance documents for benefit-cost analysis. Appendix D documents water supply unit values that may be used to estimate avoided and alternative costs for water provided for public benefit purposes. Appendix E details methods, data, and sources for other methods to quantify ecosystem benefits. Appendix F describes a range of benefits models that may be used to quantify monetary benefits. Appendix G is a more detailed description of discounting and discount rates.

5.1 Background

This section describes how physical benefits can be monetized. Figure 5-1 shows a general flowchart for monetizing economic benefits. The figure does not show all of the detailed steps that might be required to monetize benefits.

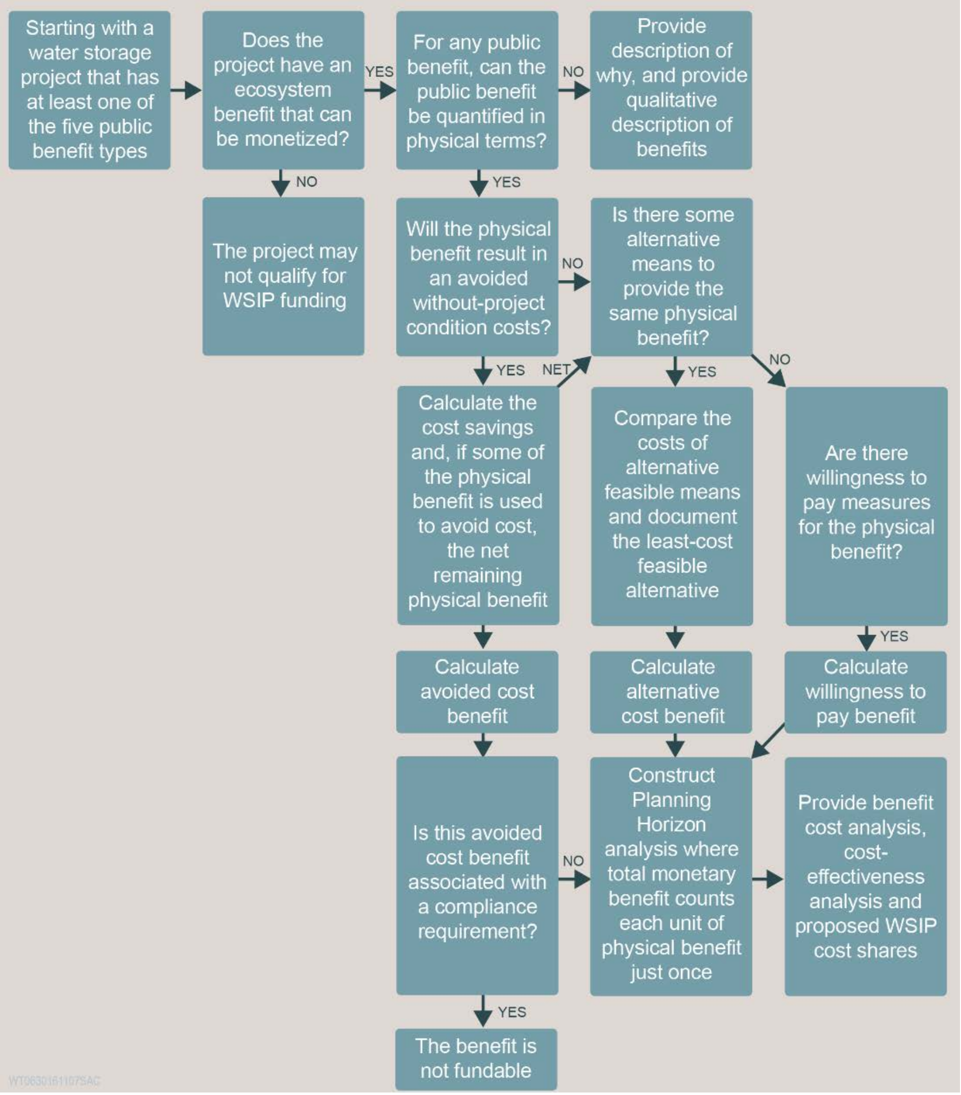

Figure 5-1. ***General Flowchart for Monetizing Physical Public Benefits.***

This section documents a large number of data sources, studies, and models. The reference of any data, studies, or models does not imply the endorsement of that information for specific application unless it is appropriately applied as part of a stated requirement in the regulations.

5.1.1 What is a Monetary Benefit?

Monetized public benefits represent improvements that will be compared to proposed WSIP cost shares. Conceptually, monetary “benefit” and “cost” are closely related economic measures and can be readily combined and compared. The economist’s definition of benefit means that the beneficiary (a person, entity, or group) is willing to give up something of value, generally expressed as an amount of money, for the physical benefit. For purposes of the WSIP, a dollar amount of benefit is the amount California should be willing to give up for the improvement.

Economists often define benefit as willingness-to-pay. In practice, this willingness is conditioned by budget; by alternative opportunities for use of that budget, especially the price and quality of substitutes; and by potential cost savings. A benefit may be determined by the amount of cost avoided by a purchase. An individual’s benefit from a good is affected by the price and quality of substitutes. For example, the benefit of an outdoor recreation experience depends on the price and quality of alternative recreation opportunities. Similarly, California’s benefit from a proposed project’s physical benefits will depend on avoided costs and the price and quality of alternative means for obtaining that physical benefit. These principles – willingness-to-pay, avoided cost, and alternative cost – provide the basis for the three approaches to monetary benefits calculations.

Willingness-to-accept compensation is a different measure of benefit, generally applied when physical benefits decrease. Because WSIP projects will increase physical benefits, the willingness-to-pay measure is generally appropriate. However, an estimate of alternative cost of a good (for example, of water) can be based on acquiring a substitute physical amount of the good from an existing user, so willingness-to-accept compensation may be used.

For this Technical Reference, physical benefits must be monetized using one or more of these three approaches. Other economic measures such as income, employment, or value of output are not the same as benefits and should not be included with benefits (see also Section 5.3.3).

5.2 Economic Assumptions

This section details the assumptions that are required for use in any economic benefit-cost analysis. The planning horizon analysis for the WSIP compares without-project and with-project condition in the future. They are compared over all years in the planning horizon of the project, not just one year as might be done, for example, for an environmental impact comparison. A project investment analysis is inherently a forecast or projection of future development and natural resource conditions, comparing physical and economic benefits of the with- and without-project conditions over an entire planning horizon, not just one future year. Section 4.2.1.6 of this document describes how benefits can be interpolated and extrapolated to create a planning horizon analysis using as few as two future condition years with quantified estimates.

5.2.1 Planning Horizon

The planning horizon must be the expected life of the proposed project in years plus the construction period, or 100 years, whichever is less.

The planning horizon defines the duration of this comparison period. Conceptually, the planning horizon includes the construction and operations period and, if benefits continue, the entire period within which benefits are received. For practical reasons, the planning horizon is normally limited to 100 years. Beyond 100 years, benefits and costs are extremely uncertain, and with discounting, they contribute little to present value.

5.2.2 California Accounting Perspective

The portion of all public benefit cost shares allocated to the WSIP will be determined by the share of all public benefits received by Californians. That is, the benefits analysis should differentiate monetary benefits for Californians versus benefits to non-Californians, to the extent practical, and only monetary benefits for Californians should be proposed for funding. For purposes of the California accounting perspective, Californians are defined as people residing in the state, businesses operating in the state, and properties located in the state. The California perspective includes local and state government costs ultimately paid by Californians.

The accounting perspective should not be an issue for most public benefit categories because virtually all of the benefits will be received by Californians. However, some studies have demonstrated non-use benefits for California special-status species for people not residing in the state. Non-use benefits, primarily applied to special-status species, are willingness-to-pay for the option to use a good at some future time, for knowing that the good will be bequeathed to future generations, and for knowing that the species will continue to exist. People who do not live in California may value California rare species and make voluntary contributions toward their betterment. Conceptually, these are legitimate benefits, but not from the California perspective.

Also, local cost savings or benefits claimed that are actually transfers from other Californians should not be included. Applicants should not count local benefits only. If a project captures water that would otherwise be used by other Californians, or have benefits for other Californians, those lost benefits must be counted as impacts. Benefits to one set of Californians that are completely offset by impacts on other Californians will not be counted as fundable public benefits. Only net public benefits are fundable.

5.2.3 Analysis in Constant Dollars

All future costs and benefits must be displayed in constant dollars for each year of the planning horizon. Expressing costs or benefits in constant dollars means displaying money over a number of years according to its purchasing power in a stated year (that is, as if there will be no inflation). To calculate the present value of benefits and costs using the real, inflation-free discount rate, the analysis requires constant dollar benefits and costs for each year of the planning horizon. Directions below show how the planning horizon analysis shall be developed.

5.2.4 Discount Rate

A 3.5 percent real (inflation-free) annual discount rate shall be used for all calculations that convert a constant dollar monetary value of benefit or cost into an equivalent value at another point in time. The discount rate accounts for the time value of money and allows all benefits and costs occurring in different future years to be compared and combined. An expanded discussion of the discount rate is provided in Appendix G.

5.2.5 Choice of Constant Dollar Year

The analysis shall be conducted in constant 2015 dollars, so all benefits and costs should be adjusted to 2015 price levels.

Benefit and cost data often come from a range of recent historical years. To account for inflation, these dollar values must be adjusted to a common price level. All monetized values must be adjusted to the stated constant dollar year so that all costs and benefits can be consistently compared at the same general price level.

The year 2015 has been selected because inflation levels through 2015 are known (see Section 5.2.6). A constant dollar year beyond 2015 cannot be selected because inflation beyond 2015 may not be known when applications are prepared. Note that the constant dollar year is not the same as the common point in time at which present value of costs and benefits are compared.

5.2.6 Price Indices for Updating Past Benefits and Costs to 2015 Dollars

Feasibility studies for some proposed projects might have been conducted in the past in constant dollar terms at that time, and other benefit and cost data might have come from different years in the recent past. With 2015 as the required constant dollar year, all benefits and costs must be displayed in 2015 price levels. Rather than require past costs and benefits to be recalculated, price indices can be used to update some past benefits and costs estimates to 2015 dollars. For updating project construction costs that are less than 5 years old, Reclamation Construction Cost Trends (Reclamation, 2016) should be used (Section 6.5).

Benefit estimates less than 5 years old at the time of submission of the WSIP application may be used but must be escalated to 2015 values. Benefit estimates that are more than 5 years old must be reconsidered and recalculated in 2015 values, unless the applicant provides justification that recalculation is not needed or possible.

Monetized benefits estimated before 2015 may be escalated to 2015 values using the yearly average consumer price index for California (CPI-U), as shown in Table 5-1. For example, if a project had a water quality benefit of $100 in 2010, this benefit would be worth $110.00 in 2015 dollars (1.100 times $100).

Applicants may use other published price indices to update past benefit estimates if justification is provided. Generally, the applicant must justify why the alternative price index is superior to the index presented in Table 5-1 for the benefit claimed.

Table 5-1. Price and Cost Escalation Factors That may be Used for Estimates Made in Previous Years.

If the historical dollar value was provided in these dollars:	**Multiply the dollar amount by this to bring it to 2015 dollars**		
	For most benefits, use consumer price index[1.]	**For flood damage reduction benefits, use housing construction cost index[2.]**	**For non-project, associated costs, use GNP implicit price deflator[3.]**
2015	1.000	1.000	1.000
2014	1.015	1.003	1.010
2013	1.033	1.074	1.029
2012	1.048	1.160	1.045
2011	1.072	1.179	1.0644
2010	1.100	1.186	1.086

[1]Source: CPI for California urban consumers (DOF, 2016b)

[2]Source: U.S. Census Bureau, 2016

[3]Source: Gross National Product Implicit Price Deflator, Annual (Federal Reserve Bank of St. Louis, 2016)

5.2.6.1 Flood Damage Reduction Benefits for Residential Structures

For updating flood damage reduction benefits, the index of costs of residential housing (U.S. Census Bureau, 2016) should be used. The recommended index in Table 5-1 is calculated as the average cost per unit in 2015 divided by the average cost per unit in the past year.

5.2.6.2 Non-Project Costs

Non-project costs or associated costs are not included in the proposed project's cost estimate, but are required for a beneficiary to receive the benefits. Non-project costs must be subtracted from gross benefits to obtain the public or non-public benefits that are directly compared to project costs. Examples include local variable conveyance costs for beneficiaries receiving water supply, or fuel and other materials costs of commercial fishermen. These costs may be updated to 2015 dollars using the GNP Implicit Price Deflator indices shown in Table 5-1. For example, suppose a water quality project evaluated in 2010 required costs that were not project costs. If $100 in 2010 water quality benefit required $50 of non-project cost in 2010, this cost would be worth

$54.30 (1.086 times $50) in 2015, and the 2015 net benefit available to cover project costs would be $55.70 ($110.00 minus $54.30).

Applicants may choose to use price indices that are more specific and accurate for a given cost or benefit category than the indices provided above. Justification must be provided.

5.2.7 Real Energy Prices for Future Cost Projections

Real energy costs are expected to increase in real terms in the future. Future real energy costs or energy cost savings shall be escalated 1.7 percent annually to 2024, unless otherwise justified. That is, energy costs are expected to increase 1.7 percent faster than inflation. Real unit energy costs shall be held constant thereafter, unless justified by independently published information. Justification must state the reasons for and calculation of the different escalation or future value and the study or other published information used.

Energy costs have a strong influence on groundwater pumping and conveyance costs, and some projects may produce electricity. The California Energy Commission (CEC) (CEC, 2014) mid-demand scenario predicts that real electricity rates will increase 1.7 percent annually from 2012 to 2024. The electricity prices that provide this result are shown in Table 5-2.

Table 5-2. Energy Prices, CEC 2014 Final Forecast

	Average Price (2012 cents per kilowatt-hour)		
Electricity Year/Period	**Low-Demand Scenario**	**Mid-Demand Scenario**	**High-Demand Scenario**
2012	13.4	13.4	13.4
2015	14.0	14.6	15.2
2020	14.2	15.7	17.2
2024	14.9	16.4	18.0

Source: CEC, 2014

The CEC has not provided a basis for energy cost escalation after 2024.

5.2.8 Calculating Yearly Planning Horizon Benefits from Future Conditions

A future condition is a set of socioeconomic, development, climate, regulatory, and other conditions, defined for a specific year or years within the planning horizon. Economic benefits of water storage projects occur each year over a planning horizon that often is decades long. Proper calculation of benefits must account for when they occur in the planning horizon. The analysis of without-project and with-project conditions is performed for specific years, called future conditions. The years 2030 and 2070 are the future conditions for which hydrologic and other physical benefits must be analyzed.

Monetized benefits and costs over the planning horizon must be converted to present values, so an estimate must be calculated for each year, not just the two future condition years. Trends, interpolations, and, if needed, extrapolations are used for this purpose. The following sections describe how to apply these concepts to generate a full sequence of monetized values over a planning horizon.

5.2.8.1 Real Economic Benefits May Trend over Time

As discussed in Section 5.2.3, any trend in dollar values caused by economy-wide inflation should not be included, and all future benefits and costs must be monetized based on price levels in the constant dollar year, 2015. However, real (inflation-adjusted) benefits or costs might increase or decrease over time. For example, real energy benefits or costs should increase up to 2024.

Three likely reasons for changing real economic benefits are that the physical quantity of benefit changes over time, population will increase over time, and real prices or unit values might change over time. Trends in benefits may consider trends in physical benefits, population growth, land use, water use, climate and sea-level conditions, and real prices or unit values. Also, with SGMA, the real value of water is expected to increase over time up to 2042 (see Section 5.3.3). Any trends based on prices or unit values increasing faster or slower than inflation should be based on independently published information.

For monetization, applicants may estimate separate monetized values for each future condition, or they may apply the monetized value per unit of physical benefit derived from the 2030 analysis to the physical changes at the 2070 condition. If applicants select the option of using the 2030 monetized value per unit for 2070, they may understate the 2070 benefits because of 1) population growth, 2) climate change, and 3) SGMA. Applicants should review the potential for increasing real economic benefit per unit beyond 2030 before simply using 2030 unit values for 2070.

5.2.8.2 Using Extrapolation and Interpolation to Complete the Planning Horizon Analysis

This section repeats some information provided in section 4.2.1.6, but expands to include examples and tables that illustrate planning horizon analysis. To calculate and compare the present value of benefits and costs, the economic analysis requires dollar benefits and costs for every year of the planning horizon. Where benefits or costs increase over time, it is not necessary to develop hydrologic distributions or other forecasts for every year in the planning horizon. Rather, two future condition analyses are required (2030 and 2070), and the remaining years of the planning horizon analysis can be completed using extrapolation and interpolation.

In calculating the benefits or impacts from the start of project operations until the 2030 future condition year, applicants may interpolate between values calculated for current conditions and 2030 conditions, if current condition estimates are available. If not, a trend based on extrapolation backward using 2030 and 2070 conditions shall be used. In calculating the benefits and impacts from the 2030 future condition year until the 2070 future condition year, applicants shall interpolate between the values calculated for 2030 conditions and 2070 conditions. If other important changes in physical or economic conditions occur at other years during the planning horizon, applicants may also include those years as points for interpolation. Due to the great uncertainty in conditions beyond 2070, benefits and impacts within the planning horizon but beyond 2070 shall be held at the 2070 values.

The examples in Table 5-3 and Table 5-4 use 2030 and 2070 as the future condition years. These points in time are used to establish a trend and show the interrelationship of planning horizon, future condition, and hydrologic period for analysis.

Table 5-3. Example Calculation of Monetary Benefits from Hydrologic Record for Analysis using 2030 and 2070 Future Conditions.

Year of Hydrologic Record for Analysis	**2030 Condition**			**2070 Condition**		
	2030 Condition Water Supply Change [1.]	**2030 Unit Value for Year Type**[2.]	**2030 Benefit of Water Supply**[2.]	**2070 Condition Water Supply Change** [1.]	**2070 Unit Value for Year Type**[2.]	**2070 Benefit of Water Supply**[2.]
1922	AF	$/AF	AF x $/AF	AF	$/AF	AF x $/AF
1923	AF	$/AF	AF x $/AF	AF	$/AF	AF x $/AF
1924	AF	$/AF	AF x $/AF	AF	$/AF	AF x $/AF
1925	AF	$/AF	AF x $/AF	AF	$/AF	AF x $/AF
Etc.…	AF	$/AF	AF x $/AF	AF	$/AF	AF x $/AF
2011	AF	$/AF	AF x $/AF	AF	$/AF	AF x $/AF
2012	AF	$/AF	AF x $/AF	AF	$/AF	AF x $/AF
2013	AF	$/AF	AF x $/AF	AF	$/AF	AF x $/AF
			Avg2030 [3.]			Avg2070 [3]

1. With-project supply minus without-project supply, for each year.
2. All benefits are adjusted to 2015 dollars. Applicants may calculate separate values for 2070, or they may apply the 2030 unit values.
3. Avg2030 and Avg2070 are the average over all years of the hydrologic record and are the expected annual benefits for each development condition.

Table 5-4. Example Calculation of Project Costs and Benefits over the Planning Horizon.

Year of Project Construction or Operation	**Project Costs and Benefits by Year of Analysis (2015 $)**	
	Project Costs	**Monetized Project Benefits**
2020	Construction	No benefits to monetize yet
2021	Construction	
2022	Construction	
2023	Construction	
2024-2029	OM&R[1]	Interpolate using current benefits and Avg2030 from Table 5-3, or use Avg2030, or extrapolate using Avg2030 and Avg2070 from Table 5-3
2030	OM&R	Avg2030 from Table 5-3
2031-2069	OM&R	Interpolate using Avg2030 and Avg2070 from Table 5-3
2070	OM&R	Avg2070 from Table 5-3
2071-2123[2]	OM&R	Avg2070 from Table 5-3

[1] OM&R is operations (including power), maintenance, and replacement cost as needed during the operational life of the project. The year 2024 is the first year of project operation.

[2] The year 2123 is the last year of project life in this example.

The interpolations in Table 5-3 and Table 5-4 are examples. Additional years may be used for interpolation, or the applicant may justify use of a constant economic value over some duration of the planning horizon. Reasons can include the following:

- If any public benefit amount is not expected to trend over the planning horizon, the future condition benefit would be the same in every year of the planning horizon and the same dollar amount should be used over the entire planning horizon.
- An applicant might be able to justify benefits remaining constant over part of the planning horizon, such as using only the 2030 condition benefits for the remainder of the horizon.
- If important without-project condition infrastructure changes are reasonably known during the planning horizon (e.g., completion of other water supply, conveyance, habitat, or other projects) that result in a substantial change to the level of physical changes provided by the applicant’s project, one or more additional future condition years are recommended to show how the level and trend of benefits are affected.
- If important economic or related policy changes are projected to occur during the planning horizon (e.g., the full implementation of sustainable groundwater management under SGMA), an additional future condition year is recommended to account for changes in monetized values of benefits or impacts. Applicants shall use the interpolated values for physical conditions at that additional future condition.

For example, if a major conveyance project will phase in substantial changes in water delivery between 2035 and 2040, analysis could be based on the following points in time:

1. Current condition without new conveyance
2. 2030 without new conveyance
3. 2035 with new conveyance
4. 2070 with new conveyance

So, benefits between completion of construction and 2030 would be based on interpolation using 1 and 2, benefits for 2030 to 2035 would be based on interpolation using 2 and 3, and benefits for 2036 to 2070 would be based on interpolation between 3 and 4. Applicants should be careful to distinguish between changes or trends in physical conditions and changes or trends in economic values used to monetize the physical conditions.

5.3 Economic Methods for Monetizing Benefits

This section describes economic methods for monetizing the physically quantified benefits in general terms, provides a recommended sequence of steps, summarizes WSIP unit values, and discusses common analytical options and errors. Quantified impacts shall be monetized in the same manner.

The applicant shall calculate, display, and justify, for each public and non-public benefit, the benefits and unmitigated impacts monetized using each of the following approaches, to the extent it is applicable to the proposed project:

1. Avoided cost: reduction in a without-project cost that would occur as a result of a proposed project.
2. Alternative cost: the cost of the least-cost means of providing at least the same amount of physical benefit.
3. Willingness-to-pay: the dollar amount Californians would be willing to pay for the physical benefit, if it can be justified and documented.

If multiple reasonable economic methods exist to estimate willingness-to-pay, the applicant shall justify the method selected.

The appropriate level of analysis for quantifying each public benefit should allow the Commission and staff to make a knowledgeable judgment about whether the magnitude of the public benefit justifies its requested public cost share. The monetized benefit of the proposed project shall be calculated as the avoided cost (if any) plus, for any portion of the physical benefit not monetized as an avoided cost, the minimum of the feasible alternative cost value (if any) and the willingness to pay value (if any).

5.3.1 Steps for Monetizing Benefits

The following sequence is recommended to avoid unnecessary effort and reduce potential for error.

1. Identify avoided costs
2. Identify feasible alternatives and alternative costs
3. Estimate willingness-to-pay values for each net physical benefit
4. Display and justify the preferred approach for monetizing benefit

Step 1: Identify Avoided Costs. Avoided costs are a benefit when the project reduces without-project condition costs because such costs would no longer be needed or expected or would be delayed. Examples include flood damage reduction, reduction in emergency response costs, water supply cost savings, or reduced water treatment costs. It is important to document that the cost avoided because of the project would actually be incurred in the without-project condition. To document this avoided cost, planning documents that pre-date the WSIP are preferred.

Of the three approaches, avoided costs are typically identified and estimated first because they result from a comparison of the with- and without-project condition. Also, avoided costs are sometimes not fundable public benefits by the WSIP because they are associated with compliance obligations. For example, an applicant might expect high costs to comply with a future instream flow requirement, so it plans to use some of the proposed project's water for instream flows. If so, the project water supply used to avoid the cost would not be associated with a net improvement in physical benefit conditions; that is, the project is providing the same physical benefit that would be provided in the without-project condition.

For some projects, part of the water might be used to replace a without-project supply, and some project water remains for other uses. This remaining amount is the net physical benefit. For example, suppose that, in the without-project condition, 500 acre-feet of water is provided for environmental purposes, and that water costs $800 per acre-foot to provide. In the with-project condition, assume that the proposed project can provide 3,000 acre-feet of environmental water, and the applicant would like to use 500 acre-feet to avoid the without-project cost. The avoided cost benefit is $400,000 (500 acre-feet times $800), and the net physical benefit is 2,500 (3,000 minus 500) acre-feet.

Applicants should not double-count an avoided cost benefit by counting both the avoided cost and the quantity of physical benefit replaced by the project. If no avoided cost benefit is claimed, and none of the physical benefit is used in Step 1, all of the physical benefit remains to be valued in Steps 2 and 3.

For each benefit category claimed, applicants shall provide a calculation of any cost savings (without-project cost minus with-project cost), if any, that is caused by the project. Indicate the year(s) that the saving occurs during the planning horizon. Show the amount of physical benefit, if any, required for avoiding costs each year and the remaining amount. The remaining amount is the net physical benefit that can be valued using alternative cost or willingness-to-pay.

For avoided costs, the appropriate level of analysis depends on the type of public benefit, the size of the avoided cost benefit claimed relative to all project benefits, and the size of the project. For projects where avoided cost benefits are a large share of all benefits claimed, the quality of cost estimates for avoided and delayed projects should be similar to the quality of project cost estimates. For avoided water costs, recommended unit values can be used or other unit benefits, if justified.

In most cases, the avoided costs are assigned as benefits to the years of the planning horizon they would have occurred.In some other cases, the project will cause another action or project, planned for the without-project condition, to be delayed rather than avoided. The costs of the delayed project should be shifted in the with-project condition relative to the without-project condition. The delay results in the costs being discounted more, thus providing a cost reduction in present value terms.

Step 2: Identify Feasible Alternatives and Alternative Costs. For each benefit category claimed, and for any net physical benefit remaining after being monetized using avoided cost in Step 1, applicants shall estimate the cost of the least-cost alternative means of providing the net physical benefit amount.

Alternative costs are similar to avoided costs. The difference is that avoided costs represent plans that would no longer be needed because of the project, whereas alternative costs represent options that could be implemented to provide the same physical benefit as the project. If feasible alternatives exist, the cost and quality of these substitutes can be used as an estimate of the monetized benefit.

If at least one feasible alternative means exists that can provide the same net physical benefit as the proposed project, the least cost of these alternative means shall be documented and its cost provided. Examples include the following:

- For a proposed project that provides habitat or water for ecosystem improvement or water quality improvement, alternatives could include a different project, real property acquisition, or water transfers that could provide the same amount (in net physical benefit) of restoration of aquatic habitat or restoration of native fish and wildlife. For example, water transfers from willing sellers who own existing, upstream storage might be used to provide the same amount of instream flow as the proposed project.
- For flood damage reduction, upgrade or repair of downstream levees or additional flood space in an existing reservoir could provide the same level of protection as the proposed project.
- For recreation, improvements in recreation facilities at an existing local reservoir could provide the same amount and quality of recreation.

A more detailed description is provided in Section 5.4. The scope of alternatives to consider includes all alternatives that could provide the same amount (or greater) and types of benefits as the project. Alternatives that could provide the same benefits in the same place are preferred, but alternatives that provide similar benefits close to the project can be considered.[1] An alternative must be substantially different from the proposed project, not a minor variation of the proposed project.

Generally, alternatives considered in a feasibility analysis and in environmental documentation can provide a basis for an alternative cost analysis. Alternatives should be technically, environmentally, physically, and legally feasible. Many alternatives can be ruled out under these criteria. If alternative ways of providing a public benefit were evaluated but dismissed as infeasible in the feasibility study or other published document (such as a plan formulation study), applicants shall briefly summarize the results of that analysis. Feasible alternatives studied in the feasibility study or environmental documentation, or in previous studies, should be described and documentation provided.

The extent to which an alternative action could substitute for the proposed project's net physical benefit should be considered. The proposed project and its alternatives may be mutually exclusive, substitutes, or complements, and their scales may be different. Such relationships are normally explored in feasibility studies and environmental documentation.

Alternatives should be sized to provide the amount of net physical benefit not quantified as an avoided cost in Step 1. If an alternative would provide the full amount of total physical benefit as the proposed project, the alternative' costs should not be added to any avoided cost to avoid double-counting. If an alternative provides a greater amount of physical benefit than the proposed project, the alternative should be resized or only a share of the alternative cost can be claimed. If the alternative's physical benefit is less than the net physical benefit of the proposed project, additional action, if feasible, should be included so that the same total amount of net physical benefit is achieved. If the alternative provides more categories of physical changes than the proposed project, only a share of the alternative's cost is appropriate. Differences between the alternative and the proposed project in the amount, timing, and quality of benefits must be explained.

For alternative costs, appropriate level of analysis depends on the type of public benefit, the size of alternative cost benefit claimed relative to all project benefits, and the size of the project. For projects where alternative cost benefits are a large share of all benefits claimed, the quality of cost estimates for alternative costs should be similar to project cost estimates.

Step 3. Estimate Willingness-to-Pay Values. Willingness-to-pay benefits are the maximum amount Californians would pay to obtain the project's net physical benefit if no alternatives were available. In this context, alternatives are the project-level alternatives investigated in Step 2. The maximum willingness-to-pay for benefits by individual Californians is affected by the price and quality of substitutes available to them.

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[1] This approach is similar to the NMFS' 2009 Biological Opinion on Chinook Salmon and Sturgeon, which suggests that alternatives be evaluated and agencies may select an option that is most practical. "NMFS cares only that the stressor be sufficiently reduced" and less about the option selected.

Applicants may select methods described in Section 5.4 or other methods if supporting documentation is provided. Applicants must justify the methods selected.

For willingness-to-pay benefits, the appropriate level of analysis depends on the type of public benefit, the size of the willingness-to-pay benefit claimed relative to all project benefits, and the size of the project.

Step 4. Display and Justify the Preferred Approach for Monetizing Benefit. For each public benefit, the applicant must calculate, display, and document the benefits monetized using one or more of these approaches: avoided cost, alternative cost, and willingness-to-pay. Generally, the approach for monetizing benefit should be the avoided cost plus, for the remaining net physical benefit, the minimum of the alternative cost and willingness-to-pay approaches. The applicant must select an approach to quantify the total economic benefit and justify why it was chosen.

5.3.2 Multiple Methods for Calculating Economic Benefits

More than one reasonable method for monetizing the public or non-public benefits may exist. Applicants must select and justify a benefits estimate that reflects the most likely without-project condition, avoided costs where applicable, the alternative cost, and the most appropriate willingness-to-pay method based on available studies and data. Comparison of estimates derived from multiple methods is encouraged to show a range of potential physical and economic benefits, though not required. Section 5.4 explores benefits methods for each of the public benefits categories. Applicants should consider uncertainty in future economic conditions and describe how the uncertainty would affect monetized benefits (see Section 10).

5.3.3 Use of Unit Values

It is expected that most public and non-public benefit categories will be provided via water released from or managed by a proposed storage facility. For many of these benefits, the alternative cost of water supply or the willingness-to-pay for water supply can be approximated using unit values of water that reflect differences in timing and location. If the public benefits can be provided using means other than water supply, other measures of alternative cost and willingness-to-pay should also be provided. For example, if a water temperature reduction benefit could feasibly be provided by purchasing and releasing stored water or by installing a temperature control device, costs of these alternatives must be considered, and the lower cost used as an alternative cost approach.

The unit values may be used in cases where a proposed project provides water for flow or diversion as water supply, and the unit values represent a feasible alternative source. The unit values are not appropriate for water provided that replaces (avoids) an existing or planned project in the without-project condition. In this case the avoided project cost is the correct measure of benefit.

Applicants should consider the location and type of use of water provided by the proposed project in order to assess whether and how to apply the unit values described below. Competition for water through a water transfer market should also be considered. For example, the unit values may be appropriate for situations where local agricultural users would use the water. However, if the water would be provided for non-local, urban uses, especially under shortage conditions, the unit values may be too low and another method may be appropriate. Section 5.4.1.3 provides methods for evaluating the benefits of water supply that will reduce urban (M&I) water shortage.

The unit values are shown in Table 5-5 and documented in Appendix D. The unit values were developed from a statistical analysis of water transfer prices from 1992 through 2015 and an application of the Statewide Agricultural Production Model (SWAP), including assumptions related to SGMA. SGMA mandates that affected groundwater basins must be managed for sustainable yield by either 2040 or 2042. For the unit values presented below, 2045 was assumed to be the year in which sustainable yield is fully achieved. Applicants may use the same assumption if it applies to their projects.

The analysis finds that the real value of water south-of-Delta will increase substantially with implementation of SGMA because groundwater use will be limited by sustainable yield. Appendix D provides details on how the sustainable yields were estimated using calibration results from an existing regional groundwater model. As such, they are only approximations – actual sustainable yields are not known at this time for most affected regions in California. Applicants may also use their own unit values or other benefit methods if careful explanation and justification are provided. If using the unit values in Table 5-5, values between 2030 and 2045 shall be developed by interpolation. The unit values shall not be increased past 2045 unless applicants provide justification based on independently published information.

Table 5-5 provides the unit values on a consumptive use basis for most regions, but on an applied water basis for Delta Export regions. Applicants may need to adjust the unit values for different situations. For example, if the potential use of the water is for transfer, or if the alternative cost of water for flow is to be calculated, generally, only the consumptive use fraction may be transferred. If the unit values are used to value applied water, they should be adjusted to an applied water basis using consumptive use and applied water information appropriate for the location of the proposed project's use of the water. Applicants must carefully explain and justify any adjustments.

Table 5-5. Unit Values of Water for WSIP.

2030 conditions (2015 dollars)

Water Year Type (Sacramento Valley 40-30-30 or San Joaquin Valley 60-20-20 Index)	Sacramento Valley (in $/AF of consumptive use)	Delta Export (in $/AF of applied water)	Eastside San Joaquin Basin (in $/AF of consumptive use)	Friant Service Area (in $/AF of consumptive use)
Wet	$145	$204	$106	$200
Above Normal	$191	$256	$133	$251
Below Normal	$255	$267	$189	$261
Dry	$275	$285	$201	$278
Critical	$345	$360	$375	$324

Table 5-5. Unit Values of Water for WSIP.

2030 conditions (2015 dollars)				
Water Year Type (Sacramento Valley 40-30-30 or San Joaquin Valley 60-20-20 Index)	**Sacramento Valley (in $/AF of consumptive use)**	**Delta Export (in $/AF of applied water)**	**Eastside San Joaquin Basin (in $/AF of consumptive use)**	**Friant Service Area (in $/AF of consumptive use)**
2045 and later conditions with SGMA (2015 dollars)				
	Sacramento Valley (in $/AF of consumptive use)	**Delta Export (in $/AF of applied water)**	**Eastside San Joaquin Basin (in $/AF of consumptive use)**	**Friant Service Area (in $/AF of consumptive use)**
Wet	$150	$414	$309	$256
Above Normal	$198	$519	$388	$321
Below Normal	$264	$633	$437	$481
Dry	$283	$674	$466	$512
Critical	$354	$1,056	$728	$1,105

The Table 5-5 unit values are appropriate for relatively small incremental amounts of water supply relative to the existing water uses available as feasible alternative sources. If an action or water supply will provide a large amount of water relative to available alternative sources, then the unit values in Table 5-5 may not be appropriate.

5.3.4 Avoiding Double-Counting

Double-counting is a common problem in benefits analysis, and it can be difficult to identify in projects with complex operations that provide multiple, related benefits. In general, one measure of each physical benefit should be monetized, and each unit of physical benefit should be monetized just once. Benefits for both intermediate and end products should not be added together for the same benefit category. For example, if a project provides flow for water quality improvement, the analysis should not count both the alternative cost of the flow amount and the willingness-to-pay for the water quality improvement. If a project provides habitat for a species, the analysis should not add together both the value of the habitat and the value of the species that relies on the habitat (unless the habitat provides additional value beyond its use by the species). Also, values from different methods used to monetize the same physical benefit should not be aggregated. Each unit of physical benefit must be monetized and included in the summation only once.

Sometimes, an action will provide multiple physical benefits that can be included. For example, if flows provide habitat benefits both in-river, near the project, and farther downstream, in the Delta perhaps, all of those physical benefits should be included. However, if an alternative such as a water transfer could also provide these benefits, the alternative cost of the water transfer should not be counted more than once because the water transfer also provides the same three physical benefits.

5.3.5 Methods and Models that Do Not Estimate Economic Benefits

Some economic models and methods have been pre-screened and are not discussed in detail in this Technical Reference because they do not provide economic benefits as a measure. They are useful measures that are often used in economic impact analysis, and measured economic effects may be associated with state benefits, but they do not provide the benefits measures required. Young (2005) describes a range of economic methods that are suitable for estimating benefits and discusses why some measures of economic activity and cost recovery are not appropriate measures of benefit.

The following are models that provide measures of economic activity or cost recovery but not economic benefits and shall ***not*** be used by applicants to quantify the benefits of water storage projects:

- Input-output (I-O) models and related software. I-O models provide measures including output, value added, income, and employment associated with regional economic activity and growth. I-O does not account for opportunity costs or re-employment opportunities for resources. Project impacts on output, value added, income, and employment may represent a reallocation of resources within the state and not a net increase in a cost or benefit. Examples of I-O models that provide inter-industry sales are IMPLAN and REMI.
- Models that forecast economic growth. Similarly, some models forecast economic growth in terms of value of output, income, and employment. As with I-O models, these measures are not economic benefits. Project impacts on economic growth may represent a reallocation of resources within the state and are not viewed as a net increase. Similar to I-O models, economic forecasts cannot be used for benefits estimation although they may provide helpful information.
- Financial models that describe changes in costs, revenues, or cash flow to an agency. These models are generally not appropriate for estimating the economic benefits of a project. Agency rate structures are often characterized by average-cost pricing and are constrained by existing contracts and laws. More importantly, they are designed to recover agency costs and represent costs and revenues from the agency’s perspective, not the state’s perspective. Financial models can be important for estimating some components of the with-project condition such as water revenues and prices.

5.3.6 Accounting for Third Party Effects

When valuing water, applicants may consider the potential economic costs to third parties that may not be reflected in a willingness to pay or alternative cost estimate. For example, an alternative cost of water that is based on purchasing water from existing users such as agriculture, may result in real economic costs beyond what is paid in compensation to the users. Fallowing land that provides habitat benefits imposes an environmental cost and may require mitigation. Reduced production may impair the net returns of local economic sectors that rely on the production and have no way to make up for the loss.

The unit values of water provided in Section 5.3.3 are based on estimates that do not, in general, incorporate such third party costs. Economic impacts of California water transfers were recently analyzed for Reclamation's Long-Term Water Transfers Environmental Impact Statement/Environmental Impact Report (2015). Economic costs in linked industries were not estimated, but the analysis indicated that, of the water provided by crop idling or fallowing, the large majority would likely be from rice. Therefore, any additional mitigation costs or economic costs of idling are likely to involve reduced rice production.

Applicants may consider mitigation costs for water transfers that idle cropland if such costs can be justified and estimated. These costs might include mitigation for special status species such as giant garter snake, or for waterfowl.

Economic costs in sectors linked to a directly-affected sector like rice production are not normally included in benefit-cost analysis. In general, resources that become temporarily unemployed because of crop idling have alternatives in the economy that reduce or even eliminate costs. For example, reduced dairy feed production in one region of California may not reduce dairy production because producers can import feed from other regions or other states (although higher feed cost can be included as a cost if it can be documented). Rice mills do not have a similar option, however, because little or no unmilled rice is available from other areas. When rice land is idled, additional economic costs occur because net revenue (revenue minus variable costs) of milling and related processing are also lost.

No recent, publicly-available information on California rice milling variable costs was found. If applicants can document rice milling losses and the avoided milling costs, the net revenue losses can be included as additional economic costs of land idling. That is, in addition to the unit values paid to growers (the basis of the unit value estimates in Section 5.3.3), applicants can, with documentation, count an additional cost based on net revenue losses in the milling sector.

5.4 Tools and Methods

This section provides guidance on approaches, tools, and methods specific to water supply and the five public benefit categories. The general benefits approaches to use are: avoided cost, alternative cost, and willingness-to-pay. For water supply generally, and each type of public benefit, tools and methods are described.

The selection of an approach and specific method can depend on the expected size of the public benefit. The appropriate level of analysis for monetizing each public benefit depends on the magnitude of that public benefit compared to all public benefits or the size of the proposed project. Where the WSIP funding request is a small fraction of total project cost, less effort may be justifiable. Where the magnitude of a public benefit will be small as a share of all public benefits, simpler methods are justifiable.

If physical benefits cannot be monetized, the applicant shall provide justification why and include a qualitative description of the economic importance of the benefits. If ecosystem benefits cannot be documented in physical and economic terms, justification for WSIP funding may not be possible. This section focuses on quantifying benefits, but applies equally to quantifying impacts.

5.4.1 Water Supply Benefits

Applicants must ultimately determine which project costs must be assigned to non-public benefits, such as water supply, to justify their public funding request. In addition, some eligible public benefits may be monetized using the value of water as water supply. For example, emergency response releases for Delta levee failure events provide water supply for agricultural and urban uses; also, groundwater projects that “clean up and restore groundwater resources” (Water Code Section 79753(a)(2)) for water supply can claim water quality benefits. This section outlines principles and examples for water supply benefit estimates.

5.4.1.1 Water Supply Avoided Costs

Avoided costs apply if the proposed project will result in some without-project costs to be avoided or delayed. Examples include:

- The avoided costs of other water supply projects that were planned but, with the proposed project, are not needed. Such projects might include groundwater, surface water, recycled water, conservation, or desalination projects. The applicant must demonstrate that the avoided or delayed project is part of the without-project condition.
- Water supply obtained by temporary water transfers will be avoided because of the proposed project. The unit values described above may be used where appropriate if they can be adjusted to the location of the use of the proposed project’s water supply.
- The amount of without-project supply provided by existing projects will be reduced. If the without-project supply is surface water provided by the CVP or SWP, the unit values may apply. In other cases, the avoided supply will be local surface water or groundwater. The avoided costs of these supplies can be used as the monetized value.

Avoided costs of groundwater supplies can be difficult to calculate. With SGMA, groundwater depletion cannot continue indefinitely. SGMA sets target dates to attain sustainable conditions, depending on the current status of the groundwater basin. The avoided costs of groundwater use should include replenishment costs needed to maintain sustainable yield after the applicable target date. Therefore, avoided groundwater costs include (1) the variable costs of pumping water, including energy, maintenance, treatment and conveyance; and (2) the avoided costs of water needed for replenishment in the without-project condition. Item 2 would not be included where sustainability can be met through natural replenishment.

5.4.1.2 Water Supply Alternative Costs

If the proposed project's water supply could be obtained by a feasible alternative, the cost of this alternative will influence or determine the monetary water supply benefit. The costs of feasible alternatives that could provide the same water supply can be used. Applicants may provide alternative cost estimates using the unit values unless not applicable to or infeasible for their projects. If alternative ways of providing water supply were evaluated but dismissed as infeasible in the feasibility study or other published document (such as a plan formulation study), applicants shall briefly summarize the results of that analysis. Other considerations are similar to those for avoided costs.

5.4.1.3 Water Supply Willingness-to-Pay

The water unit values provided in Table 5-5 may not apply to specific situations. They may not be appropriate for local areas with limited hydrologic connectivity to the regions included in Table 5-5, and they do not apply for severe water shortage that might result from a Delta or drought emergency.

Most water supply is delivered for a price. The price of water can be used as a measure of benefit where water is priced at its opportunity cost (i.e., what it could earn if sold to another user, adjusted for conveyance costs), sellers are able to provide more water at that price, and buyers are able to take the quantity of water they want at that price.

Water is often not priced at its opportunity cost. Water service revenues may include non-price mechanisms: fixed service charges, charges based on land area, and one-time service or connection fees. Prices and other charges are normally designed to recover average costs, not to reflect opportunity costs. In agricultural regions, water is often not allowed to move freely among potential sellers and buyers. Project applicants may need to use local water prices for project revenue and financial feasibility calculations, but local water prices are often not appropriate as a benefit measure. Agriculture's willingness-to-pay for new water supply is directly determined by how the water supply would change net income. For agricultural water, the unit values in Table 5-5 can generally be used to value agricultural water. These values were estimated through a combination of observed, voluntary water transfer information and estimates of how changes in water supply affects net income of potential agricultural buyers or sellers. Unit values may need to be reduced for any non-project costs before being compared to project costs. For example, agricultural users may need to pay for local conveyance or pumping costs that are in addition to costs from a proposed project. Local conditions may also justify using unit values different from those provided in Table 5-5.

M&I supply is normally metered and sold for a price per unit delivered. Even though M&I water is not generally priced according to opportunity costs, the price provides important information about benefits. Absent drought conservation, water buyers are mostly able to take the quantity they want, and sellers provide whatever quantity is demanded at the price determined by their rate structure. Water price normally accounts for a large share of revenues used to cover a supplier's average costs. Therefore, where M&I water supply is a proposed project's benefit, M&I water prices can provide a basis for monetizing benefits.

The total economic benefit from water supply includes two important concepts: producer surplus and consumer surplus. Producer surplus for water suppliers is defined as the total revenue minus all variable costs of providing water service. Variable costs should take a long-run perspective and include all future costs that vary with the amount of water provided. The resulting revenue net of long-run variable cost is available to cover existing fixed costs including capital recovery and project costs.

Consumer surplus is the willingness-to-pay of water customers above what they actually pay. With no water supply shortage, consumers purchase and use water to the point where their incremental benefit (willingness-to-pay) is equal to the price. With shortage enforced by rationing, consumers cannot take the full amount of water they want at the given price. If a proposed project's water supply will reduce shortage, consumer surplus will increase and should be included in a willingness-to-pay estimate. This situation can be assumed during drought conditions or following an emergency event where water supply to end water users is cut off.

The preferred method for estimating M&I consumer surplus costs during shortage requires an economic demand function for the affected water users. This demand function relates quantity of water demanded to the price per unit paid and can be developed using the "point-slope" method. The water price and quantity taken without shortage define a point on the demand function and the slope is defined by the elasticity of demand. Elasticity may be estimated specifically for local conditions, but is usually developed based on existing studies. With this demand function, the increase in consumer surplus provided by reducing shortage can be calculated.

A constant elasticity of demand (CED) function can be used to show how this method works. The CED function is expressed by the following equation:

$$Q = aP^e$$

where

"Q" is the quantity of water demanded,

"P" is the price of water,

"a" is the CED coefficient, and

"e" is the elasticity of demand, $e < 0$

Given an observed Q_0 and P_0, quantity and price from a time when there is no shortage, and given an elasticity of demand "e", the CED coefficient can be derived. Rearranging the CED equation,

$$a = Q_0/P_0^e$$

With the calculated CED coefficient, the marginal willingness-to-pay can be calculated for any shortage quantity Q_s:

$$P_s = (Q_s/a)^{(1/e)}$$

where

“P_s“ is the marginal willingness to pay at the quantity Q_s

The amount of consumer surplus lost due to shortage can be derived as the integral under the demand function and above price P_0 from P_0 to P_s, or a linear approximation is acceptable:

$$CS = (Q_0-Q_s)*(P_s-P_0)/2$$

where

CS is the consumer surplus loss due to shortage of Q_0-Q_s

The elasticity of M&I water demand varies by economic sector, time of year, conservation history, and other factors. Applicants should use locally estimated demand elasticities if available. Generally, empirical studies are nearly unanimous in finding that M&I demand is price inelastic. This means that the percent reduction in quantity taken following a price increase is often much less than the percent increase in price. Absent local sector-specific information, an acceptable range of M&I demand elasticities is -0.15 to -0.35 (MCubed and RMann Economics, 2016). The lower end (-0.15) applies to regions where permanent conservation and price have already induced high levels of conservation to obtain low per-capita use rates.

Price and quantity data are obtained from the affected water retailers. Where tiered water rates are charged, an average price can be estimated using total revenue from metered sales divided by quantity of water sold. Generally, revenues from service fees, development fees, property taxes, or any revenue that is not based on quantity sold should not be included in these calculations.

For emergency response, a simplified method of obtaining benefits estimates for urban shortage cost reduction in southern California or the San Francisco Bay Area is provided in Section 5.4.6.1.

5.4.2 Ecosystem Improvements

Ecosystem improvements “contribute to restoration of aquatic ecosystems and native fish and wildlife” (Water Code Section 79753(a)(1)). Physical benefits are positive physical changes associated with ecosystem improvements, primarily including:

- Increases in the amount or quality of wetland, riparian, or aquatic habitat, including flow
- Increases in the survival rate, population, or chance of recovery for native fish and wildlife

Benefits will involve one or more of the physical changes and associated metrics specifically identified in the CDFW ecosystem priorities. Since ecosystem improvements must be at least half of all public benefits funded, quantifying ecosystem improvements is important, and the appropriate level of analysis is relatively high. Existing biological or ecological information relevant to a project may not be sufficient for the quantification or monetization of ecosystem benefits. In many cases, new information gathering and field studies may be justified. For small projects, or for projects seeking WSIP funding equal to a small share of total project cost, a lower level of analysis may be appropriate.

As compared to other public benefits types, few standardized methods or models have been developed for monetizing ecosystem benefits. Ecosystem services, the goods provided by ecosystems, and the monetary benefits of ecosystem improvements can take many forms. Any improvement that is directly caused by a physical ecosystem benefit can be regarded as an ecosystem benefit. Examples of such benefits include recreation (i.e., sport fishing for native fish improved by flows), water quality (i.e., water treatment by new wetlands), and flood control benefits provided by new wetlands. Such ecosystem improvements can be counted as WSIP ecosystem improvements and for allocating WSIP funding, but the economic methods for these types of benefits described in Sections 5.4.3 through 5.4.5 can be used to quantify them.

The statutory language in Chapter 8 − Proposition 1 implies that ecosystem benefits must be quantified. However, physical changes that increase the survival rate, population, or chance of recovery for native fish and wildlife can be uncertain and difficult to quantify, and the monetary benefits associated with those measures are also uncertain. Nevertheless, physical and economic measures of this type are still desirable. The amount of increase in survival rate, population, or chance of recovery expected from proposed ecosystem improvement is important. Applicants must provide all related physical measures to the extent possible (e.g., the timing and geographic extent of the improvement, and the share or numbers of population affected by the ecosystem improvement).

Alternative cost and willingness-to-pay approaches for ecosystem benefits are both important, and both should be provided where possible because either approach alone could provide an incorrect measure of benefit.

The alternative cost approach alone may overstate the public benefit where the physical benefit achieved is small. For example, if a water storage project releases water for ecosystem improvement at a time when it actually provides little or no benefit for fish, the alternative cost approach likely provides a benefit estimate that is too large—the true benefit is actually near zero.

On the other hand, if a large physical benefit could be obtained at a small alternative cost, the willingness-to-pay benefit might overstate how much California should be willing to pay. For example, if ecosystem improvement water would provide a large physical and monetary willingness-to-pay benefit for fish, but the alternative cost of providing that water is small, the willingness-to-pay approach provides a benefit estimate that is too large.

The alternative cost approach can help establish whether WSIP funding requests are reasonable and help ensure cost-effective investments relative to other opportunities. Also, the alternative cost approach is relatively reliable in the sense that economic cost measures for land and water for habitat are relatively certain as compared to monetized physical benefits in terms of the survival rate, population, or chance of recovery for native fish and wildlife. Therefore, the physical change measures, the willingness-to-pay associated with these measures, and the alternative cost measures are all important, and all should be provided where possible.

The steps below may reduce the amount of investigation and detail required:

1. If a project's water would replace water that would also be provided for ecosystem improvement in the without-project condition, there is an avoided cost benefit but there may be no net physical benefit in ecosystem conditions to quantify. The without-project condition and with-project operations must be considered to ensure that net physical changes are defensible.
2. If the amount of water supply to be provided by the project for ecosystem improvement can be estimated, and an alternative means exists for providing the same amount of water (net physical benefit), the alternative cost must be estimated. Water unit values provided in Table 5-5 and Appendix D can be used.
3. If other feasible means exist to provide the same ecosystem improvement, these means should be explained, their costs assessed, and the cost of the least-cost alternative means should be provided. For example, if wetlands are to be developed using project water supply, the alternative cost of buying wetlands on the market should be considered.
4. Physical change measures, such as increased survival rate, population, or chance of recovery for targeted species, must be provided and monetized wherever possible. Guidance for salmonids is provided in Section 5.4.2.3.
5. At a minimum, if the amount of physical improvement in habitat or other measures of improvement to native fish and wildlife cannot be quantified, the ecosystem improvements benefits (Section 4.7, Ecosystem Analysis) must be accompanied by a biological justification for the use of water in the amounts and timing as proposed. Where physical changes cannot be quantified, the significance of ecosystem funding

must still be documented in terms of its institutional, public, and/or technical importance. In such a case, the following types of information are recommended:

- The type of physical benefit expected and its relationship to CDFW and State Water Board priorities and REVs.
- How the project will be operated to provide the benefit, how monitoring will establish the physical changes, and how operations will be adaptively managed in response to monitoring.
- Why the benefit is important to Californians; who is affected, how, and why the benefit matters to them.

Many studies describe the types of ecosystem services provided by water storage projects and provide valuation methods. Some relevant studies are summarized in Appendix E.

5.4.2.1 Ecosystem Improvement Avoided Costs

Ecosystem improvements could result in a variety of avoided costs, but some avoided costs are not fundable public benefits. If water supply is provided for ecosystem purposes to replace a without-project supply, the avoided cost of the without-project supply is a benefit, and unit water supply values (Table 5-5) may be used. However, as discussed in Section 5.3.1, Step 1, there may be no increase in restoration of aquatic ecosystems and native fish and wildlife, so there may be no eligible WSIP ecosystem benefit. If the avoided cost represents a without-project compliance obligation, applicants must show how much of the water meets the compliance obligation and how much provides benefit above the compliance obligation.

An ecosystem improvement could contribute to recovery of a special-status species. If a project would allow costs of other improvements for special-status species to be reduced, the costs of these improvements might provide a basis for avoided cost estimates. ESA actions and plans could provide justification for avoided cost benefits. However, two key considerations are whether the action or plan is a compliance obligation, and whether the action or plan would otherwise be implemented in the without-project condition. If the answer to both of these considerations is “yes,” there may be an avoided cost, but it may not be a fully fundable benefit. If the answer to both considerations is “no,” there will be a fundable avoided cost benefit.

ESA permitting or consultation processes and CESA authorizations include terms and conditions, reasonable and prudent measures, and potentially reasonable and prudent alternatives imposed by fish and wildlife agencies to meet requirements of those statutes. As compliance obligations, project actions that meet these conditions may not be fundable by the WSIP. However, ESA recovery plans list additional actions for which there is no assigned responsibility and other project actions that may help the species that are beyond or outside of existing compliance obligations. These types of actions represent potential fundable, alternative cost benefits.

5.4.2.2 Ecosystem Improvement Alternative Costs

If a project will provide an action that is not a compliance obligation, it may be fundable. If the associated improvement will not be provided in the without-project condition, the action will add to whatever level of recovery is provided without-project, and there will be a net improvement. The costs of recovery plan actions might be used for alternative cost estimates. If a project provides a recovery action or a substitute for a recovery action, the alternative cost of the recovery action can be used as a measure of alternative cost for the net improvement.

Figure 5-2 shows how to decide if a recovery plan action cost can qualify for public funding and how to use the cost information. As an example, suppose that (1) a project will achieve a 1-degree water temperature reduction downstream, (2) a recovery plan action has been evaluated that would also provide a 1-degree reduction, and (3) the recovery plan estimated that the cost of the temperature reduction in that plan would be $1 million. Starting in Box 1 of Figure 5-2, applicants decide if that recovery plan action is included in the without-project condition. If not, move to Box 4, and if the project would provide the same 1-degree reduction as the recovery plan, proceed to Box 7. In this example, the recovery plan action cost of $1 million is a valid alternative cost estimate for the proposed project action.

However, from Box 1, if the water temperature reduction goal of the recovery plan is included in the without-project condition, proceed to Box 2 and determine if the project would provide the same 1-degree reduction as the recovery plan. If the project would merely substitute for the recovery plan action, a 1-degree reduction is achieved both in the without- and with-project conditions. Therefore, there is no net improvement in water temperature conditions (Box 3). There is an economic cost savings, being the $1 million cost of the recovery plan action that is avoided, but there is no net improvement, so the project action would not be a fundable WSIP benefit. If, however, the project action would add to the without-project temperature reduction, proceed to Box 5.

Box 5 indicates if and how to adjust the cost of the recovery plan action when the project does not provide the same improvement as the recovery plan. If the example project will achieve a 3-degree water temperature reduction downstream, the recovery plan action and the project action are now not the same magnitude. From Box 2, the project will reduce temperature by 2 degrees more than the recovery plan action alone. The applicant needs to decide if the recovery plan cost of $1 million for a 1-degree reduction is useful information. Suppose that the recovery plan action cost can be scaled up to $3 million for the 3-degree reduction. If so, proceed to Box 7. The net improvement of 2 degrees provided by the project can be valued at perhaps $2 million on an alternative cost basis. If the recovery plan action cost cannot be scaled up to the 3-degree improvement level, some other basis for alternative cost, shown as Box 6, is required.

Recovery costs for native fish species are detailed in Appendix E. Additionally, recovery costs are provided for salmonids (NOAA, 2014) and for Delta smelt (DFG and DWR, 2005) in Appendix E.

Applicants may provide alternative cost estimates using the unit values unless not applicable to or infeasible for their projects.

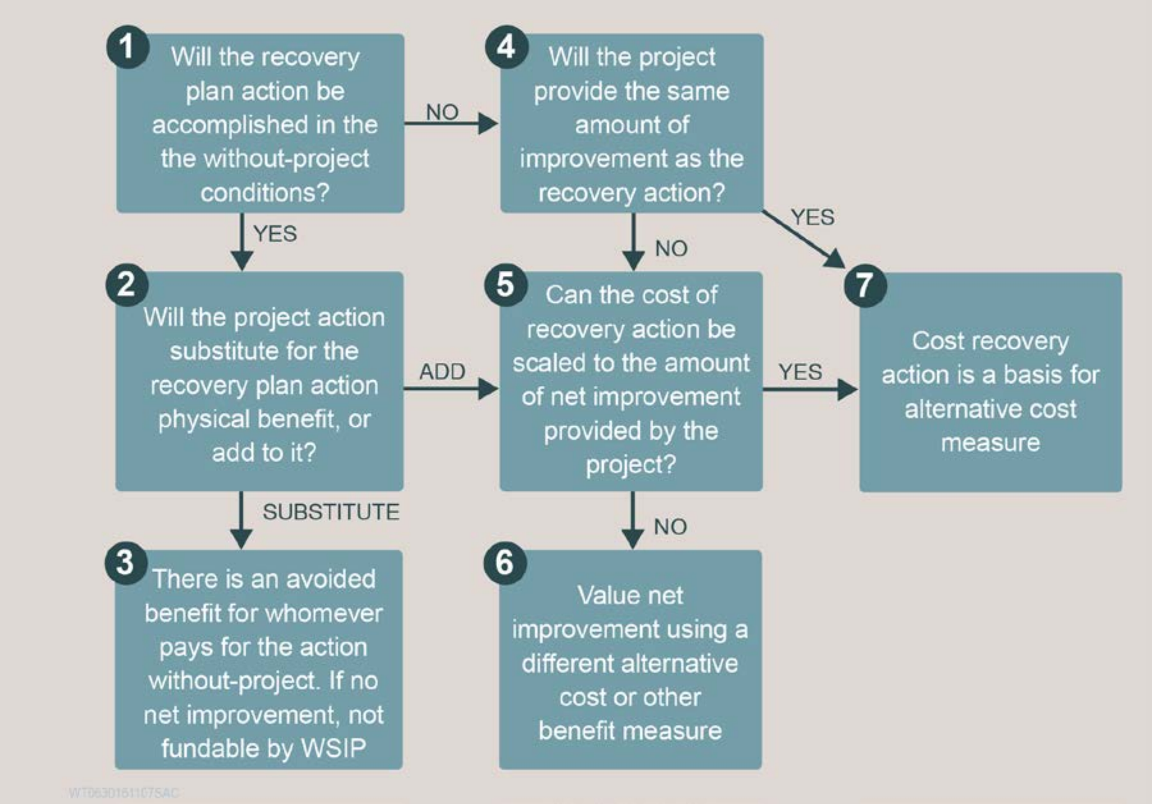

Figure 5-2. Deciding Whether and How to Use Costs of a Recovery Plan Action.

Most ecosystem benefits could be obtained without the proposed project, using alternative means. If water supply is provided for ecosystem purposes and there will be a net improvement (not an avoided cost or a compliance obligation), the alternative cost of the supply, if one is feasible, must be provided. Unit water supply values (Table 5-5) can be used to calculate the alternative cost of the water supply. If the purpose of this water supply is to improve water quality for aquatic ecosystems and native fish and wildlife, the alternative cost to provide the same water quality improvement, if feasible, must also be provided. For example, if operations of existing upstream dams could be modified to provide the same water quality improvement, the cost of the least-cost modification must be provided.

If the project would increase the amount of wetland, riparian, or aquatic habitat, the feasible alternative cost of that habitat must be estimated and provided. The alternative cost of habitat can be estimated as the cost to create, restore, or purchase and protect the habitat by feasible alternative means. For wetlands and other ecosystem improvements measured in acres, acreage may be traded in open markets and in mitigation banks. The market price of acreage of similar quality can be used as the measure of alternative cost. Data sources are suggested in Appendix E.

If the increase in habitat will increase the survival rate, population, or chance of recovery for native fish and wildlife, the alternative costs of other feasible measures that might achieve this restoration must be provided. The previous section noted that, if recovery actions will not be provided in the without-project condition, the cost of the recovery action is a measure of alternative cost.

Cost data relevant for these alternative cost considerations, such as actions targeted to survival rate improvements, are provided in Appendix E.

5.4.2.3 Ecosystem Improvement Willingness-to-Pay

Willingness-to-pay values are based on the physical change's measures of survival rate, population, or chance of recovery for native fish and wildlife, or perhaps, the willingness-to-pay for the quantity of wetland, riparian, or aquatic habitat provided by the project.

Ecosystem services, the goods produced by ecosystems, may include a variety of valuable products. Wetlands, for example, may produce fish and wildlife species, recreation opportunities, aesthetics, water quality, carbon sequestration, and flood damage reduction. For wetlands, each of these benefits could be valued separately.

Ecosystem services may be associated with use and non-use values. Use values include consumptive uses, like fishing, and non-consumptive uses, like wildlife viewing. Non-use values for rare species including existence, option, and bequest values. Existence values are benefits from knowing that a species will continue to exist. Option values are benefits from knowing that there will be the option of enjoying a use value in the future even if there is no plan to do so. Bequest values are benefits from passing species on for future generations to enjoy. Recovery of endangered fish might be associated with use (fishing) values, value in the food chain, and non-use values.

One approach of valuing ecosystem services attempts to add up the benefits of all products provided by a physical benefit such as an acre of wetland or a population of fish. DWR's Economic Analysis Guidebook (DWR, 2008a) discusses ecosystem services provided by water. Griebler and Avramov (2015) describe ecosystem services provided by groundwater specifically. Ecosystem services encompass the full range of types of benefits provided by an ecosystem. Ecosystem services benefits can be applied for all services that water provides, but WSIP fundable ecosystem benefits must be the result of the restoration of aquatic ecosystems and native fish and wildlife. With the large number of services provided, the uncertain amount of these services, and lack of location-specific value information for many ecosystem services, valuation using this method can be expensive and ultimately unreliable.

Still, project applicants must provide willingness-to-pay estimates where possible. For water quality and recreation benefits caused by the ecosystem improvement, see the water quality and recreation methods below. (Note: these can be classified as ecosystem improvement even though water quality and recreation methods are used to quantify them.)

Some willingness-to-pay estimates are based on market prices. For ecosystem products sold in competitive markets, market price can be used as the basis for willingness-to-pay. For fall-run Chinook salmon, for example, use values in commercial and recreational fisheries can be used. More detail on valuation of fisheries is provided in Appendix E. However, the suggested unit value for fall-run Chinook salmon discussed below, which includes non-use values, is likely to be larger than the sum of use values. Where use values are proposed, associated private and public costs required to produce and market the product should be included to obtain a net benefit.

For ecosystem improvements that increase property values, the increased value of property is a partial measure of the present value of the ecosystem services provided by the improvement. Where a large share of the value of ecosystem services is captured by local or proximate properties, the increase in property values associated with the improvement might be determined using market land price or hedonic pricing (regression) techniques (see Appendix E). In general, expected future annual net benefits that are tied to land can become part of the market price of the land. Applicants must not double-count benefits by including both a property value based estimate and the direct values of the ecosystem services that caused the property value to increase.

Most ecosystem services are public goods that are not traded in markets. Survey methods have been developed to query the public about their willingness-to-pay for ecosystem services. Contingent valuation studies may be used to obtain the total value of ecosystem services provided by a project. However, many studies have questioned the validity of survey methods for accurately eliciting willingness-to-pay (Hausman, 2012; Diamond and Hausman, 2012; Neill et al., 1994).

Non-use benefits of a resource should be counted primarily when special-status species are involved and are significantly affected. The significance determination should be made by a biologist with expertise in the special-status species involved. If non-use values are claimed and survey methods applied, survey questions could be designed to assess the project’s physical changes. Survey methods should be designed and administered to avoid bias, and respondents should demonstrate a significant willingness-to-pay response to scale (magnitude of the improvement) and zero willingness-to-pay for zero improvement. Benefits should be split into California and non-California benefits according to numbers of households or population. If possible, non-use values should be reported separately from use values.

Benefit transfer methods can be used if no direct valuation survey results are available. Benefits transfer methods extrapolate benefits estimates from a different location to the proposed project's location. Extrapolations from other studies must consider the kinds and amounts of project benefit relative to the benefits in the source study. The source study for the benefits transfer should have the following characteristics:

- It should provide willingness-to-pay for the same or similar species or other improvements.
- The demographics of beneficiaries in the source study area should be similar to the Californians who would benefit from the proposed project.

These two qualifications are similar to those stated by Loomis et al. (2014).

The source study should also have the following characteristics:

- If the amount of improvement in the source study is similar to the proposed project's amount, willingness-to-pay values can be interpolated to the subject project.
- If the amount of improvement in the source study is not similar to the proposed project's amount, the source study can be used only if statistically significant relationships exist between the amount of improvements and willingness-to-pay. The significant relationship can be interpolated to the subject project.
- The benefits transfer should be applied to California households. The share of respondents that stated no willingness-to-pay in the source study should be applied to California households. The share of households that were non-respondents in the source study should be assumed to have no willingness-to-pay.

Appendix E summarizes seven contingent valuation studies for west coast salmon and steelhead trout. The summary concludes that most of these studies do not provide a good basis for benefit transfers to California for the types and magnitudes of physical changes likely to be proposed by California WSIP projects. Reasons include the following: study results are not reliable; the species involved are not comparable; the effects of population size or chance of recovery on stated willingness-to-pay are not significant or are negative; or the baseline and improvement numbers for special-status species affected by proposed WSIP projects are small relative to the numbers proposed in the source study.

However, two studies provide a reasonable basis for benefit transfer for potential WSIP projects.

The first study (Layton et al., 1999) provides a basis for a benefit transfer to California non-listed fall-run Chinook salmon. The size of the study's smallest hypothetical population (i.e., 500,000 salmon) is comparable to the population of fall-run Chinook salmon in California. The study suggests a total economic value of about $2,500 per adult per year entering fresh water. This appears to be an acceptable unit value for improvements to non-listed salmon species provided by a proposed water storage project.

The second study (Hanemann, 2005) provides an update to earlier work on the San Joaquin River (Hanemann et al., 1991). The survey instrument asked if people would vote for a bond measure that would:

> *"Increase water flows in the San Joaquin River in order to restore the salmon runs, which would include sufficient water to maintain a continuous flowing river in almost all years. Additional benefits would include increased habitat for other San Joaquin Valley fish and wildlife, and increased recreational opportunities such as canoeing and rafting."*

The survey also stated that:

> *"Whereas there used to be tens of thousands of salmon in this stretch of river, these salmon runs have been completely destroyed, along with much of the river habitat for other fish, birds, and wildlife."*

Results found that 11.9 million California households would be willing to pay an average of $137 to $162 per household annually, or $1.6 billion to $1.7 billion annually for the proposed improvement.

From the survey language above, the proposal would "restore the salmon runs" that "used to be tens of thousands." It is difficult to determine exactly how respondents would have interpreted this scenario. If the range of potential improvement perceived was 20,000 to 50,000 fish, the apparent willingness-to-pay per fish, for 15 million households, is $41,000 to $122,000.[2] The median of these values is roughly $80,000 per fish.

For purposes of comparison, another way to assess the benefit of restoring the salmon run is to estimate alternative costs of restoration. NOAA (2014) states:

> *"We estimate that recovering Central Valley Chinook salmon and steelhead could cost between $17 and $37 billion over the next 50 years."*

Appendix E shows recovery plans for these fish indicating that the minimum population size of the two listed Central Valley populations (spring-run Chinook salmon and steelhead trout) required for recovery is 10,500 adults, measured as escapement. With a 100-year planning period and using the 3.5 percent discount rate, NOAA's estimate suggests a recovery cost per escaping adult of $58,000 to $120,000.

These two sources of information, the stated benefit and the alternative cost of recovery, provide a reasonably consistent basis for a recommended economic value for listed species improvement. If physical benefits of a water storage project can be measured in escapement of winter-run Chinook salmon, spring-run Chinook salmon, or Central Valley steelhead trout, a benefit of $100,000 per fish per year (one fish escaping 1 year) is reasonable.

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[2] 15,000,000*137/50,000 to 15,000,000*162/20,000

Recommendations

For ecosystem improvements quantified as increased numbers of non-listed fall-run Chinook salmon, a value of $2,500 per escaping fish per year may be used.

For ecosystem improvements quantified as increased numbers of listed fish, specifically winter-run Chinook salmon, spring-run Chinook salmon, or Central Valley steelhead trout, a value of $100,000 per escaping fish per year may be used.

The recommended values of $2,500 per fish for fall-run Chinook salmon, and $100,000 for spring-or winter-run Chinook salmon or Central Valley steelhead trout, should not be compared to the use values suggested by the market value of a fish or the economic value of recreational fishing.

First, for the winter- and spring-run Chinook salmon and Central Valley steelhead trout, the recommended values are primarily non-use values, the benefits people experience from preservation of these endangered or threatened species. Many persons place a value on rare species even though they state no intent to ever consume them, fish for them, or even see them. The recommended values are assigned to the fish that return to reproduce and support the long-term existence of the species. Many studies have established that, for rare salmonids, these non-use values exceed use values by orders of magnitude. Indeed, it is generally not legal for fishermen to target or keep these threatened species.

Second, for every returning adult, somewhere between 10 and 100 juvenile fish did not survive. These non-survivors have economic value in the food chain. They are consumed by other fish, birds, and marine mammals, and some are caught and kept by fishermen. The recommended value includes economic values associated with all those fish that did not survive to be returning adults. For the fall-run Chinook salmon, which is a species of commercial and recreational importance, the value per returning adult is not comparable to the value per caught fish. The Pacific Fisheries Management Council (PFMC) recommended exploitation rate for this run was recently 70 percent (PFMC, 2016). That is, a returning adult may be associated with two or more fish caught by ocean recreational and commercial fishermen.

No unit values are provided for other CDFW priority species. CDFW's highest priority species for the WSIP are species listed under the CESA or federal ESA, as well as other sensitive or at-risk native species that depend on the Delta and its tributaries for their survival. Fish species that meet one or more of these criteria include winter-run, spring-run, fall-run, and late-fall-run Chinook salmon; Central Valley steelhead and rainbow trout; green sturgeon; white sturgeon; Delta smelt; longfin smelt; Pacific lamprey; and Sacramento splittail. In addition, aquatic, riparian, and wetland habitats that support migratory birds of the Pacific Flyway, neo-tropical migratory birds, and native reptiles, amphibians, mammals, and plants are priorities for CDFW.

For these other species, there are no specific measures of economic benefit to recommend for population numbers. However, their habitat, or water provided for their habitat, can be valued using an alternative cost approach.

5.4.2.4 Total Ecosystem Benefits

Monetized ecosystem improvement benefits are, generally, the lesser of the alternative cost or willingness-to-pay benefit. To the extent that avoided cost benefits are associated with a substitution of physical changes provided in the without-project condition, they do not contribute to restoration as required for ecosystem benefits. Applicants must not double-count benefits by summing results from different methods for the same physical benefit.

5.4.3 Flood Damage Reduction

Flood damage reduction benefits are typically quantified by estimating the expected flood damage downstream of a project and comparing the with-project to the without-project condition. For proposed WSIP projects, another category of flood control benefit is included by statute: “increases in flood reservation space in existing reservoirs by exchange for existing or increased water storage capacity in response to the effects of changing hydrology and decreasing snow pack” (Water Code Section 79753(a)(3)). In other words, the proposed project can be credited with a flood control benefit to the extent that it provides water storage capacity to replace storage capacity lost in another existing reservoir due to its reoperation for flood control.

Most flood damage reduction benefits are estimated using avoided costs. For large urban flood damage reduction benefits, USACE’s HEC-FDA model is the most widely accepted method. DWR’s Handbook for Assessing Value of State Flood Management Investments provides a detailed description of the state’s preferred analysis for projects with substantial flood damage reduction benefits (DWR, 2014).

The state has awarded grants for stormwater management projects that reduce flood damages through the Integrated Regional Water Management and Proposition 1E Stormwater Flood Management programs. The state’s recent guidelines for preparing grant applications recommended that applicants use a model developed for DWR, the Flood Rapid Assessment Model, or similar models like HEC-FDA to estimate benefits, and many of these grant applications have done so. In addition, this section describes other non-modeling approaches to estimate flood damage reduction benefits (DWR, 2008b, 2010). Applicants must describe and justify the method or methods used. Applicants must avoid double-counting benefits by summing results from more than one method to value the same damage reduction.

5.4.3.1 Flood Damage Reduction Avoided Costs

For flood damage reduction, avoided costs are generally the flood damage costs avoided because of the project, including damage to structures and contents, roads, and other infrastructure; emergency response and public assistance costs; lost use of facilities and infrastructure; and cleanup costs. Avoided injuries and fatalities are important metrics for avoided flood damage, but these are not typically monetized. A useful general reference is DWR’s Handbook for Assessing Value of State Flood Management Investments (DWR, 2014).

For flood damage reduction, an appropriate level of analysis depends on the share of all public benefits that is flood damage reduction and the size of the project. Three methods are recommended, depending on the level of analysis desired. All methods estimate EAD. The reduction in EAD caused by a project should be entered as a benefit in each year of the planning horizon for present value calculations. Generally, damages to structures should be based on their depreciated value, not on replacement costs.

Low Level of Analysis: Frequency and Damage Reduction for Historical Events

First, applicants must delineate the area that would receive flood damage reduction benefits from the project. Then, document historical events that caused damage, the frequency of those events, and for each event, the dollar amount of damage. Next, estimate the dollar amount of damage reduction that would be created by the project. Update the historical dollar damage amount for inflation and for future land uses.

For each historical event, determine a range for a representative interval probability. The representative interval probability is a range of probability within which the event damages have the same average dollar amount as the observed historical event. For example, if one historical flood caused $200,000 in damages and was a 1-in-40-year flood, and the same average damages would occur in floods ranging from a 1-in-20-year to a 1-in-50-year flood, the representative interval probability is 3.0 percent (0.05 minus 0.02). In this example, the EAD from the flood event is $6,000 (0.03 times $200,000). Without-project EAD would be the sum of the expected damage over all events and intervals. If there were still damages with-project, the with-project expected damage and EAD would be calculated the same way. Benefits attributable to the project is the EAD reduction (without-project EAD minus with-project EAD).

Medium to High Level of Analysis: EAD Calculation using Historical Flow Distribution

This approach requires an expected exceedance distribution of flood events and estimates of damages for each event. If a damaging event has not occurred historically, or if historical damages cannot be documented or updated, flow-depth and depth-damage curves must be developed. See Section 4.9, Flood Risk Reduction Analysis, and Section 4.5, Riverine Hydrologic/Hydraulic Analysis, for methods to develop information on flood depths. Determining the value of potential future flood damages also require detailed research on the future replacement costs of structures and business activity in the floodplain.

EAD is calculated by first estimating flood damages that would occur at each flood event and corresponding exceedance probability, both with and without the project. Exceedance probabilities are the chance that an event larger than the given event could occur. So, for a 1-in-20-year exceedance probability, there is a 5 percent chance of a larger event in any year. For a 1-in-50-year exceedance probability, there is a 2 percent chance for a larger event in any year. Interval probabilities are the chance of an event that is between the sizes of the two events shown for two exceedance probabilities. Therefore, there is a 3 percent chance of an event between the 1-in-20-year and the 1-in-50-year events. The difference between the two exceedance probabilities is a chance of an event with a size being the average of the two events at the two exceedance levels. EAD is calculated as the sum of each interval probability times the average damage in that interval, summed over all interval probabilities. DWR's Flood Rapid Assessment Model performs these calculations.

In Table 5-6, with damage estimates developed for the 1-in-20, 1-in-50, 1-in-80, and 1-in-120-year events included, the total EAD is $12,292. In this example, for small events more likely than 1 in 20 years, there are no damages either with- or without-project. For big events less likely than 1 in 120 years, damages are the same either with- or without-project. The probability of an event for which flood damages can be reduced by the project is 4.2 percent of years.

Table 5-6. Calculating Flood Damage Reduction Benefits Using Historical Flow Distribution.

Event Probability		**Expected Event Damages**		
Exceedance	**Expressed as a percent**	**Without Project**	**With Project**	**Project Event Benefit**
1/20	0.050%	$100,000	$0	$100,000
1/50	0.020%	$300,000	$0	$300,000
1/80	0.013%	$600,000	$0	$600,000
1/120	0.008%	$800,000	$0	$800,000

EAD($000) = $12.3

EAD($000)=(0.05-0.02)*(300+100)/2 **+**(.02-.013)*(600+300)/2 **+**(.013-.008)*(800+600)/2

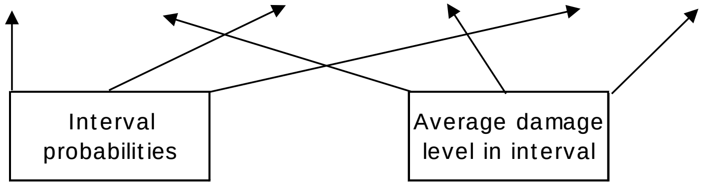

Figure 5-3 shows this example in relation to a damage exceedance curve. EAD is the area under the damage exceedance curve, but no calculation is required for events that are too large or small to be affected by a project. The estimate of damages in each of the three probability intervals are shown as three rectangles. As in Table 5-6, total EAD is calculated by adding together the areas of the three rectangles in the figure.

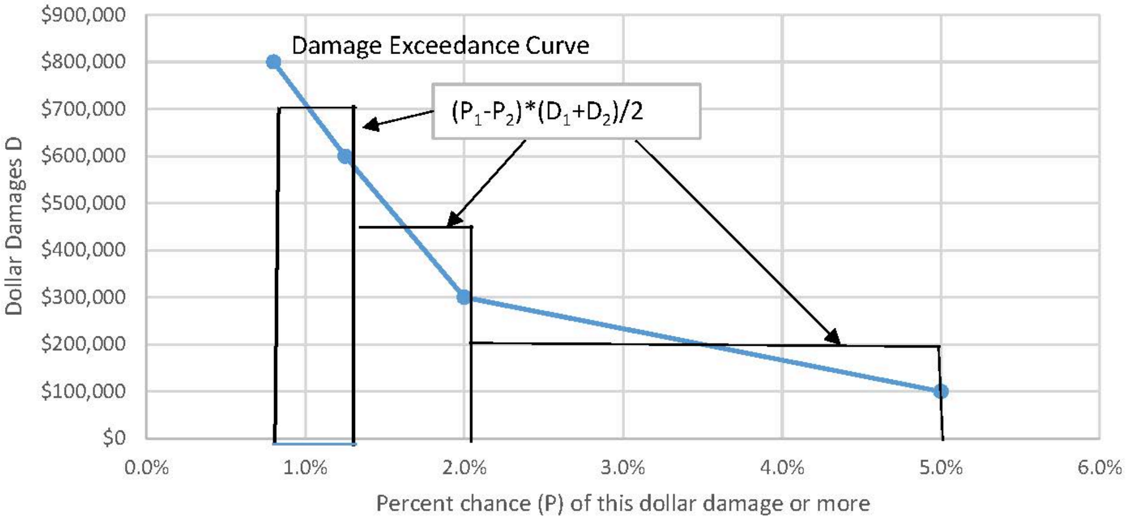

Figure 5-3. EAD and the Damage Exceedance Curve.

The amount of work necessary for this method can be minimized by recognizing the range of events for which the proposed project has some benefit. Relevant upper and lower end points of the damage-exceedance probability calculations are where damages with- or without-project are the same. Damage costs beyond these end points do not affect the estimates of benefits.

High Level of Analysis: HEC-FDA or Similar Model

The recommended method for a high level of analysis is to use established models to estimate avoided damage and avoided costs. For large projects with a substantial urban flood damage reduction benefit, HEC-FDA is preferred, but other models are accepted with complete documentation. Flood damage reduction models are discussed in more detail in Appendix F and in the Handbook for Assessing Value of State Flood Management Investments (DWR, 2014).

5.4.3.2 Flood Damage Reduction Alternative Costs

For flood damage reduction, alternative costs might involve improved levee systems downstream, more use of existing storage space for flood protection, or relocation of valuable structures, people, and business activity out of the floodplain. Applicants should consider whether an alternative plan for providing the same level of flood damage reduction could be more cost-effective. If alternative feasible plans exist, applicants should show the costs of alternative plans for flood damage reduction. If the annualized cost of an alternative plan that provides the same flood damage reduction benefit is less than the benefit estimated using an EAD method, the alternative plan cost is the preferred measure of benefit. Alternative plans may also be used to consider the economics of project operations. If the project provides flood reservation space, the use of that space for flood damage reduction should be compared to other flood damage reduction methods such as levee upgrades or repairs downstream, if feasible. As with any alternative cost approach, identifying a feasible alternative may be challenging given the physical, regulatory, permitting, and land use constraints.

5.4.3.3 Flood Damage Reduction Willingness-to-Pay

This approach has rarely been used to quantify flood damage reduction benefits. Some studies have been conducted using hedonic demand analysis and contingent valuation survey methods to estimate willingness-to-pay for reducing flood damage. The studies are limited to certain locations, and their results do not apply generally in California. Examples of such studies are provided below.

Schultz and Schmitz (2008) used the hedonic valuation approach to estimate impacts on residential property values of being located within Omaha, Nebraska’s 100-year floodplain. Shabman et al. (1998) conducted a similar hedonic valuation study in Roanoke, Virginia. That study also used a contingent valuation survey approach to estimate willingness-to-pay for flood protection for the same subject area as considered in its hedonic pricing analysis.

The challenge with these approaches is that large, costly flood events are rare, so residents find it difficult to understand the probabilities and the true damages and costs. Local initiatives to raise taxes for flood damage protection suffer the same problem. Information regarding flood insurance premiums might be helpful. If the project will remove lands from the floodplain, the present value of reduced insurance premiums may be a useful, though partial, benefit measure. However, Schultz and Schmitz (2008) demonstrated that using avoided flood insurance premiums to account for residential property value differences in flood prone versus non-flood prone areas tended to under-estimate flood mitigation benefits.

Generally, hedonic pricing or survey methods for flood damage reduction are not recommended unless an applicant has an existing study specific to its project or study area or it intends to conduct such a study.

5.4.4 Water Quality Improvements

Eligible improvements are “water quality improvements in the Delta, or in other river systems, that provide significant public trust resources, or that clean up and restore groundwater resources” (Water Code Section 79753(a)(2)). Water quality improvements that restore ecosystems can be accounted for as ecosystem improvements. Some of the water quality methods here might apply, but if the benefit contributes to the restoration of aquatic habitat and native fish and wildlife, it can be counted as an ecosystem benefit.

Benefits will involve one or more of the parameters specifically identified in State Water Board’s water quality priorities: temperature, dissolved oxygen, nutrients, mercury, and salinity. Surface water quality improvements for M&I and agricultural users may not be public benefits eligible for WSIP funding unless it provides a benefit to a public trust resource. If improved water quality improvement provides a public trust benefit, that benefit is eligible for funding.

Eligible water quality improvements include improvements that clean up and restore groundwater resources. Groundwater quality improvements for agricultural and urban uses are eligible for funding. Benefits should generally be estimated using avoided or alternative costs. Most salinity improvement benefits can be estimated using available quantitative equations or mathematical models.

The benefits approaches described below generally apply to both surface water and groundwater quality improvements and to both public and non-public water quality benefits. Applicants must treat an estimated benefit as a public benefit or a non-public benefit based on the definition of water quality improvement provided in statute.

5.4.4.1 Water Quality Avoided Costs

Water quality avoided damage costs can include the following: salinity damages to water infrastructure, plumbing, and appliances; taste and odor costs experienced by water users; health costs; utility costs; treatment costs; costs of supplies used for blending; regulatory compliance costs; and avoided or delayed project costs. Appendix F describes economic models of salinity for urban areas in California.

The use of avoided cost to estimate water quality improvement benefits usually involves end-user costs (i.e., costs borne by households and businesses). However, some water treatment or cleanup projects planned by water utilities for the without-project condition could be avoided or delayed because of the project; these should be counted as avoided costs. In many local areas, groundwater quality improvement costs are planned or mandated. If the costs of these plans or mandates are expected in the without-project condition, avoided costs are an appropriate basis for benefits.

In many cases, particularly where degraded groundwater is to be cleaned up, water supply from storage may be used to dilute or replace poor quality supplies. If a proposed project provides a water supply for groundwater quality improvement, or if water supply is increased by the water quality improvement, the water supply can be valued by use of unit values (Table 5-5). Project applicants may also provide avoided costs based on their own avoided cost estimates, if those are well documented. Documentation of water quality costs over a recent history can help establish the potential value of water quality improvements.

Two models of urban salinity costs are available to estimate avoided damage costs; one corresponds to the southern portion of the San Francisco Bay Area, and one corresponds to the south coast area in Southern California. Economic methods for quantifying the benefits of salinity improvements to agriculture are also available. For agricultural salinity, models that estimate the cost of additional water application for leaching, with crop yield reduction beyond established salinity thresholds, are preferred. These urban and agricultural salinity models are described in Appendix F.

5.4.4.2 Water Quality Alternative Costs

The alternative cost approach applies well to water quality improvement. The types of actions included in an alternative cost approach are similar to those for avoided costs. Alternative costs for water quality improvement usually involve engineering costs of water treatment.

As with other benefit categories, the difference between the avoided costs and the alternative costs of water quality improvement depends on the without-project condition. With avoided cost, the project improvement replaces some other existing cost or planned improvement. With alternative cost, the alternative need not be implemented, so the applicant must also estimate, if possible, the willingness-to-pay for the improvement.

For water quality improvements related to flow provided by the proposed project, applicants may provide alternative cost estimates using the unit values unless not applicable to or infeasible for their projects' contingencies

5.4.4.3 Water Quality Willingness-to-Pay

Market price methods have little direct application for water quality because water quality is not sold in competitive markets. However, market prices of many goods used to avoid water quality problems (i.e., bottled water, water softeners, and water filters) and prices of goods that can be damaged by water quality problems (i.e., plumbing, fixtures, and appliances) can be used to infer willingness-to-pay.

For monetizing the value of improved water quality in natural water bodies, hedonic pricing may be used to estimate the property value increase obtained by properties on or near the waterfront. For example, Leggett and Bockstael found that fecal coliform had a significant effect on property values on the Chesapeake Bay (Leggett and Bockstael, 1998). Crompton reviewed a study of water quality in the Willamette River, Oregon, which attempted to determine increases in property values associated with substantially improved water quality over the 1960 to 1970 period (Crompton, 2004; Barranger, 1974). For hedonic pricing, the water quality improvement must be large enough to have a significant influence on the property values. Similar properties that have experienced similar water quality differences can serve as a sample for estimation.

Inferred willingness-to-pay, survey methods, and benefit transfer methods may all provide usable willingness-to-pay estimates, depending on circumstances; however, they may provide only partial benefits estimates. Inferred willingness-to-pay methods can be applied to actions of residential customers (in particular, purchases of bottled water and home water filters). One study estimated benefits of avoiding degraded water quality by increases in bottled water sales (Zivin et al., 2011). Survey-based methods can be used to elicit willingness-to-pay for water quality improvements. Numerous examples are available, such as Viscusi et al. (2004, 2007) and Carson and Mitchell (1993). Water quality benefits are often valued by benefits transfers, comparing projected improvements to actual changes and unit values estimated for other studies.

Useful values and studies for a benefit transfer application may be available from sources such as the Beneficial Use Values Database (BUVD) (Larson and Lew, 2011), maintained at the University of California at Davis. The BUVD was compiled for the State Water Board. The BUVD is:

> *"… an informational database of economic values for beneficial uses of water collected from a variety of sources, including scholarly journals,*

> *books, conference proceedings, government reports, and working paper series. Currently, it is available for review to the public in its alpha version.*
>
> *The purpose of the BUVD is to provide an educational and informational tool to the general public and interested specialists, documenting the economic values for beneficial uses of water identified by the California State Water Resources Control Board (State Water Board). It is envisioned that the BUVD be a companion to the Water Quality Standards Inventory Database, which currently provides information to the public on water quality standards for, and beneficial uses of, water bodies throughout California, but no information on the value of those beneficial uses."*

5.4.5 Recreation

Outdoor recreation facilities and activities associated with water storage projects in water bodies such as reservoirs, rivers, streams, lakes, and wetlands are eligible for WSIP funding. Benefits from outdoor recreation at any lakes and reservoirs should be included if the reservoirs are directly affected by the proposed project and are open to the public. Recreation benefits should be net of any unmitigated recreation losses caused by inundation or system reoperation. Recreation benefits on downstream waterways might be affected. Improvements in recreational fishing for native fish can be counted as an ecosystem benefit, but fishing benefits for non-native fish are recreation benefits.

5.4.5.1 Recreation Visitation Data and Models

Recreation use at new facilities, or changes in use at existing facilities, must be estimated as a basis for recreation benefits claims. The most common metric of recreation use is a visitor-day, normally one person visiting for any part or all of a calendar day. A number of studies have investigated reservoir recreation use in California (DWR, 2007; Wallace Roberts & Todd, LLC, 2003; Reclamation, 2006; Haas, 2003; Jackson et al., 1998). Studies of the effects of fluctuating reservoir levels on recreation use and value are also available (Platt, 2000).

Models of recreational use and benefits generally include in their inputs one or more site characteristics related to the project's features and operations. The important site characteristics to include depend on the model selected to estimate use. USACE's Technical Report R-96-2 (Ward et al., 1996a) provides an overview of recreation models for large reservoirs, including examples of site characteristics that can be included in such models. The model has not been tested to prove its applicability for any new California facility. However, it helps guide development of new analysis by showing explanatory variables that were significant at that time.

Other sources of guidance and information on recreational use estimation are available from federal and other agencies that manage water projects in the western United States, notably USACE and Reclamation. See for example, Reclamation's Economics Guidebook (Reclamation, 2010); USACE's Planning Guidance Notebook (USACE, 2000); and DWR’s Handbook for Assessing Value (DWR, 2014). California Department of Parks and Recreation also documents and estimates recreation activity trends every 5 years in its Statewide Comprehensive Outdoor Recreation Plan, a document which offers planning tools and relevant guidance for projects in California (California State Parks, 2016).

Travel cost models are statistical studies that estimate visitation as a function of price where distance travelled is an important part of the price paid. The basic premise with the approach is that travel costs are much of the price required for accessing the site. The farther away one lives from the site, the larger travel costs are, so visitation decreases, all else being equal. The resulting regression equation is interpreted as a demand function that can be used to estimate both quantity of use and benefits. The area under the demand curve and above cost represents net willingness-to-pay (i.e., consumer surplus), the typical measure used to represent recreation benefits (Reclamation, 1996). A summary of travel cost literature is provided by NOAA (no date). Applications of travel cost models are available (Ward et al., 1996b; Loomis and Cooper, 1990; Plater and Wade, 2002).

For benefits estimates with a higher level of detail, an original travel cost model could be developed and used to estimate visitation and benefits together, preferably including effects on other reservoirs. Currently, there are no known recent travel cost models available for reservoir recreation in California, and it is unlikely that a new travel cost model can be developed within the time frame allowed by the WSIP.

Since a proposed reservoir does not exist yet, a new or existing travel cost model would need to cover existing reservoirs that are similar to the proposed facility. Data on the origin of visitors would be required. Data on lake characteristics and facilities at the existing reservoirs that attract visitation would also be required. Results, along with the planned features of the new facility, would be used to construct a demand function for the new facility. The demand function could be used to estimate visitation, given a proposed admission price, and economic surplus at that price.

For large facilities (more than 1.5 square miles or 960 acres of surface area) where recreation benefits are an important share of non-ecosystem benefits claimed, applicants should develop recreation visitation estimates based on a recreation facilities plan and market analysis. The market analysis should consider project recreation facilities and capacities and amount of use at existing, similar facilities.

For small facilities, and where recreation benefits are not a large share of public benefits, the simplest approach is to estimate visitation based on visits per unit of surface area for similar small local reservoirs. For this low level of detail, a simple extrapolation of use from a similar site or facility is allowed, but methods and analysis should be well documented.

At a minimum, visitation estimates must account for:

- The size of the facility
- Recreation activities allowed

- Recreation facilities provided and their capacities
- Amount of visitation at other similar facilities
- Seasonal closures and conditions in which facilities are not usable (e.g., storage conditions and water quality including temperature)

Visitation and benefits estimates should consider, if possible, the share of visitation that is a shift from other recreation sites in the state. Characteristics of existing, substitute reservoir recreation sites are generally available from the entities that manage those sites, including USACE, Reclamation, the United State Forest Service, California State Parks, and county and regional parks. Distance to existing, substitute sites can be estimated using a geographic information system (GIS) or simpler methods such as Google Maps®.

In addition to the visitation estimates, the applicant should provide its best estimate of the usage fees likely to be charged for visitors and expected revenues. Expected recreation facilities operations costs should be reported and included with project costs.

The WSIP visitation model, documented below and in Appendix F, will be used by reviewers to consider visitation estimates for reservoirs with campsites and facilities for private boating and a surface acreage of 1.5 square miles (960 acres) or more. Applicants may use the model to supplement their recreation plan and market analysis.

Applicants must calculate the monetized benefits associated with the estimated visitation. If a travel cost model is used, the model would be interpolated to the new facility to provide visitation and economic benefits. For most projects, the USACE unit day value method documented in Section 5.4.5.7 may be used as a basis for associating reservoir recreation benefits with visitation.

The applicant must determine what specific hydrologic and other physical information is needed to support the methods it selects to quantify recreational visitation and benefits. For example, if an applicant’s boating visitation model requires an input variable such as average acres of boatable surface during the summer boating season, that estimate needs to be based on the storage project’s physical description and operations analysis. In addition, that operations analysis must be the same as, or demonstrated to be consistent with, the operations analysis used for other benefits analyses such as for water supply, ecosystem, flood control, and hydropower.

5.4.5.2 WSIP Visitation Model

A visitation model, documented in Appendix F, provides visitation estimates for most surface storage facilities that allow camping and private boating with a surface area more than 1.5 square miles (960 acres). The model includes:

- Estimates of day visits and camping visits
- The influence of local population
- The influence of the size of the facility

- Consideration of monthly storage conditions
- Consideration of campsites and boat lanes
- Consideration of how the presence of other reservoirs/recreation areas affect visitation

Appendix F documents the recreation visitation model. The model is based on select State Parks facilities. Table 5-7 provides annual estimates of visitation for seven California reservoirs where recreation is managed by California State Parks. These data, disaggregated to monthly visitation, have been used to develop visitation-estimating equations.

Table 5-7. Recent Estimated Annual Visitation Data for California Reservoirs.

Year	Folsom Lake	Lake Oroville	San Luis Reservoir	Turlock Lake	Millerton Lake	Lake Perris	Silver-wood Lake
2004	878,000	1,364,348	441,636	58,745	340,293	1,075,667	265,534
2005	1,141,890	1,058,533	449,154	57,637	602,058	818,624	275,593
2006	1,218,886	1,048,379	541,940	65,094	541,940	702,361	354,145
2007	956,772	756,124	454,718	59,012	292,807	625,198	409,839
2008	1,062,053	999,720	285,821	63,352	339,818	646,850	340,652
2009	1,232,656	1,037,009	144,222	52,145	372,801	622,333	314,040
2010	1,258,840	1,095,283	156,974	49,409	355,875	545,777	284,522
2011	1,491,025	1,095,188	149,890	41,290	473,578	617,463	334,628
2012	1,393,113	800,873	139,844	43,580	601,923	658,026	340,506
2013	1,276,223	1,010,307	170,464	42,840	541,258	684,173	362,965

Source: Data provided by California State Parks, 2004 to 2015

Applicants may use this model as one method for predicting visitation under the following conditions: a travel cost model is not developed or available; and the proposed surface storage facility is more than 1.5 square miles (960 acres) of surface area, with camping and boating facilities. To predict visitation at a proposed new facility, an applicant would estimate visitation per maximum acre for the new facility using the regressions and multiply by maximum acres. The model can also be used to compare alternative operations that result in different storage levels.

The applicant should ensure that recreation facilities are properly planned for the proposed storage reservoir; facilities should include an appropriate mix of all facilities in relation to the size of the reservoir, even if those facilities are not included in the visitation model. For example, parking facilities, picnic areas, and restrooms should be available. Visitation at facilities that are much different from those in the dataset might need to be evaluated using different methods, and results should be compared to other, similar facilities where data are available. Since numerous factors can influence recreation attendance at a reservoir in any given year, annual variation in reservoir storage is not always correlated with annual variation in facility attendance.

Visits are not the same as a recreation day. For valuation using the USACE unit values, a day visit should be assumed to be 1 day, and a camping visit should be assumed to last 3 days.

5.4.5.3 Riverine Recreation Methods

In general, the project's description and operations modeling should be the basis for site characteristics needed to estimate riverine recreational use. The application's operations model may not provide the exact metric or set of metrics in the required units, so some unit conversion, averaging, or interpolation may be required. The project footprint and operations model results may also need to be combined with a GIS or similar analysis to estimate, for example, miles of shoreline or boatable stream.

Characteristics of river-based recreation may require other analysis beyond the project's operations model. Examples include:

- Flow and stage estimates of river reaches affected by the storage project may be needed to support an estimate of river-based recreation.
- Flow, water quality, and ecosystem analysis may be needed to support use estimates of a recreational fishery affected by the project.

The applicant must determine such requirements and demonstrate that the inputs are drawn from, or at least consistent with, the analysis being used in other parts of its application and feasibility study.

5.4.5.4 Recreation Associated with Groundwater Storage Projects

Opportunities for recreation at groundwater storage facilities are more limited than for surface reservoirs. Groundwater storage projects could potentially include trails, developed wildlife viewing, picnic tables, and associated support facilities such as restrooms and parking. Recreational uses at such facilities can be estimated and valued similar to non-water uses of parks at storage reservoirs, including picnicking, hiking, wildlife viewing, and, if applicable, camping. In addition, groundwater storage projects that provide water for streamflow augmentation, or are operated to reduce stream diversions during popular recreation times of year, could provide some benefit for riverine recreation.

In order to estimate visitation, the same approach must be used as described above for estimating visitation at a surface reservoir, except that a more restricted set of activities and facilities would be available. Applicants must consider attributes such as miles of hiking trails; wildlife viewing areas, and number of picnic areas and campsites. Visitation and benefits estimates should consider the share of visitation that is a shift from other nearby recreation sites. The unit day value method (USACE, 2014) or other appropriate methods described below can be used to monetize the value of the recreation use.

5.4.5.5 Recreation Avoided Costs

Avoided costs methods are not generally applicable.

5.4.5.6 Recreation Alternative Costs

Some alternative cost methods for recreation may be appropriate. In particular, the feasibility and cost of providing increased recreation opportunities at other local reservoirs should be explored. Applicants should discuss other opportunities for the same recreation types within the region, note if facilities have adequate recreation access provided, and discuss utilization of the existing facilities. The share of use that occurs during full utilization periods should be noted. This background will also help establish the value of additional recreation supply for the region.

5.4.5.7 Recreation Willingness-to-pay

USACE's Unit Day Values for Recreation for Fiscal Year 2015 (USACE, 2014) includes assignment of points for location, quality and other factors. This method is acceptable for estimating unit values for water-based recreation. Applicants will need to use USACE guidance to develop the points (USACE, 2000). The actual unit day value selected for a project depends on the assignment of points. The range of potential unit day values for 2015 is shown in Table 5-8.

Table 5-8. Conversion of Points to Dollar Values, USACE 2015 Unit Day Value Methods.

Point Values	General Recreation Values	General Fishing and Hunting Values	Specialized Fishing and Hunting Values	Specialized Recreation Values other than Fishing and Hunting
20	$5.13	$6.84	$28.56	$18.07
30	$5.86	$7.57	$29.30	$19.53
40	$7.32	$8.30	$30.03	$20.75
50	$8.30	$9.03	$32.96	$23.44
60	$9.03	$10.01	$35.89	$25.88
70	$9.52	$10.50	$38.08	$31.25
80	$10.50	$11.23	$41.01	$36.38
90	$11.23	$11.47	$43.94	$41.50
100	$11.72	$11.72	$46.39	$46.39

Source: USACE, 2014

From USACE (2000):

> *"The choice of a unit day value must account for transfers to avoid double counting of benefits. The net value of a transfer of use from one site to another is the difference in unit day values for recreation at the two sites."*

If USACE methods or travel cost methods cannot be applied or are unreliable for documented reasons, market prices (admission fees or revenues), hedonic pricing, survey methods, or benefits transfers can be used.

Market price methods have applicability to recreation when recreation services are provided privately and prices are charged for admission. Outdoor recreation services are provided by marinas, guides, charters, and/or concessionaires. Prices charged by operators are useful information where competition exists. Differences in prices charged among operators, and changes in prices over time, may enable estimation of demand functions. Also, concessionaires normally pay the reservoir owner for their use of facilities. This can be useful information for benefits analysis. For many use values, only part of the value might be determined from the price of access. Many outdoor recreation services occur without marina admission, guide services, or other entry or admission fees.

Hedonic pricing has many applications for recreation because property values can be increased by nearby recreational amenities (Crompton, 2004). However, the total recreation benefit should include the benefits of proximate property owners and any users who do not live nearby. Also, it may be difficult to determine what share of property values should be attributed to the recreational amenities and what share should be given to other attributes such as aesthetics and open space.

Survey-based methods estimate recreation benefit based on stated willingness-to-pay. Contingent behavior and valuation studies use general population or recreationist surveys to estimate changes in recreation visitation and consumer surplus at a site. The survey results can be averaged and aggregated or used to construct visitation and willingness-to-pay models (CALFED, 2006).

Benefit transfer is a common method for recreation. Typically, economic values from a similar site are adopted with adjustments for size, amenities, and distance from population centers. The BUVD provides many studies that might be used for benefit transfer. The Benefit Transfer and Use Estimating Model Toolkit, available through the Agricultural and Resource Economics Department of Colorado State University, provides a database of potentially useful studies (Loomis et al., 2008). Any use of benefits transfers should address potential issues of comparability as well as potential issues with the conduct of the original study.

The Sportfishing Values Database provides information about numerous recent non-market valuation studies, including information from more than 100 travel cost and survey studies. The database describes the resource and the change that provide the basis for the reported value, including species and resource quality characteristics. In addition, the database describes study characteristics (including respondent sample information), the valuation methodology, and other study-specific conditions (Industrial Economics, 2011).

5.4.6 Emergency Response

The primary intent of public funding for emergency response is to provide water supply from a proposed storage project that can be used to repel seawater from the Delta following a Delta levee failure event or other emergency. Water supply might also be used to manage contamination following an accidental or intentional chemical spill upstream of the Delta, or the water supply might provide an alternative local supply in case of contamination or outage. Benefits can be claimed to the extent that there is a quantified commitment to provide water when triggered by an emergency.

Water storage projects might have other emergency response benefits, such as:

- Providing water for firefighting. This is water supply beyond what is normally planned for in a municipal water supply system. Surface storage projects may be available to provide water to fight wildfires. Analysis should consider the service area around the reservoir for which the reservoir would provide water supply, the amount of firefighting time saved because of the reservoir, the additional water delivery capacity enabled by reduced response time, and potential cost savings.
- Water supply reliability following an earthquake. If the water storage project will provide new water supply reliability following an earthquake, Applicants shall explain how, and monetize the amount and duration of outages with and without the water storage project, using methods described in Section 5.4.1.
- Water supply during a drought emergency. During drought emergency, M&I economic benefits are the increased net revenue of water providers plus the increased economic surplus (the benefit of avoided shortages and rate hikes) of water users.

In all of these cases, benefits can be claimed to the extent that there is a commitment to provide water supply in an emergency. Emergency response costs that are part of flood control benefits are discussed in Section 5.4.3. Most emergency response benefits are expected to be monetized using avoided costs or alternative costs.

5.4.6.1 Emergency Response Avoided Costs

Examples include avoided end user shortage costs, costs of emergency water supplies, costs caused by reduced quality of exports, and reduced fire damage where supplies are more reliable for wildfire or fire following an earthquake. There has been little direct estimation of expected costs of these events, but information is available from the Delta Risk Management Strategy (DRMS), and work is being completed for DWR’s Delta Flood Emergency Preparedness, Response and Recovery Project and the Delta Stewardship analysis of Delta levee priorities.

Release of water from storage during an emergency must be accounted for in subsequent years following the release. Operations models such as CalSim II coupled with urban and agricultural water cost models can show how the release of a large volume of stored water may increase water shortages and water supply costs in subsequent years. With information about the frequency of Delta levee failure events, an expected value of annual cost can be estimated; this is the cost that would be avoided by supplying water from the new storage project instead of an existing facility.

DRMS and subsequent work on Delta levee risk economics provides information that can be used to quantify emergency response benefits where levee failures will result in water shortage in the Bay Area or southern California. The economic costs of urban shortage can be estimated using data provided in the DRMS economics technical appendix, Appendix E, Tables E-26 and E-27 (URS and Jack R. Benjamin & Associates, Inc., 2008). These data show the economic costs of water shortages at 5 percent increments of annual shortage for the Bay Area and southern California for 2005 and 2030.

Mann (2011) updated these costs to 2009 dollars using the Gross National Product Implicit Price Deflator. Regression analysis was used to estimate the dollar cost of shortage as a function of the percent shortage. The resulting regression equation can be used to provide a rough estimate of urban shortage costs where the percent shortage caused by the event is known. The costs are based on annual average shortage percentages (%short), so if the duration of the shortage is half of a year, the cost estimates should be halved. Avoided costs should be updated to 2015 dollars.

The selected equation form, based on fit, was:

Equation 1) $\text{Log}(\text{cost/yr}) = a + b*(\%\text{short}) + c*(\%\text{short})^{1.2} + d*(\%\text{short})^{1.4}$

Where,

cost/year is in millions of dollars, and

$0 < \%\text{short} < 100$

For example, regression results for two urban regions and two points in time are shown in Table 5-9.

Table 5-9. Coefficients for Urban Shortage Cost Equations.

Region/Year	**Estimated Coefficients**					**Adjusted R^2**
	a	b	C	d	R^2	
SF Bay Area 2005	-0.03876	0.80145	-0.61443	0.12437	0.999	0.999
SF Bay Area 2030	0.19934	0.63921	-0.48113	0.09722	0.998	0.996
Southern California 2005	0.55518	0.52782	-0.39929	0.08205	0.998	0.995
Southern California 2030	0.64273	0.54513	-0.41805	0.08712	0.999	0.997

Since the dependent variable is the logarithm of cost/year, the million dollar cost per year is calculated as the antilog of the calculated result from the regression equation. Economic methods provided in Section 5.4.1.3 may also be used for more detail.

The U.S. Department of the Interior (USDI) provides background on wildland fire benefits and costs (USDI, 2012). If a proposed reservoir can provide water for firefighting, applicants shall identify the area surrounding the reservoir within which the reservoir would be used for firefighting, estimate the probability of fire events within that area, and estimate cost and damage savings from use of the reservoir rather than the next-best alternative. For fire following an earthquake, show where and how project facilities could provide improved water supply reliability, probably through redundancy, following an event.

5.4.6.2 Emergency Response Alternative Costs

Methods described in Section 5.4.1, Water Supply Benefits, may apply if the alternative project or source can be clearly distinguished as supply for a local drought or other emergency supply and as the lowest cost alternative to provide that supply. The economic benefit attributable to providing a volume of water from new storage during an emergency can be estimated as the savings in cost of providing that same volume of water from the lowest cost alternative source. For example, if 100 AF of water from storage can be used temporarily for emergency municipal supply instead of for another purpose, and a temporary pipeline is the lowest cost alternative, the benefit of the emergency municipal supply is that alternative cost avoided.

5.4.6.3 Emergency Response Willingness-to-Pay

No specific, recent applications are known. Information to estimate willingness-to-pay to avoid water shortage is shown in Table 5-9. No studies or models are known that estimate willingness-to-pay to avoid larger-scale emergencies such as a Delta disaster.

5.4.6.4 Expected Benefit

Emergency use does not occur every year, so the benefits when they occur, whether estimated as avoided cost or alternative cost, must be combined with the frequency (probability of occurrence) to compute the expected benefit. For example, if the emergency supply is needed only once in 50 years, the probability associated with the benefit is 1/50, and the benefit must be multiplied by the probability to compute expected annual value of the benefit.

Applicants must justify the probabilities of occurrence claimed for emergencies, using the available historical record for the portion of the study area receiving the emergency response benefit. Probabilities can be adjusted for well-supported changes in future conditions as compared to the historical record, including climate change. For multiple kinds or magnitudes of emergencies, a frequency for each event must be determined. The overall expected benefit is the monetized value of the benefit for each event, multiplied by its probability of occurrence. The sum over the resulting amounts is the expected annual benefit. For each event, the amount of water provided from storage is not available for other public or non-public benefits, and that loss must be accounted for in the operations analysis of the proposed project. See Section 4.11 for direction on how to incorporate releases associated with emergency events into the project operations analysis.

SECTION 6

Estimating Project Costs

This section provides direction and recommendations on estimating project costs for economic analysis for the WSIP. Section 8 describes additional information that may be required to allocate costs.

The applicant shall estimate and display the capital costs, including construction, initial environmental mitigation or compliance obligations, and land acquisition, to establish eligible capital costs for WSIP funding. The applicant shall also estimate additional costs incurred during project operations including operations and maintenance (O&M), repair, replacement, and additional environmental mitigation or compliance obligations required during the planning horizon. The economic analysis shall include the total project costs for comparison to project benefits.

6.1 Cost Estimating

Cost estimates are important in determining the economic feasibility of a proposed project and are required for allocating costs to beneficiaries. Project costs depend on the exact configuration of a project, features provided to enable or realize specific types of benefits, and how the project will be operated. Cost estimates are developed based on the best available project information and should reflect reasonable expectations of costs for a specific level of estimate. The levels of accuracy of cost estimates vary at different stages of project planning and design. Cost estimates range from preliminary estimates in the early stages to more accurate estimates in the final design phase prior to construction. Typically, cost estimates for a project are developed in chronological order from preliminary-level estimates to final design-level estimates with each update superseding the previous one. The accuracy and confidence of the cost estimates are expected to increase as the project design is refined with a more detailed level of design data. Typically, cost estimates are refined as the project development progresses with increasing levels of design data and are used to verify that the project is still feasible and cost-effective. Preparation of cost estimates requires knowledge of construction materials, equipment, and labor production rates relative to project conditions.

6.2 Levels of Cost Estimates

Different organizations, including governmental agencies and private sectors, may use different levels or types of classifications of cost estimates. Regardless of the levels or types of classifications used by an organization, the cost estimates begin at initial design and end with a 100 percent design just prior to the time of bid and construction.

The Association for the Advancement of Cost Engineering (AACE) International defines the following five levels of cost estimates, known as AACE Estimate Classes, for a project:

- Class 5: Concept-level estimate, 0 percent to 2 percent level design
- Class 4: Concept study or feasibility-level estimate, 1 percent to 15 percent level design
- Class 3: Budget authorization or control-level estimate, 10 percent to 40 percent level design
- Class 2: Control or bid-level estimate, 30 percent to 70 percent level design
- Class 1: Check estimate or bid/tender, 50 percent to 100 percent level design

The level of accuracy of cost estimates increases in chronological order from Class 5 to Class 1. A Class 5 cost estimate contains the highest level of risk and uncertainty, while a Class 1 cost estimate has the lowest level of risk and uncertainty.

USACE, in its guidance and procedures for cost estimates for civil works projects, references ASTM International’s Standard E2516-06, Standard Classification for Cost Estimate Classification System, which is effectively the same as the AACE Estimate Classes (USACE, 2016).

Reclamation classifies projects using two broad categories: planning stage and final design stage. In the planning stage, projects are separated into three progressive categories: preliminary, appraisal, and feasibility. In the final design stage, projects are designated by a percent design complete up to 100 percent.

One of the eligibility requirements of the WSIP is a completed feasibility study. Because a feasibility study is required, cost estimates for the WSIP should conform to Reclamation’s feasibility-level estimates or AACE’s Class 4 (feasibility-level) estimates, or better. Feasibility-level cost estimates are based on information and data obtained from feasibility-level designs and layouts from which quantities for materials, equipment, and labor can be calculated.

The U.S. Society on Dams (USSD) provides the following two methods for developing project cost estimates (USSD, 2012):

- Unit price estimates are developed using current unit prices that are developed using previous bid contracts, cost curves, construction catalogs, detailed analyses, vendor quotes, and regression analyses.
- Detailed estimates are developed to estimate potential contractor’s bid prices, including all direct costs and indirect costs (i.e., project overheads, business overheads, profit, and bonds) to perform the work.

Both methods can produce the same level of confidence in the cost estimates. Selecting the appropriate method depends on the level of estimate, the complexity of the project, and relative amount of labor costs versus material costs. Typically, detailed estimates are developed for major items that are variable and cannot be confidently quantified by unit prices.

The following sections describe key components of cost estimates from cost estimating guidelines from Reclamation (Reclamation, 2007) and USSD (USSD, 2012).

6.2.1 Pay Items

Pay items are elements of work with similar, interrelated units that may be combined to be performed in one general operation. Each pay item typically represents a separate and distinct class of work. Pay items are used in estimates and in the bidding schedules of solicitations and consist of descriptions of elements of work for which payments or charges to accounts are to be made.

6.2.2 Quantities

Quantities for major items are obtained from the design layouts developed in sufficient detail. Quantities are represented by the numbers and units of measures (e.g., pounds, cubic yards, linear feet) for each pay item of work. Quantities should not be increased to cover contingencies.

6.2.3 Unit Prices

Unit prices include the cost components for labor, materials, and equipment necessary to perform the work designated in the pay items for the proposed scope of work. Unit prices for labor, equipment, and materials required for construction may be affected by geographical location of the project; weather conditions; project accessibility; availability of labor, materials, and housing; power sources for construction; and other project conditions. Project cost estimates shall use unit prices of labor, materials, land, and other inputs that are no more than 5 years old at the time of the submission of the application.

6.2.4 Design Contingencies

Design contingencies are intended to account for uncertainties as the project progresses from the planning phase to the final design phase. These uncertainties include unlisted items, design and scope changes, and cost estimating refinements. Design contingencies should be listed as a separate line item in the cost estimate. In general, the less refined the estimates, the higher the allowance percentage is used, and conversely, the more refined the estimate, the lower the allowance percentage is used. Typically, design contingencies allowance ranges from 5 to 10 percent of the construction cost. Determining the appropriate percentage allowance for design contingencies is based on the cost estimator’s experience and professional judgment.

6.2.5 Construction Contingencies

Construction contingencies represent the dollar values of the uncertainties in the estimates to compensate for unforeseen or changed site conditions, minor changes in plans, quantity overruns, and other uncertainties. The percentage allowance used should be based on engineering judgment of the major pay items in the cost estimate, reliability of the data, adequacy of the projected quantities, and general knowledge of site conditions and level of uncertainty. The allowance amount for contingencies varies inversely with the certainty of the engineering and geological information and data. Generally, as the project detail and level of development are refined, the amount of contingency should decrease. Construction contingencies allowance typically ranges from 20 to 25 percent of the construction cost.

6.2.6 Mobilization and Demobilization

Depending on the level of detail of the cost estimate, the estimator may include equipment mobilization and demobilization as a percentage of the overall cost of the project. If not listed as a separate line item, the allowance for mobilization and demobilization is typically 5 percent of the contract cost, depending on the size of the project and whether onsite project management is required.

6.2.7 Contract Cost

The contract cost is intended to represent the estimated cost of the contract at the time of bid or award. This cost can include allowances for design contingencies, but not construction contingencies.

6.2.8 Field Cost

The field cost is an estimate of the capital costs of a project from award to construction closeout. The field cost equals the contract cost plus construction contingencies.

6.2.9 Non-Contract Costs

Non-contract costs include engineering and design, construction management, project closeout, contract administration, legal services, permitting, and other general expenses. The non-contract costs allowance is typically 20 to 25 percent of the field cost.

6.2.10 Construction Cost

Construction cost is a major portion of the total project cost. Construction cost consists of the costs of the construction of the physical features of the project, relocation of existing real property, clearing and restoring lands, service facilities, and site investigations. Total construction cost consists of the field cost and the non-contract costs.

6.3 Capital Costs

The applicant shall estimate and display the capital costs, including, to establish eligible capital costs for WSIP funding.

Eligible capital costs are the costs of construction or acquisition of a tangible physical property with an expected useful life of 15 years or more. Capital costs include the following items:

- Construction, initial environmental mitigation or compliance obligations, and land acquisition.
- Major maintenance, reconstruction, or demolition for reconstruction of facilities, reoperation, or retrofitting.
- Equipment with an expected useful life of 2 years or more
- Costs incidentally but directly related to construction or acquisition, including planning, engineering, construction management, architectural and other design work, environmental impact reports and assessments, environmental mitigation or compliance obligation expenses, permitting, appraisals, legal expenses, site acquisitions, and easements.

Financing costs such as interest during construction shall not be included in capital costs.

6.4 Total Project Cost

The total project cost includes the capital costs, interest during construction, environmental mitigation or compliance obligations after completion of construction, and O&M, repair, and replacement costs during the planning horizon. All benefits and costs should be discounted and compounded, respectively, to the start of project operations using the required discount rate.

6.5 Economic Assumptions

The applicant shall provide cost estimates in 2015 dollars, escalated to 2015 as needed using Reclamation Construction Cost Trends (Reclamation, 2016).

6.5.1 Conveyance Costs

The costs for conveying water through existing facilities shall be based on existing non-energy variable costs and escalated energy costs.

Benefits that are compared to project costs shall be net of any non-project costs including conveyance costs and losses from the project to the water supply destination. All water delivered through conveyance systems shall be assigned a water delivery cost per acre-foot based on variable costs. For the SWP system, DWR’s Bulletin 132 provides costs of water deliveries (DWR, 2015). The variable cost of the SWP is the variable operations, maintenance, power, and replacement (OMP&R) component plus the off-aqueduct charge, which are also charges based on the amount of deliveries. For the CVP system, Reclamation charges O&M rates.

Reclamation's CVP O&M rates may be used for conveyance costs through the CVP system, and SWP's OMP&R and off-aqueduct charges may be used for conveyance costs through the SWP system. Conveyance losses in the Delta or conveyance channels must be estimated and incorporated into the cost calculation, if appropriate.

SECTION 7

Comparing Benefits to Costs

Benefit-cost calculations are required to document the expected return for public investment. All project benefits, and all public benefits, are compared to project costs to help establish appropriate cost shares and to help consider and establish the financial feasibility of the project. The required values are calculated using the planning horizon analysis.

7.1 Economic Assumptions

The applicant shall display and compare the present value of monetized benefits and total discounted project costs of the proposed project, all shown in 2015 dollars as of the start of project operations.

7.2 Tools and Methods

For each benefit category, the applicant shall provide the present value of the expected net monetized benefits over the planning horizon, in 2015 dollars, discounted to the start of project operations using the required discount rate. Net monetized benefits are benefits minus any impacts caused by the proposed project or other costs (other than project costs) that are required to realize the benefit. For the project as a whole, the applicant shall provide:

- The total project costs in 2015 dollars, discounted or compounded to the start of project operations.
- The ratio of total present value of the net monetized benefits to the total project costs.

7.3 Metrics

The overall benefit-cost ratio of the proposed project, considering all costs, benefits, and impacts, is the measure of the project’s economic feasibility.

Public benefits that cannot be quantified in physical or monetary terms may not qualify for funding. However, they may influence the overall assessment of an application. Qualitative description of unquantified public benefits should be provided. Information regarding the potential magnitude of unquantified benefits relative to quantified benefits should be provided. Where benefits cannot be monetized, at a minimum, the following information should be provided:

- The type of physical benefit expected and its relationship to CDFW and State Water Board priorities and REVs, if any.

- Explanation of why the benefit cannot be monetized at this time, and evidence that the proposed project will produce the claimed benefit that will be measurable and how it will be measured.
- The following information to help determine whether economic benefits of an unquantified benefit are important:
  - The number of persons affected, where they are located, and the way they are affected
  - Evidence that the affected people have an interest in the effects (i.e., they have expended time or money because of the effects)

SECTION 8

Allocating Costs to Beneficiaries

Costs must be allocated to beneficiaries in a manner that demonstrates financial and economic feasibility and that supports the WSIP funds requested. The proposed cost share for each benefit category must be justified by and consistent with its level of quantified benefit. The cost allocated to any public benefit must not exceed the dollar amount of that public benefit. Costs for the five public benefit categories may be allocated to the State of California, the United States, local governments, or private interests. However, the portion of the public benefit costs allocated to the WSIP shall only include public benefits received by Californians and must not exceed 50 percent of the total capital costs of any funded project. The cost allocation must also document that at least 50 percent of the public benefits funded by the WSIP are ecosystem improvements.

8.1 Economic Assumptions

For each benefit category, the applicant shall provide the following items:

- The estimated WSIP cost share for each public benefit category, in present values, and an explanation of how the cost share was calculated.
- A tentative allocation of all costs to the project beneficiaries and an explanation of how the allocation was calculated.

As stated above, public benefit cost shares for the five public benefit categories may be allocated to the State of California, the United States, local governments, or private interests. The portion of the public benefit cost share allocated to the WSIP shall:

- Consider the share of the public benefit received by Californians
- Not exceed 50 percent of the total capital costs of any funded project
- Be at least 50 percent for ecosystem improvements
- Not be associated with ~~existing~~ environmental mitigation or compliance obligations except for those associated with providing the public benefits

8.2 Tools and Methods

A proposed water storage project will typically have multiple purposes such as water supply, hydropower, ecosystem, recreation, water quality, and flood control. Cost allocation is the process of partitioning project costs among project purposes (or benefit categories) and among beneficiaries. Cost allocation methods are typically based on shares of project physical changes or reservoir space, or on economic benefits.

The use of the facilities method allocates cost on the basis of share of facilities used. The facilities method is appropriate for some cost allocations. If all project benefits are provided using water supply or reservoir space, and all benefit categories have equal access to water supply or space in different hydrologic conditions, costs may be allocated based on share of water supply or space provided. However, economic benefits received by some benefit categories using this method may be less than their assigned cost. For a cost allocation to be feasible, the economic benefits to each beneficiary must be at least as large as the beneficiary's proposed cost share. Also, some benefit categories may not have a dedicated supply or reservoir space (e.g., recreation), so they may not receive any costs under this allocation method. The facilities method generally does not work well for projects having joint-use facilities serving multiple purposes. The conditions for an unambiguous and feasible cost allocation using only water supply or reservoir space rarely exist.

For large multi-purpose projects, costs are usually allocated in consideration of economic benefits. Although benefit-cost analysis and cost allocation are separate processes, cost allocation typically follows benefit-cost analysis.

Cost allocation is often viewed as a cooperative venture that keeps all beneficiaries in the venture, and each beneficiary wants the others to participate because they help cover the costs. A necessary condition for a feasible cost allocation is that a project must have total expected benefits that exceed its total costs. This ensures that a feasible cost allocation exists – that is, each beneficiary receives a cost share that is less than its expected benefit. If a beneficiary is asked to pay a cost more than the benefit received, it would not want to participate. This might require reconsideration of project operations and, ultimately, economic feasibility.

Also, each beneficiary is typically expected to pay, at a minimum, the cost it imposes on the project. If a beneficiary imposes a cost on the project that is greater than that beneficiary's cost share, the other beneficiaries would prefer to exclude that beneficiary. Projects normally have specific costs that are attributable to only one beneficiary or purpose. Recreation marinas or hydropower turbines are examples of these specific costs. If hydropower benefits cannot cover such specific costs as turbines, it is economical to exclude hydropower features from the project.

Viewing cost allocation as a cooperative venture, the range of feasible cost allocations has the following characteristics: all beneficiaries are better off by their participation (their benefits exceed their allocated share of costs); and no beneficiary imposes a cost on the project that is more than its cost share. In the case of the WSIP, the proposed cost shares must also exclude allocations that are not allowed; for example, statute requires that no more than 50 percent of cost can be allocated to public benefits funded by the WSIP, and the ecosystem improvement cost allocation must account for at least 50 percent of the public benefits funded by the WSIP. Any tentative cost allocation must meet these requirements, and the ratio of benefit to proposed cost share for any beneficiary must exceed one. If costs allocated to public benefits exceed the 50 percent requirements, another funding source (other than the WSIP) must be identified that will contribute costs that exceed the requirements.

A simple allocation method that may meet the requirements outlined above is to allocate project costs among the benefit categories in proportion to monetized benefits. If total benefits exceed costs, a proportional allocation allows each benefit category to pay less than its benefit. A simple proportional allocation may not meet the other requirements for a feasible allocation.

The separable cost-remaining benefits (SCRB) method is a common approach used for allocating costs (Griffin, 2006). The resulting allocation meets the requirements of a feasible allocation, though it may not meet the additional 50 percent limits imposed by statute. Costs of the proposed project are allocated to purposes (benefit categories) according to the following steps:

1. Separable Costs. The cost of the project in the absence of a particular purpose (e.g., hydropower) is calculated by reengineering the project plan to exclude the purpose (e.g., no hydropower benefit) but with the same amount of benefit for all other purposes. For example, the difference between the project cost with and without the hydropower purpose is the separable cost—the portion of project cost that can be clearly and solely attributed to hydropower. A hydropower turbine would be a separable cost for hydropower.

   This step is important because if the separable cost is greater than the benefit of the single purpose, the project would be economically superior by omitting that purpose, and the other beneficiaries would be better off if that purpose were omitted from the project. This step also ensures that no single purpose will be asked to pay costs in excess of benefits.
2. Joint Cost. Once separable costs of each purpose are established, the joint cost can be calculated as the total cost minus the sum of the separable costs. The joint cost of the proposed project serves all benefit categories and is often a large part of total cost for a multi-purpose storage project.
3. Remaining Benefits. Each separable cost is subtracted from that purpose’s benefit to calculate the remaining benefit of the purpose (i.e., the benefit that is not already accounted for by the separable cost). The remaining benefits are summed, and the share of the total remaining benefit for each purpose is calculated. The joint cost is allocated according to the share of remaining benefit of each purpose.
4. Cost Shares. The cost allocated to each purpose is its separable cost plus its share of joint cost. Each beneficiary’s costs are less than their benefits, ensuring that each beneficiary has a positive net benefit and that no purpose is assigned any cost that is clearly caused by any other purpose.

Alternative justifiable expenditure, another allocation method, is similar to SCRB except that specific costs are used instead of separable costs (HDR Engineering, 2012). This reduces computational effort since the project does not need to be reengineered with a new cost estimate for each purpose. After specific costs are identified, the joint costs are allocated in the same way as described for SCRB.

Alternative justifiable expenditure and SCRB are among the acceptable methods for cost allocation. However, they do not normally consider constraints on cost allocation like those required for the WSIP. An unconstrained application of alternative justifiable expenditure and SCRB could result in a WSIP constraint being violated, and results might need to be adjusted to meet the constraints.

Applicants must include a tentative cost allocation among benefit categories. The cost allocated to a public benefit will generally be greater than the share funded by WSIP, because only capital costs are funded by WSIP and the capital cost share may be limited by the 50 percent requirements in statute. Applicants must:

- Provide cost shares that are less than benefits for every benefit category. If any category's cost share is more than its monetized benefit, explain why non-monetized benefits are sufficient to justify the cost share.
- Provide public benefit cost shares that meet the 50 percent requirements in statute. If more than 50 percent of cost is allocated to public benefits, show the non-WSIP sources that will fund the excess.
- Because the WSIP funds only capital cost, show how other costs allocated to public benefits (e.g., O&M costs) will be funded.
- Compare each cost allocation by benefit category to the specific cost of that benefit. If the allocation is less than the specific cost, explain why.
- Show that the tentative cost allocation meets the statutory requirement (Water Code Section 79755(a)(2)) that benefits available to a party shall be consistent with that party's share of total project costs.

8.3 Metrics

Metrics will include the total capital cost; present value of the total project costs; the share of cost allocated to ecosystem, other public benefits, and non-public benefit categories; and the public funding request for each public benefit. The public funding request cannot exceed 50 percent of eligible capital costs.

SECTION 9

Determining Cost-Effectiveness and Public Benefit Ratio

The cost-effectiveness of the proposed project is demonstrated by calculating and justifying the cost of the least-cost alternative means for providing the same amount or more of the total public and non-public physical benefits as provided by the proposed project, if there is at least one feasible alternative means of providing the same amount or more of all physical benefits. If project alternatives were considered as part of the feasibility study or other published document (such as a plan formulation study), applicants shall provide the document containing the analysis of alternatives and provide within the application a brief summary of the least-cost feasible alternative and the reasons for rejecting the alternative in favor of the proposed project.

The applicant shall also determine and display the ratio of all public benefits to the total WSIP funding request. All public benefits are the total benefits in the five public benefit categories, adjusted to the California accounting perspective, divided by the total WSIP funding request, both in present value terms.

9.1 Economic Assumptions

Economic assumptions used to calculate the cost of the least-cost alternative means for providing the total physical benefits as provided by the proposed project must be consistent with methods described in sections 5 and 6.. The public benefit ratio shall be based on the quantified public benefits and the requested WSIP funding.

9.2 Tools and Methods

The alternative cost approach reveals the least-cost means of providing each physical benefit taken alone. One alternative means of obtaining all the physical benefits can be calculated as the total of these single-purpose alternative costs. If another feasible alternative is identified that is substantially different from the proposed project, can provide all of the physical benefits of the proposed project, and has a cost potentially less than the cost allocated to all physical benefits, the cost shall be estimated and provided.

To calculate the public benefit ratio, applicants shall provide:

- The present value of net monetized public benefits in 2015 dollars, discounted to the start of project operations.
- The estimated WSIP cost share for each public benefit category, in present value dollars, compounded to the start of project operations, and an explanation of how the cost share was calculated, consistent with Section 8.

- The requested WSIP funding for each public benefit.

9.3 Metrics

The cost of the least-cost alternative means shall be displayed over the planning horizon, discounted using the approved discount rate, and expressed in present value terms for comparison to the present value of project costs.

The applicant shall calculate the public benefit ratio as the present value of the net monetized public benefits divided by the total requested WSIP cost share.

SECTION 10

Evaluating Sources of Uncertainty

Quantification of benefits and impacts requires a number of assumptions and estimates about future conditions with and without the proposed project. These assumptions have uncertainty regarding their magnitude, timing, and scope. To assess the importance of key assumptions, applicants must evaluate how changes in these assumptions would affect quantification of benefits and the water storage project's public benefit ratio. This is called sensitivity analysis. The sources of uncertainty in a complex analysis are many, so sensitivity analysis focuses on identifying those that are potentially most important—that is, most capable of changing the results in a meaningful way. Projects that perform relatively well over a range of future conditions, as demonstrated by sensitivity analysis, are more resilient.

If quantitative sensitivity analysis is provided, the same methods and datasets should be used as in the analysis of expected physical benefits and impacts, modified to incorporate the change (the modified assumption) for which the sensitivity analysis is being performed. To avoid an unreasonably large number of analyses, each potential change for which the sensitivity analysis is being performed is evaluated independent of other changes. Combinations of changes may provide useful information, but are not required. Both with- and without-project conditions must be modified for the potential change. Quantification may include both physical and monetary changes resulting from the change in assumption. However, if the initial step in the physical analysis indicates little or no meaningful effect on results, no further analysis of physical or monetary changes is warranted.

Quantitative or descriptive sensitivity analysis is required to evaluate the effect of climate change conditions, future projects and water management actions, other conditions identified by the applicant, and drought. The sensitivity analysis is an important part of the scoring criteria for projects' relative environmental value and resiliency.

10.1 Uncertainty Associated with Climate Change

Section 6004 of the proposed WSIP regulations describes the sensitivity analysis of potential uncertainties that applicants must consider, including climate change conditions not considered in the without-project condition.

The applicant shall describe how potential changes in climate represented by more extreme conditions than in the 2070 Future Conditions could affect the public benefits claimed. These two conditions are defined in section 2.12.2.3. Applicants shall describe how operations of the proposed project could be adapted to sustain public benefits under the described conditions. The applicant shall provide documentation or calculations and assumptions used to support the conclusions.

10.2 Future Project and Water Management Actions

Other potential future changes related to water management, regulatory conditions, and other resource conditions are also provided for sensitivity analysis. Applicants must address other potential future changes related to potential projects and water management actions that are relevant for their projects, as may be included in the applicant's CEQA cumulative impact analysis, could affect the public physical benefits claimed. Applicants shall describe how operations of the proposed project could be adapted to sustain public physical benefits claimed. The applicant shall provide documentation or calculations and assumptions used to support the conclusions, using either quantitative or non-quantitative (descriptive) sensitivity analysis. Other potential future changes identified in the cumulative analyses for environmental documents for the proposed projects must be included.

Applicants must provide a sensitivity analysis to identify how the expected physical changes caused or created by the proposed project could be changed by other water management actions and those included in the proposed project's CEQA cumulative effects analysis. The following list of potential future projects, water management actions, and environmental and regulatory conditions are examples of future conditions that, while not included in the without-project conditions, may affect the future condition in structural, operational, and regulatory ways:

- Potential changes related to water storage
  - Current or impending FERC relicensing processes
  - San Luis Reservoir modifications, including corrective action to reduce seismic risks, low-point improvement, and expansion
  - Other local water storage projects identified in the proposed project's CEQA cumulative effects analysis
- Potential changes related to flood management
  - CVFPP basin-wide feasibility studies
  - Local and regional flood management plans, including Lower San Joaquin River and Delta South Regional Flood Management Project
  - Other local flood management projects identified in the proposed project's CEQA cumulative effects analysis
- Potential changes related to ecosystem conditions and management
  - Yolo Bypass – Salmonid Habitat Restoration and Fish Passage Project, NMFS Biological Opinion Action I.7
  - San Joaquin River Restoration Program – Full Restoration Flows
  - Other local, state, or federal ecosystem restoration or management activities
- Potential changes related to groundwater and other water management

  - Sustainable yield requirements of implementing SGMA, to the extent those are not already included in the with- and without-project quantification of benefits and impacts
  - Proposed State Water Board and Governor’s Order water conservation mandates
  - Friant-Kern Canal and Madera Canal Capacity Restoration Projects
  - Friant-Kern Canal Reverse Flow Project
  - San Luis Drainage Reevaluation Program

- Potential changes to Delta operations and management
  - California WaterFix and California EcoRestore (formerly the Bay Delta Conservation Plan)
  - Potential changes to the State Water Board Water Quality Control Plan for the San Francisco Bay-Sacramento/San Joaquin Delta Estuary
  - Delta-Mendota Canal Recirculation Project
  - Franks Tract Project
  - North Bay Aqueduct Alternative Intake
  - North Delta Flood Control and Ecosystem Restoration Project (McCormack-Williamson)

10.3 Other Sources of Uncertainty

The applicant may identify other assumptions or estimates about future conditions that have sufficient uncertainty regarding their magnitude, timing, and scope to warrant additional sensitivity analysis. Changes, such as in regulatory or ecosystem conditions, may have impacts on project analysis that change the potential public benefits in a meaningful way. Quantitative or descriptive sensitivity analysis is required to evaluate the effect of other conditions identified by the applicant. Applicants shall disclose any other potential sources of uncertainty and describe alternative operational strategies or adaptations the proposed project could employ to provide alternative public benefits or to maintain the level of public benefits provided by the project if future conditions differ from the with-project future conditions.

10.4 Drought

Another metric used to assess resiliency is the ability of a project to perform during droughts. Applicants shall describe the amount of water stored in the water system due to the project that could be used for public benefits at the beginning and end of a five-year drought for the 2070 conditions. The five-year drought is defined as five consecutive dry or critical years in the hydrologic data used in the analysis for the 2070 conditions. Applicants shall specify the drought period within the hydrologic data set used and describe the significance of the amount of water in the water system due to the project to system flexibility and maintaining public benefits during the drought period.

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Metrics

This section summarizes the metrics used to display results of an applicant's analysis, including metrics specifically required to support evaluation criteria. Metrics include a description of what is being measured, the units of measurement, and some key relationships to other metrics. Because of the wide range in possible physical changes, methods, and models, the units of measurement are often stated as examples. Applicants may use other metrics as needed in their analysis, for example to provide results from one analysis as input into a subsequent analysis. Included in the tables below are metrics required to support specific evaluation criteria.

Tables 11-1 through 11-10 provide a comprehensive summary of metrics that could be used by applicants to support physical and economic quantification of benefits. The metrics also provide a framework for technical review by Commission staff, DWR, CDFW, and the State Water Board. The tables include the broad range of metrics that any potential application might use. However, a typical application would only need to provide some of these metrics. Many metrics will not apply for projects that do not have the relevant type of physical effect or do not claim the relevant type of benefit. Other metrics may relate to specific recommended or optional quantification methods or models, so would not be used if that method is not used. For more detail on a metric and how it can be calculated using models or other quantitative analysis, see the appropriate topics in Sections 4 through 10 of this Technical Reference.

Table 11-1. Summary of Metrics: Project Features, Water Operations, Water Supply, and Hydropower.

Row	Description	Units of Measurement	Notes and Relationship to Other Metrics
Proposed Project's Facilities			
1	Gross storage capacity	AF	Note relationships to individual benefit categories if any. May be zero for without-project condition
2	Active storage capacity	AF	
3	Diversion/recharge capacity	Flow rate (cfs or AF per unit time)	Note relationships to individual benefit categories if any. May not apply to some projects. May be zero for without-project condition
4	Release/extraction capacity	Flow rate (cfs or AF per unit time)	
5	Dedicated capacities	AF or percent	Provide the amount or share of dedicated space, if any, for each benefit,
6	Maximum water surface area	Acreage	Only required for lake recreation
Other Affected Storage Facilities			
7	See 1 through 6	Repeat of metrics above as needed to quantify effects on other storage facilities that are affected by the proposed storage project.	
Water Operations and Balance			

Table 11-1. Summary of Metrics: Project Features, Water Operations, Water Supply, and Hydropower.

Row	Description	Units of Measurement	Notes and Relationship to Other Metrics
8	Project diversion from river or other surface water	AF, reported as time series, overall average, and average by water year type, as necessary	Many of the metrics for water operations may be zero for without-project condition.
9	Amount of diversion lost to project in conveyance	AF, reported as time series, average, and/or average by water year type, as necessary	Provide by fate of losses go (i.e., evaporation, seepage to groundwater)
10	Diversion/recharge entering project storage	AF, reported as time series, average, and/or average by water year type, as necessary	Generally, this is the project diversion from river or other surface water minus the amount of diversion lost to project in conveyance
11	Amount of stored project water lost from the project	AF, reported as time series, average, and/or average by water year type, as necessary	Provide by fate of the losses (i.e., evaporation, seepage to groundwater) and by benefit category if available.
12	Water in project storage	AF end of month, reported as time series and average by water year type.	For water stored by dedication or by quantifiable storage rule, provide by benefit category and explain.
13	Water diverted or released from project storage	AF by year, reported as time series, overall average, and average by water year type.	Provide by benefit category. Report monthly averages where needed to support specific benefits. Public benefit categories may not have deliveries (see metrics by benefit category in subsequent tables). If water is delivered or released that serves multiple purposes, show the amounts that serve each purpose.
14	Amount of diverted or released water that is consumptively used or otherwise not recoverable	AF, reported as time series, average, and/or average by water year type, as necessary	
15	Amount of diverted or released water returned to hydrologic system	AF, reported as time series, average, and average by water year type, as necessary	
Hydropower			
16	Energy generated	Net megawatt-hours (generation minus consumption)	Provide by appropriate time scale, such as by month. Note if the generation is peak vs off-peak. Include how generation varies over time according to reservoir storage/year type.

Notes:

- Provide estimates for 2030 and 2070 conditions, with- and without-project, over hydrologic period or by water year type or hydrologic condition as applicable.
- Water year type shall be based on either the Sacramento River 40-30-30 index or San Joaquin River 60-20-20 index, depending on the project’s location.

Table 11-2. Summary of Metrics: Groundwater Effects.

Row	Description	Units of Measurement	Notes and Relationship to Other Metrics
These apply to any groundwater storage, remediation, or conjunctive use project; these also apply to surface storage projects that may provide benefits to or impacts on groundwater.			
1	Groundwater levels	Feet below ground surface, reported as average level, and/or level in dry years	All metrics must be displayed at appropriate spatial and time scale to quantify benefits. See Groundwater Analysis section of this document for detail on input and output metrics important for demonstrating benefits.
2	Groundwater quality	Electrical conductivity (EC), or concentration (mg/l)	
3	Flow gradients	Head/elevation differences (ft), subsurface flows (volume per unit time) and directions (e.g., north)	
4	Groundwater- surface water interaction	AF per unit time gained/lost from streams, reported by location and year type	

Notes:

- Provide estimates for 2030 and 2070 conditions, with- and without-project, over hydrologic period or by water year type or hydrologic condition as applicable.
- Water year type shall be based on either the Sacramento River 40-30-30 index or San Joaquin River 60-20-20 index, depending on the project’s location.

Table 11-3. Summary of Metrics: Riverine and Delta Hydrodynamics.

Row	Description	Units of Measurement	Notes and Relationship to Other Metrics
Riverine Hydrodynamics			
1	Flow	AF/month or cfs, reported as time series, average, and/or average by water year type, as necessary	One or more of these metrics may be needed to link water storage project operations to benefits and impacts. Measurement units are examples. See Riverine Hydrologic/Hydraulic Analysis in Section 4 of this Technical Reference for detail on input and output metrics provided by specific models.
2	Stage	Water surface elevation, in ft above a specified datum	
3	Velocity	Feet per second	
4	Sediment transport, Geomorphology	Mass suspended or moved (units depend on model used)	
Delta Hydrodynamics			
5	Flow	AF/month or cfs, reported as time series, average, and/or average by water year type, as necessary	One or more of these metrics may be needed to link water storage project operations to benefits and impacts. Measurement units are examples. See Delta Hydrodynamics/Hydraulic Analysis in Section 4 of this Technical Reference for detail on input and output metrics provided by specific models.
6	Delta Outflow	Net Delta outflow index (NDOI) as defined by D-1641, cfs or AF/Month, reported as time series, average, and/or average by water year type, as necessary	
7	Stage	Water surface elevation, ft msl at a specified datum	
8	Velocity	Feet per second	
9	Salinity	Electrical conductivity, mg/liter of water exported, X2 position, reported as time series, average, and/or average by water year type, as necessary	
10	Fingerprinting	Percent of source or fate by location	
11	Particle Tracking	Residence time (e.g., days)	

Notes:

- Provide estimates for 2030 and 2070 conditions, with- and without-project, over hydrologic period or by water year type or hydrologic condition as applicable.
- Water year type shall be based on either the Sacramento River 40-30-30 index or San Joaquin River 60-20-20 index, depending on the study area location.

Table 11-4. Summary of Metrics: Ecosystem.

Row	Description	Units of Measurement	Notes and Relationship to Other Metrics
Physical Benefit Measure is Length, Area, or Water Amount, Flows, or Quality			
1	Flows	In cfs or AF per month	Relate to project operations and hydrodynamics metrics. See also flow-related water quality metrics Relate to river recreation where applicable.
2	Dissolved oxygen	Concentration in mg/l	Relate to project operations and hydrodynamics metrics. See also the water quality DO metric.
3	Temperature	Degrees F	Relate to project operations and hydrodynamics metrics. See also the water quality temperature metric.
4	Groundwater elevation	Feet relative to ground surface	Relate to project operations. See also the groundwater levels metric.
5	Riparian and floodplain habitat	Acres and distribution (locations/stationing along riverine systems)	Relate to project operations and hydrodynamics metrics. See other ecosystem floodplain metrics. Relate to flood control metrics where applicable.
6	Temporal and spatial diversity	Distribution (location), abundance (#), and condition of habitats	See also similar metric in Aquatic Habitat
7	Wetlands improved	Acres	Potential benefit for WQ and water users See also Refuges/wetlands metric in Aquatic Habitat Note that a recreational viewing benefit may count as an ecosystem benefit
8	Additional wetlands	Acres	See also Refuges/wetlands metric in Aquatic Habitat
9	Pyrethroids, organophosphates, selenium, and CECs	Concentration (unit depends on constituent)	Relate to project operations and hydrodynamics metrics.
10	Low salinity Delta, Suisun Bay and Marsh	Salinity (EC or mg/l TDS), X2 position	Relate to project operations and hydrodynamics metrics. See also Delta tributary natural regime metric in Water Quality
Physical Benefit Measure is Aquatic Habitat, Function *			
Specific metrics including location and frequency depend on project, species.			
11	Floodplain productivity	Primary and secondary productivity (productivity, composition, abundance)	Relate to project operations and hydrodynamics metrics. See other ecosystem floodplain metrics. Relate to flood control metrics where applicable.
12	Floodplain fish	Measures of fish growth (size at time, condition, and survival (#, percent change)	Relate to project operations and hydrodynamics metrics. See other ecosystem floodplain metrics. Relate to flood control metrics where applicable.
13	Temporal and spatial distribution and diversity of habitats.	Distribution, abundance (#), diversity, condition factors of species life stages	See also similar metric in Length, Area, or Water Amount, Flows, or Quality
14	Refuges/wetlands	Distribution, species composition (diversity indices), condition, species served	See also wetland metrics in Length, Area, or Water Amount, Flows, or Quality

Table 11-4. Summary of Metrics: Ecosystem.

Row	Description	Units of Measurement	Notes and Relationship to Other Metrics
15	Eliminating barriers to movement/migration.	Fish life stage abundance (# by life stage, percent change) at barriers	Relate to project operations and hydrodynamics metrics where appropriate.
16	Entrainment risk	Abundance of entrained fish at diversion (#, percent change)	Relate to project operations and hydrodynamics metrics where appropriate.
17	Non-native species	Distribution, abundance, diversity, condition, and survival (#, percent change)	Relate to project operations and hydrodynamics metrics where appropriate.
Physical Benefit Measure is a Specific Species			
Specific metrics including location and frequency depend on project, species.			
18	Salmon and steelhead (S&S) redds	Number supported by aquatic habitat.	Relate to aquatic habitat, project operations and hydrodynamics metrics as appropriate.
19	S&S eggs and fry	Number hatched	Relate to aquatic habitat, project operations and hydrodynamics metrics as appropriate.
20	S&S rearing and out-migrating	Number reared	Relate to aquatic habitat, project operations and hydrodynamics metrics as appropriate.
21	S&S catch	Number caught in ocean and rivers	Relate to aquatic habitat, project operations and hydrodynamics metrics as appropriate. Note that a recreational catch benefit may count as ecosystem benefit
22	S&S stray adults	Number or percent straying from their natal stream	Relate to aquatic habitat, project operations and hydrodynamics metrics as appropriate.
23	S&S escapement	Number of fish returning to spawn	Relate to aquatic habitat, project operations and hydrodynamics metrics as appropriate.
24	Delta smelt	Fall mid-water trawl index or other abundance measure	Relate to aquatic habitat, project operations and hydrodynamics metrics as appropriate.
25	Other special status species (longfin smelt, sturgeon, other)	Measures of habitat enhancement (species, distribution, abundance, diversity, condition)	Relate to aquatic habitat, project operations and hydrodynamics metrics as appropriate.
26	Other native fish	Measures of habitat enhancement (species, distribution, abundance, diversity, condition)	Relate to aquatic habitat, project operations and hydrodynamics metrics as appropriate.
27	Non-native sport fish	Population, catch	Relate to aquatic habitat, project operations and hydrodynamics metrics as appropriate.
28	Terrestrial Species	Measures of habitat enhancement (distribution, abundance, diversity, condition) for targeted species. Measures of targeted species abundance and distribution.	Relate to aquatic and terrestrial habitat, project operations and hydrodynamics metrics as appropriate.

Table 11-4. Summary of Metrics: Ecosystem.

Row	Description	Units of Measurement	Notes and Relationship to Other Metrics

Notes:

- Provide estimates for current condition, and for 2030, and 2070 conditions with- and without-project, over hydrologic period or by water year type or hydrologic condition as applicable.
- Water year type shall be based on either the Sacramento River 40-30-30 index or San Joaquin River 60-20-20 index, depending on the study area location.
- Salmon and Steelhead include winter run chinook, fall run chinook, spring run chinook, and Central Valley Steelhead.
- Each metric might be applied multiple times for different purposes, locations and times

Table 11-5. Summary of Metrics: Water Quality.

Row	Description	Units of Measurement	Notes and Relationship to Other Metrics
1	Temperature	Degrees F	Relate to project operations and hydrodynamics metrics. See also the ecosystem temperature metric.
2	Dissolved oxygen	Concentration in mg/l	Relate to project operations and hydrodynamics metrics. See also the ecosystem dissolved oxygen metric.
3	Nutrients	Concentration (unit varies by nutrient)	Relate to project operations and hydrodynamics metrics. See also the ecosystem nutrients metric.
4	Salinity	EC or mg/l of TDS; (some models may use mg/l of sodium or chloride)	Relate to project operations and hydrodynamics metrics. See also the Delta hydrodynamics salinity metric
5	Mercury	Concentration in ppb	Relate to project operations and hydrodynamics metrics.
6	Groundwater in priority basins.	Concentration of undesirable constituents, varies by constituent	Relate to groundwater analysis metrics
7	Delta tributary natural regime to help aquatic life.	Flow in cfs by time and location	Relate to project operations and hydrodynamics metrics.
8	Reduce current or future water demand	AF diversion or demand	Relate to project operations and hydrodynamics metrics.
9	Water for basic human needs	AF per year, average or in specific conditions	Relate to project operations. Metric could be water supply to area not otherwise meeting drinking water standards, or for drought emergency supply.

Notes:

- Provide estimates for current condition, and for 2030 and 2070 conditions with- and without-project, over hydrologic period or by water year type or hydrologic condition as applicable.
- Water year type shall be based on either the Sacramento River 40-30-30 index or San Joaquin River 60-20-20 index, depending on the study area location.
- Each metric might be applied multiple times for different purposes, locations, and times

Table 11-6. Summary of Metrics: Flood Control.

Row	Description	Units of Measurement	Notes and Relationship to Other Metrics
1	Flood frequencies	Recurrence intervals or exceedance probabilities	Relate to project operations and hydrodynamics metrics.
2	Flows	Peak flow in cfs, for each flood recurrence interval	Relate to project operations and hydrodynamics metrics.
3	Stage/Depth	Peak stage/depth in ft, for each flood recurrence interval	Relate to project operations and hydrodynamics metrics.
4	Area Flooded	Maximum area flooded in acres, for each flood recurrence interval, duration	Relate to project operations and hydrodynamics metrics.
5	Response Time	Time available in hours for evacuation, flood-proofing	Relate to project operations and hydrodynamics metrics.

Notes:

- Provide estimates for 2030 and 2070 conditions, with- and without-project, over hydrologic period or by water year type or hydrologic condition as applicable.
- Water year type shall be based on either the Sacramento River 40-30-30 index or San Joaquin River 60-20-20 index, depending on the project’s location. For flood damage reduction, each metric might be applied to multiple locations and events should be associated with probabilities

Table 11-7. Summary of Metrics: Recreation.

Row	Description	Units of Measurement	Notes and Relationship to Other Metrics
1	Facilities	Types and Nos.	
2	Visitation	Number of visitor days per month or per year, by category	Project operations and hydrodynamics metrics provide water levels, flow, and other determinants.

Notes:

- Provide estimates for 2030 and 2070 conditions, with- and without-project, over hydrologic period or by water year type or hydrologic condition as applicable.
- Water year type shall be based on either the Sacramento River 40-30-30 index or San Joaquin River 60-20-20 index, depending on the project’s location.

Table 11-8. Summary of Metrics: Emergency Response.

Row	Description	Units of Measurement	Notes and Relationship to Other Metrics
1	Delta Emergency Shortage	AF and frequency of water shortage by type of use	Must be consistent with project operations and Delta hydrodynamics.
2	Delta Emergency Water Quality	Salinity of diverted water in EC or ppm TDS; duration of impairment in days	Must be consistent with project operations and Delta hydrodynamics.
3	Drought Emergency	AF and frequency of water provided for health and safety	Must be consistent with project operations.
4	Wildlands Fire	AF and frequency of water provided	Must be consistent with project operations. Proximity of proposed reservoir to acres at risk may be required to estimate avoided damage
5	Urban Fire/Fire Following Earthquake	AF and frequency of water provided	Must be consistent with project operations.

Notes:

- Provide estimates for 2030 and 2070 conditions, with- and without-project, over hydrologic period or by water year type or hydrologic condition as applicable.
- Water year type shall be based on either the Sacramento River 40-30-30 index or San Joaquin River 60-20-20 index, depending on the project’s location.
- For emergency response, each metric might be applied to multiple locations and events should be associated with probabilities

Table 11-9. Summary of Metrics: Monetizing Benefits and Impacts.

Row	Description	Units of Measurement	Notes and Relationship to Other Metrics
Benefits Quantified as Alternative Cost (Lowest Cost, Feasible Alternative)			
1	A different storage facility that could provide some or all of the physical benefits	Costs in 2015$	Also, applicants can identify more than one alternative facility that, taken together, can provide the benefits; or can combine an alternative facility with other alternative costs. This metric links to all relevant metrics of physical benefits.
2	The same amount of water supply could be provided	Annual values in 2015$, by year type or hydrologic condition if appropriate	Cost of the other water supply. Calculated, for example, as quantity by water year type times unit value by year type averaged using frequencies of year types. This metric links to physical water supply metrics.
3	The same amount of flow could be provided	Annual values in 2015$, by year type or hydrologic condition if appropriate	Cost of the other means to achieve the ecosystem or water quality flow benefit. Calculated, for example, as quantity by water year type times unit value by year type averaged using frequencies of year types. This metric links to physical flow metrics for ecosystem or water quality improvement.
4	The same DO or temperature improvement could be provided	Alternative project costs or annual costs in 2015$	Cost of alternative projects or programs that could achieve the same reduction in DO or temperature for ecosystem or water quality benefit. This metric links to DO and temperature physical metrics.
5	The same habitat could be provided	Alternative project costs or annual costs in 2015$	Cost of the alternative to provide the aquatic, riparian, wetland, or other habitat. This metric links to physical aquatic habitat and function metrics.
6	The same aquatic species benefits of the habitat could be provided	Alternative project costs or annual costs in 2015$	Cost of achieving the same amount of improvement. This metric links to aquatic species physical metrics.
7	The same barriers, entrainment, or non-natives would be reduced	Alternative project costs or annual costs in 2015$	Cost of achieving the same amount of improvement. This metric links to corresponding physical metrics.
8	The same water quality improvement could be obtained	Alternative project costs or annual costs in 2015$	Cost of achieving the water quality improvement. This metric links to physical metrics of water quality improvement.
9	The emergency response benefits could be achieved	Alternative project costs or annual costs in 2015$	Cost of achieving the water quality improvement. This metric links to physical metrics of water quality improvement.
10	The same flood damage reduction could be obtained	Alternative project costs or annual costs in 2015$	Cost of achieving the flood control. This metric links to physical metrics of water quality improvement.
11	The same amount of new recreation could be obtained by recreation improvements at another local facility	Alternative project costs or annual costs in 2015$	Cost of achieving the recreation. This metric links to physical metrics of recreation.
Benefits Quantified as Avoided Cost			
12	Costs of poor water quality without proposed project	Annual avoided damage in 2015$	Water quality damage avoided. This metric links to physical metrics for water quality improvement.

Table 11-9. Summary of Metrics: Monetizing Benefits and Impacts.

Row	Description	Units of Measurement	Notes and Relationship to Other Metrics
13	Flood damage costs without proposed project	Annual avoided damage in 2015$	Expected annual flooding damage avoided. This metric links to physical flood control metrics
14	Emergency response costs without proposed project	Annual avoided damage in 2015$	Emergency response costs, including value of lost water supply, avoided. This metric links to physical emergency response metrics
Benefits Quantified as Willingness-to-Pay			
15	Water supply or flow	Annual benefit in 2015$	Quantity multiplied by market price of water or by unit values, or estimated using other economic models. This metric links to physical metrics for water supply or flow.
16	Other habitat	Annual benefit in 2015$	Amount multiplied by market price, or estimated using other economic models of these habitat types. This metric links to physical metrics of habitat.
17	Ecosystem services of habitat, by specific service	Annual benefit in 2015$	Economic value of ecosystem service provided by flow or habitat types, summed over the services provided. This metric links to physical metrics of habitat.
18	Commercial use values for fish	Annual benefit in 2015$	Amount caught multiplied by market price of commercial fish less costs. This metric links to physical metrics of salmonid abundance or catch.
19	Recreation use values for fish	Annual benefit in 2015$	Number of fish multiplied by value using unit day values. This metric links to physical metrics of abundance or catch for any recreational fishery.
20	Recreation use values for reservoirs and associated uses, by category	Annual benefit in 2015$	Number of visitor-days by category multiplied by unit day values. This metric links to physical metrics of recreation features and visitation.
21	Total economic values for native fish	Annual benefit in 2015$	New contingent valuation or benefits transfers study; or value using values provided in Section 5.4.2.3 This metric links to physical metrics of abundance or habitat of native fish.

Notes:

- Provide estimates for 2030 and 2070 conditions, with- and without-project, over hydrologic period or by water year type or hydrologic condition as applicable.
- Water year type shall be based on either the Sacramento River 40-30-30 index or San Joaquin River 60-20-20 index, depending on the study area location.
- Annual values shall represent the average across water year type (or other way to display variable hydrologic conditions), accounting for the probabilities of occurrence and the physical and economic values associated with the water year types.

Table 11-10. Summary of Metrics: Costs, Benefit/Cost, Cost Allocation, and Public Benefit Ratio.

Row	Description	Units of Measurement	Notes and Relationship to Other Metrics
Project Costs			Include all costs and benefits over the expected life of the project. All costs and benefits must be in 2015 dollars, expressed in present value terms at the expected start of project operations using the discount rate of 3.5 percent. Interest during construction is the interest on capital expenditures between time of expenditure and start of operations.
1	Capital costs (see text for definition)	PV in 2015$	
2	Interest during construction	PV in 2015$	
3	Replacement costs	PV in 2015$	
4	Future mitigation costs	PV in 2015$	
5	Operations, maintenance and repair (OM&R) costs	PV in 2015$	
6	Present value of all project costs	PV in 2015$	
Project Benefits			
7	Present value of each project benefit category	PV by benefit in 2015$	
8	Present value of all project benefits	PV in 2015$	
9	Present value of all public benefits	PV in 2015$	
Project Performance Metric			
10	Benefit/cost ratio of project	Ratio	PV of all project benefits divided by PV of all project costs
Financial Feasibility			
11	Cash revenues and outlays over time	Annual $ by year	Shows that the project will be financially solvent over its life
Cost-Effectiveness			
12	Project Alternative Cost - The cost of achieving all project benefits by the lowest-cost, feasible alternative means		
13	Cost-effectiveness criterion	PV in 2015$	Project alternative cost minus proposed project cost This metric will be positive for a cost-effective project
Cost Allocation and Public Benefit Ratio			
14	Specific or separable cost assigned to each benefit category	PV by benefit in 2015$	Purpose-specific costs or separable costs from cost engineering, if applicable
15	Joint cost	PV in 2015$	Proposed project cost minus sum of specific and separable costs. All costs are joint costs if using s simple proportional allocation.
16	Proposed allocation of joint cost to each benefit category	PV by benefit in 2015$	Calculation depends on allocation method

Table 11-10. Summary of Metrics: Costs, Benefit/Cost, Cost Allocation, and Public Benefit Ratio.

Row	Description	Units of Measurement	Notes and Relationship to Other Metrics
17	Proposed allocation of total cost to each benefit category	PV by benefit in 2015$	Specific and separable costs plus allocated joint cost For each benefit category, total allocated cost should be less than benefit
18	Public funding requested for each benefit category	PV by public benefit in 2015$	For each benefit category and in total, public funding requested shall not exceed the cost allocated to that category. Funding request cannot exceed 50 percent of capital costs and ecosystem funding requested must be at least half of the total funding requested
19	Public benefit ratio	Ratio	PV of public benefits divided by total public funding request Note that this ratio minus 1 is the percentage by which monetized public benefit exceeds the requested public investment

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SECTION 12

Glossary

Alternative cost. The cost of the lowest-cost, feasible alternative to providing a physical benefit provided by a proposed project.

Applicant. The entity(ies) that formally submits an application for funding.

Application. The information submitted to the Commission that is outlined in the application process in section 6003 of the regulations.

Average water deliveries. The average annual quantity of water delivered for the entire period of the hydrologic record used in the water operations analysis.

Avoided cost. The reduction in a without-project future condition cost that would occur as a result of a proposed project.

Benefit categories. The public benefits and non-public benefits provided by a water storage project. Non-public benefits include water supply for agricultural, urban, and industrial uses and hydropower production.

CALFED. CALFED Bay-Delta Program developed by a consortium of state and federal agencies with management and regulatory responsibilities in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary through the CALFED Bay-Delta Program, which by means of the final programmatic environmental impact statement/environmental impact report, identified the preferred programs, actions, projects, and related activities that would provide solutions to the San Francisco Bay/Sacramento-San Joaquin Delta Estuary ecosystem, including the Bay-Delta and its tributary watersheds.

CALFED surface storage projects. Projects meeting the requirements of Water Code Section 79751(a). For the purposes of the WSIP, this includes Los Vaqueros Reservoir Expansion, In-Delta Storage Project, Sites Reservoir, and Temperance Flat.

CEQA. The California Environmental Quality Act (Public Resources Code Section 21000 et seq).

Commission. The California Water Commission.

Conjunctive use project. The coordinated and planned management of existing surface water and groundwater resources in order to maximize the efficient use of both resources. Conjunctive use projects may include development of new operational agreements and construction of appurtenant infrastructure. To be considered for a maximum project cost share exception, pursuant to Water Code Section 79756(a), these projects shall use existing facilities and resources to the maximum extent practicable. Conjunctive use projects do not include those that meet the definition of groundwater storage projects.

Constant dollar year. The year to which all dollar values are adjusted for inflation so the values can be compared.

Contaminant. Substance that impairs water quality.

Cost-effectiveness. A demonstration that a proposed project's cost is the least-cost feasible means of providing the same or greater amount of benefit. Cost-effectiveness can apply to the project as a whole (total costs to provide the full set of benefits) or to an individual public benefit relative to the WSIP cost share for that public benefit.

Cost allocation. The process for assigning project costs to benefit categories.

Current condition. Current condition is defined as the CEQA existing condition for a proposed project.

CWA 303(d) List. The list of impaired water bodies developed by the State Water Resources Control Board and approved by the United States Environmental Protection Agency, as it may be amended from time to time, prepared pursuant to Section 303(d) of the Federal Water Pollution Control Act Amendments of 1972 (codified at Title 33 of the United States Code in Section 1313(d)) The list identifies water bodies that do not meet, or are not expected to meet, water quality standards.

Dataset. Structured numerical information, derived from reference data sources, outputs of other models, or assumptions, that is used as input to implement quantification methods or calculate metrics.

Delta. The Sacramento-San Joaquin Delta as defined in Water Code Section 85058.

Delta outflow. The Net Delta Outflow Index as identified in the State Water Board's "Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary" (December 2006).

Discount rate. The real interest rate (i.e., the rate without inflation) used to adjust constant dollar benefits received or costs incurred during the planning horizon to dollars at a common point in time.

Dry and critical years average water deliveries. The average annual quantity of water delivered during the dry and critical years, as defined by the water year type index most appropriate for the location of the proposed project, in the hydrologic record used in the water operations analysis.

Ecosystem improvements. A public benefit that includes changing the timing of water diversions, improvement in flow conditions, temperature, or other benefits that contribute to the restoration of aquatic ecosystems and native fish and wildlife, including those ecosystems and fish and wildlife in the Delta, per Water Code Section 79753(a)(1). Ecosystems include both aquatic and terrestrial habitats and natural communities.

Emergency response. Has the same meaning as Water Code Section 79753(a)(4), which is a public benefit that provides an amount of water storage or supply for emergency response purposes that are outside of normal facility operations or average water supply for all other purposes (i.e., water supply is reduced for the expected (average) amount of water used for emergency purposes). For the purposes of this Program, emergency response water provided for human health and safety purposes during declared emergencies will be considered a public benefit under this category.

Entrainment. Fish being transported along with the flow of water into unnatural or harmful environments.

Environmental documentation. Documentation required for compliance with CEQA as defined in Title 14 of the California Code of Regulations in Section 15361.

Existing condition. The level of development, infrastructure, population, land use, water use, climate, and all other relevant factors including operations plans, laws, and regulations that are in place in the current or a very recent year, as required for a proposed project’s CEQA analysis, normally stated as a calendar year.

Flood control benefit. Has the same meaning as Water Code Section 79753(a)(3), which is a public benefit that reduces or prevents the extent or magnitude of the expected detrimental effects of flooding as a result of new, expanded, or reoperated storage projects.

Flow regimes. Flow conditions that retain specific process-based components that support geomorphic or ecological functions for the streams and rivers. Ecological functions are the biological, chemical, and physical structural components of an ecosystem and how they interact with each other.

Future condition. The level of development, infrastructure, population, land use, water use, climate, and all other factors including operations plans, laws, and regulations that are projected to occur in the future, normally stated as a particular year in the planning horizon. “Future condition year” means a specific year in the project’s planning horizon for which the WSIP requires quantification. These are the years 2030 and 2070.

Groundwater contamination prevention project. A project that provides water storage benefits and prevents groundwater contamination by eliminating or reducing sources of contamination; prevents seawater intrusion through the use of seawater or hydraulic barriers; prevents the migration of contaminants into down gradient groundwater basins or aquifers; or otherwise prevents groundwater contaminant plumes from expanding or spreading. Contamination means an impairment of the quality of the groundwaters of the state.

Groundwater dependent ecosystem. Has the same meaning as California Code of Regulations, Title 23, section 351(m).

Groundwater remediation project. A project that provides water storage benefits and removes or reduces one or more constituents resulting from a discharge or release of waste that has degraded groundwater quality or impaired beneficial uses, or a project that restores groundwater basin storage or storage capacity by reducing constituent concentrations below levels that impair beneficial uses of the groundwater.

Groundwater storage project. A designed project that captures, infiltrates, injects, or recharges (direct or in-lieu) water supplies into a groundwater basin for later use or to avoid or address undesirable groundwater results.

Hydrologic record for analysis. A period of historical years chosen for the analysis that has continuous hydrologic information such as precipitation, inflows, storage, flows, water diversions, and/or water consumption available.

Internal rate of return. The discount rate at which the present value of a public benefit's monetized benefit is equal to the present value of the state's cost share requested for that public benefit.

Level of development. Description of water demands based on population, land and water use patterns, water rights, and contracts at a point in time.

Local surface storage project. A project that stores water above ground in a natural or artificial impoundment that improves the operation of water systems in the state and provides public benefits. Local surface storage projects are not wholly owned or operated by the Department or U.S. Bureau of Reclamation but rather by a local agency.

Long-term planning analysis. Description of the water resources system over a long period of record (historical sequence) using projected condition inputs and considering potential changes to facilities, standards, and operations.

Magnitude of improvement. The quantity of the improvement.

Measurable improvements. Changes in physical, chemical, or biological conditions that provide public benefits and can be quantified at a specific location and time.

Method. A quantitative, qualitative, or combined approach to determining physical or monetized changes based on a set of assumptions and datasets.

Metric. A quantitative or qualitative measure of physical change between with-project and without-project conditions; each metric is specific to a type of physical change considering location, time period, units, and other attributes.

Model. A standardized and accepted quantitative method, based on procedures, computer algorithms/codes, and standard input datasets; often linked to other models and may require user interaction; may be tailored for application to a specific project analysis.

Net improvement. The gain or enhancement of a resource condition determined by comparing the with- and without-project future conditions less any negative outcomes of a proposed project.

Non-public benefit. A benefit provided by a proposed project other than the public benefits identified in Water Code Section 79753(a)(1-5).

Operations. Any decision or action, purposeful or incidental, to control or regulate the free flow of water by diverting to, impounding in, or releasing from a surface or groundwater storage or other facility(ies).

Permits. Any federal, state, or local approvals, certifications, or agreements required to construct, implement, or operate a project.

Physical benefit. A desired improvement in a good or service that is provided by a proposed project, measured in a physical, non-monetary unit.

Physical change. Expected change in: surface water and groundwater operations; water flow, Delta and riverine conditions; surface water and groundwater quality; aquatic and terrestrial biological resources; energy resources; recreation resources; or other resources affected by the change in diversion, storage, or use of water created or caused by a proposed project.

Planning horizon. The future time period, in years, over which project costs will be paid and benefits received, normally based on the expected project life plus the construction period. The planning horizon may not exceed the expected life of the project facilities plus the construction period, or 100 years, whichever is less.

Plug flow. A way to describe or model flow in a pipe that assumes the velocity of the fluid is constant across the cross section of the pipe.

Pollutant. Substance that alters water quality to a degree that unreasonably affects the waters for beneficial uses, or the facilities that serve those beneficial uses.

Potentiometric surface. An imaginary surface above the aquifer, to which water from an artesian aquifer would rise in a pipe.

Present value. The monetary value of future costs or future benefits of a proposed project, converted to a common point in time using the discount rate. As used in this document, present values of costs or benefits of a project are expressed at the start of a proposed project's operation, unless otherwise specified.

Projected condition. A set of estimates of hydrology, land and water use, water quality, ecosystem attributes, or other inputs for analysis of the water resources system (hydrology of potential climate change is addressed through sensitivity analyses discussed in Section 10, Evaluating Sources of Uncertainty.

Public benefit ratio. For purposes of this document, the ratio of the present value of the monetized net public benefits to the total requested Program cost share.

Public benefits. For purposes of this document, includes those public benefits provided in Water Code Section 79753(a).

Ramping rate. A progressive change in the discharge of water to a stream or river channel, measured as flow per unit time.

Real dollars. Dollar values from different years adjusted for inflation so they are comparable.

Recommendation. Non-mandatory technical guidance to applicants regarding with- and without-project conditions, methods, and metrics.

Recreational purpose. A public benefit that provides recreation activities typically associated with water bodies (such as rivers, streams, lakes, wetlands, and the ocean) and wildlife refuges that are accessible to the public. Recreational benefits must be directly affected by the proposed project and be open to the public, and may provide interpretive, educational, health, or intrinsic value.

Reservoir reoperation project. A project that involves the modification of the operations of an existing surface storage reservoir to achieve public benefits. A reservoir reoperation project may include construction of appurtenant infrastructures such as spillways, radial gates, tunnels, or conveyance facilities necessary for the improved operation of the existing reservoir. Such projects must result in long-term operational changes that provide public benefits, and operational changes must be documented in a facility’s operating permits and the contracts with entities responsible for managing and monitoring the public benefits.

Resilience to the effects of climate change. The flexibility a proposed project will have to adapt to hydrologic variability, sea-level rise, and other effects of climate change to ensure provision of public benefits.

Separable cost. Total project costs less total cost of the same project, but with one benefit category removed.

Spatial distribution. The geographical arrangement of a habitat, phenomenon, or species in a given area.

Spatial resolution. The minimum length, area, or volume of an affected physical resource necessary to demonstrate and describe benefits or impacts.

Spatial scale. The geographical extent of an improvement.

Specific cost. A cost of project features that is clearly just for one benefit category.

State water system. All of the state's water systems collectively, including local, regional, state, and federal systems that provide water resources benefits within California, regardless of whether the benefits are public or nonpublic.

Temporal distribution. The time of year or season in which an improvement will occur.

Temporal resolution. The minimum time necessary to demonstrate and describe benefits or impacts. For a model, it is the unit of time (e.g., monthly, daily) at which the model operates and calculates results.

Temporal scale. As used in the regulation, it is the time in the calendar year during which an improvement action will be implemented. For some quantification methods described in this Technical Reference, it may also indicate the duration of time covered by a modeling analysis.

Threshold. In the context of adaptive management, a numerical value for a specific metric that is a boundary between acceptable and unacceptable situations or conditions, or a specific metric that must be exceeded for a certain reaction, result, or condition to occur.

Tributaries to the Delta. All river systems that make up the Sacramento River watershed and the San Joaquin River watershed (i.e., the topographic hydrologic basins). Tributaries to the Delta include areas upstream of dams or other impoundments. Tributaries to the Delta do not include the Trinity River watershed or the Tulare Lake Basin.

Trigger. Used in the context of adaptive management, it is an event, situation, or measurement that initiates or requires a management action.

Undesirable result(s). With respect to groundwater, it has the same meaning provided in Water Code section 10721(wx)(1-6).

Water quality improvements. A public benefit that includes water quality improvements that provide significant public trust resources in the Delta or in other river systems, or water quality improvements that clean up or restore groundwater resources, per Water Code section 79753(a)(2). Public trust resources related to water quality improvements, for the purposes of this program and quantifying public benefits, mean fishery protection, fish and wildlife conservation, preservation of waterways in their natural state, and recreation. Water quality improvements in the Delta, or in other river systems, that provide these public trust resources are public benefits.

Willingness-to-pay. A monetary measure of what Californians would be willing to relinquish for a quantity of a good or service if there were no alternative means of obtaining that same quantity.

With-project future conditions. A quantitative and qualitative description of the conditions assumed at the future condition years, 2030 and 2070, with a proposed project; it is based on the without-project future conditions and includes additions or modifications specific to the proposed project's description and operations.

Without-project future conditions. A quantitative and qualitative description of the infrastructure, population, land use, water use, water operations, agreements, laws, regulations, climate and sea-level conditions, and other characteristics relevant to the proposed project that are assumed at the future condition years, 2030 and 2070, without a proposed project.

SECTION 13

References

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Available at: http://www.water.ca.gov/waterplan/cwpu2013/final/index.cfm

Sections of interest include:

- Volume 2 Regional Reports: DWR hydrologic region water usage by type (i.e., surface water and groundwater)
- Volume 3 Resource Management Strategies:
  - Conjunctive Management and Groundwater
  - Groundwater/Aquifer Remediation
- California's Groundwater Update 2013: http://www.water.ca.gov/waterplan/topics/groundwater/index.cfm

Water Level Data for Model Calibration (Not Exhaustive)

- DWR's Water Data Library: http://www.water.ca.gov/waterdatalibrary
- USGS' National Water Information System: http://maps.waterdata.usgs.gov/mapper/index.html

DWR Groundwater Information Center and Interactive Maps

- http://www.water.ca.gov/groundwater/
- https://gis.water.ca.gov/app/gicima

DWR Sustainable Groundwater Management Program

- http://www.water.ca.gov/groundwater/sgm/index.cfm

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Appendix A
Climate Change and Sea-Level Rise

Climate Change and Sea-Level Rise Methods

Growing evidence indicates that Earth's atmosphere is warming. Observed changes in oceans, snow and ice cover, and ecosystems are consistent with this warming trend (National Academy of Sciences, 2006; Intergovernmental Panel on Climate Change [IPCC], 2007, 2013). The temperature of Earth's atmosphere is directly related to the concentration of atmospheric greenhouse gases (GHGs). Growing scientific consensus suggests that climate change will occur as the result of increased concentrations of GHGs (IPCC, 2007, 2013). While consensus exists regarding the observed global warming trend, uncertainty remains regarding regional projections of future temperature and precipitation.

This appendix provides detailed information on methods used to develop climate and sea-level projections at two reference points: 2030 (near future) and 2070 (late future) as required by regulations for the Water Storage Investment Program (WSIP). This document describes in detail the steps followed, from spatial downscaling of climate data to running the CalSim-II Water Resources Simulation Model (CalSim-II) and Delta Simulation Model II (DSM2) models to represent conditions under future climate conditions. Figure A-1 shows the dataset development and modeling sequence.

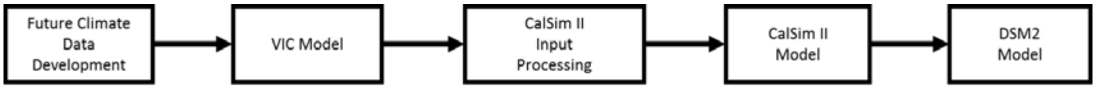

Figure A-1. Dataset Development and Modeling Sequence

Climate Scenarios Development Process

As described in the Technical Reference Document, the climate projections for 2030 and 2070 conditions were derived from the ensemble of 20 global climate projections selected by the California Department of Water Resources (DWR) Climate Change Technical Advisory Group (CCTAG) as the most appropriate projections for California water resources evaluation and planning (DWR CCTAG, 2015). The 20 climate projections, listed in Table 2-5 of the Technical Reference Document, were generated from 10 global climate models run with two emission scenarios, one optimistic (Representative Concentration Pathway [RCP] 4.5) and one pessimistic (RCP 8.5), identified by the IPCC for the Fifth Assessment Report (AR5) (2014).

Scripps Institution of Oceanography downscaled the 20 climate projections using the localized constructed analog (LOCA) method at 1/16th degree (approximately 6 kilometers [km], or approximately 3.75 miles) spatial resolution (Pierce et al., 2014).

The climate projections for 2030 and 2070 future conditions were derived using a quantile mapping approach that adjusts changes in temperature and precipitation using cumulative distribution functions created from the 20 downscaled global climate model projections. Adjusted temperature and precipitation time series for 2030 and 2070 future conditions were used as input to the Variable Infiltration Capacity (VIC) hydrologic model to generate projections of future streamflows. Future streamflow and sea-level rise (SLR) projections were used as inputs to CalSim-II and DSM2 to generate projections of future State Water Project (SWP) and Central Valley Project (CVP) performance and Sacramento–San Joaquin Delta (Delta) conditions. The primary procedures for each step in the scenario development process are described in the following sections.

Spatial Downscaling of Global Climate Models using LOCA

Development and application of global climate models is a continuously advancing research area. However, to date, the resolution of the output data produced by global climate models is too coarse to assess impacts at a watershed scale. Thus, global climate model data from Coupled Model Intercomparison Project 5 (CMIP5) simulations is scaled to a finer resolution, or downscaled, in order to translate macro-scale climate changes that are either observed or identified in climate models to changes in meteorological parameters at a local scale.

Spatially downscaled data using the LOCA method was obtained from the Scripps Institution of Oceanography. It is one of the statistical downscaling methods that involve relating the statistical properties of observed meteorological measurements at various stations to broader climate parameters at a global climate model-scale. This relationship, based on historical observations, is used as a mapping function when spatially downscaling projected climate conditions. This downscaling method is also being used for analysis being done for California’s Fourth Climate Change Assessment.

The LOCA method uses future climate projections combined with historical analog events to produce daily downscaled estimates of surface meteorological fields (minimum and maximum temperatures and precipitation). Developed by researchers at the Scripps Institution of Oceanography (Pierce et al., 2014), this spatial downscaling method includes a bias-correction process of the coarse-resolution global climate model daily temperature and precipitation fields prior to the spatial downscaling. A key feature of this bias correction is that it preserves the original global climate model-predicted change in temperature and precipitation, unlike other commonly used bias correction methods that alter the original model-predicted change in unexpected ways (Pierce et al., 2015).

Table A-1 provides summary statewide temperature and precipitation statistics for each downscaled climate projection.

Table A.1 Projected Changes in Statewide Conditions for each Model and RCP Combination, Representing Climate Periods 2016 to 2045 and 2056 to 2085, with Respect to Reference Period 1981 to 2010.

Scenarios	Climate Period 2016-2045, with Respect to Reference Period 1981 to 2010		Climate Period 2056 to 2085, with Respect to Reference Period 1981 to 2010	
	Average Precipitation Change (%)	Average Temperature Change (°F)	Average Precipitation Change (%)	Average Temperature Change (°F)
RCP 4.5 Scenarios				
ACCESS1-0_rcp45	-1.2	2.3	13.9	4.5
CCSM4_rcp45	-4.1	2.0	1.2	3.3
CESM1-BGC_rcp45	0.4	1.9	8.3	2.9
HadGEM2_CC_rcp45	-3.6	2.1	8.9	4.6
CMCC-CMS_rcp45	2.2	2.2	-4.8	4.0
CNRM-CM5_rcp45	21.6	1.5	22.2	3.5
CanESM2_rcp45	4.7	2.8	19.3	4.8
GFDL-CM3_rcp45	1.7	2.7	0.0	4.9
HadGEM2_ES_rcp45	-1.0	2.4	-5.8	5.4
MIROC5_rcp45	-1.6	2.2	-12.1	4.1
RCP 8.5 Scenarios				
ACCESS1-0_rcp85	0.9	2.8	-14.5	6.6
CCSM4_rcp85	-0.4	2.5	9.0	5.3
CESM1-BGC_rcp85	5.6	2.0	10.8	5.4
HadGEM2_CC_rcp85	0.4	3.0	-3.5	7.9
CMCC-CMS_rcp85	4.5	2.3	1.4	6.3
CNRM-CM5_rcp85	23.8	1.8	26.1	6.0
CanESM2_rcp85	2.4	3.1	35.9	7.2
GFDL-CM3_rcp85	-3.2	3.0	2.4	7.2
HadGEM2_ES_rcp85	4.2	3.0	-6.9	8.3
MIROC5_rcp85	-7.0	2.7	-4.3	5.5

Key:
% = percent
°F = degree Fahrenheit

Quantile Mapping Functions

Once spatially downscaled data was obtained for the 20 climate projections, cumulative distribution functions (CDFs) were produced for monthly temperature and monthly precipitation for the reference historical period (1981-2000) and each of the future climate periods (2016-2045 and 2056-2085) for the ensemble of the 20 climate projections at each of the 11,368 grid cells across the state (for a total of 818,496 CDFs). The CDFs were developed such that the entire probability distribution (including means, variance, and skew) at the monthly scale was transformed to reflect the mean of the 20 climate projections.

The reference historical period CDFs and future climate period CDFs were quantile mapped to determine the amount of change that would occur between the historical reference period and future climate period at each quantile.

Observed daily historical meteorology data from Livneh et al. (2013) at 1/16th degree (approximately 6 km, or 3.75 miles) spatial resolution were used as the reference meteorological data and were adjusted with the change factors created from the quantile mapping procedure. The quantile mapping procedure is explained in the steps following Figure A-2, which is a conceptual representation of the use of quantile maps.

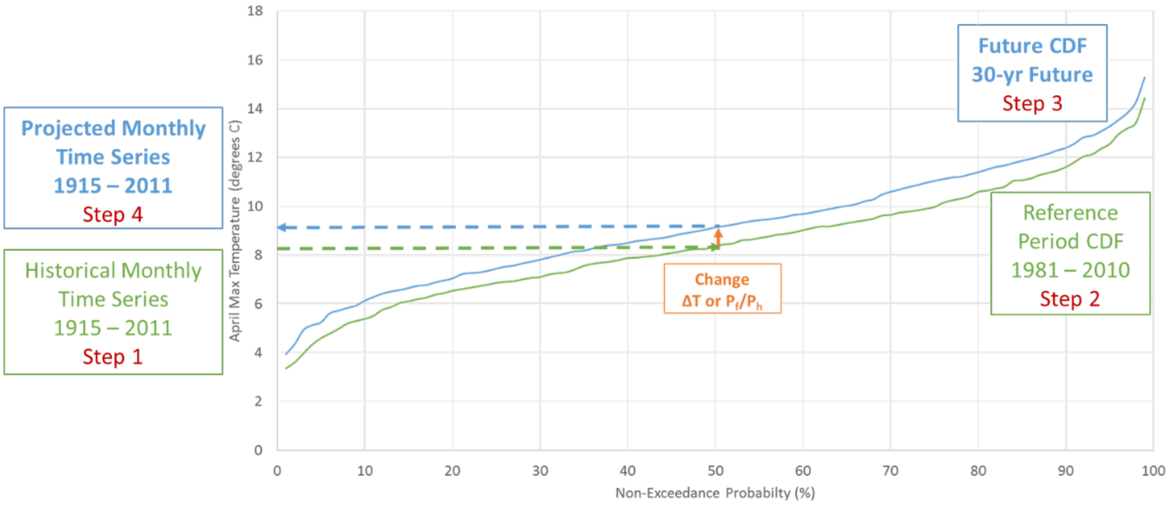

Figure A-2. Develop Climate Input Development Steps

Step 1: Development of Detrended Historical Monthly Time Series

Prior to using the historical record from Livneh et al. (2013) for quantile mapping, historical temperature data over the period 1915-2011 (centered around Year 1995) was 'anchored' (i.e., detrended) to 1981-2010.

These steps were followed to anchor the temperature data to the 1981-2010 climatological average:

1. Calculate monthly averages from daily data over the period 1915-2011.
2. Compute linear trend for each month (e.g., January, February, …, December) (time series for each month).
3. Remove the month-specific trend from the daily data. This results in a sequence of daily residuals.
4. Calculate monthly climatologies for 1981-2010 (i.e., the mean of all Januaries, the mean of all Februaries, and so on, from the values computed in Step 1).
5. Add the daily residuals calculated in Step 3 to the monthly climatology calculated in Step 4.

This approach was used for daily maximum temperature (T_{max}) and daily temperature range (DTR), and daily minimum temperature was estimated as:

$$T_{max} - DTR$$

Step 2: Development of a Mean Model-Simulated Reference Period CDF from 20 Climate Projections

To form a mean CDF representing model-simulated reference period conditions from all 20 climate projections, a 30-year slice of climate model data (precipitation, and maximum and minimum temperatures) was extracted from each of the 20 downscaled climate model simulations centered on the model-simulated reference period (i.e., 1995: 1981-2010).

For each calendar month (e.g., January) of the model-simulated reference period (1981-2010), the CDF for each climate model projection of temperature and precipitation at each grid cell was determined. There are 30 values over 30 years of reference period (e.g., for 1981-2010, one value from each year) to construct one CDF for each climate model projection. There are 20 CDFs from 20 climate model simulations.

The mean value for each quantile of the 20 CDFs was computed to form a mean model-simulated reference period CDF.

Step 3: Development of a Mean Future CDF from 20 Climate Projections

To form a mean CDF that represents simulated future conditions from all 20 climate projections, a 30-year slice of downscaled climate data (precipitation, and maximum and minimum temperatures) was extracted from each of the 20 downscaled climate model simulations centered on a future year of investigation (i.e., 2030: 2016-2045 and 2070: 2056-2085). The mean value for each quantile of the 20 CDFs was computed to form a mean simulated future CDF.

For each calendar month (e.g., January) of the future period, the statistical properties (CDF) for each climate model projection of temperature and precipitation at each grid cell was determined. There are 30 values over 30 years of future period (e.g., for 2016-2045, one value from each year) to construct one CDF for each model projection. There are 20 CDFs from 20 climate model simulations.

The mean value for each quantile of the 20 CDFs was computed to form a mean simulated future CDF.

Step 4: Development of Future Climate Change Time Series

To develop a time series of climate parameters representative of future conditions, the change was calculated as the ratio (future period divided by reference period) for precipitation and change in temperature, resulting in ‘deltas’ (future period temperature minus reference period temperature) for each quantile from the reference period and future period mean CDFs.

Using these ratios and deltas, and historical precipitation and detrended temperature data obtained from Step1, a monthly time series of temperature and precipitation at 1/16th degree (approximately 6 km, or 3.75 miles) over 1915-2011 that incorporates the climate shift of the future period was developed.

Tables 2-4 and 2-6 in Section 2.12.2 of this Technical Reference Document and Figure A-3 display the magnitude and direction of change in precipitation and temperature at each future climate condition and for each Hydrologic Unit Code-6 (HUC6) watershed within California. The average changes for the 2030 and 2070 future conditions are the results from Step 4 for 1915-2011 that incorporates the climate shift, based on the ensemble of all 20 models. The average changes for the extreme levels of climate change, represented by climate models HadGEM2-ES RCP 8.5 and CNRM-CM5 RCP4.5, are the estimated change based on the average of the deltas for those individual GCMs from Step 3.

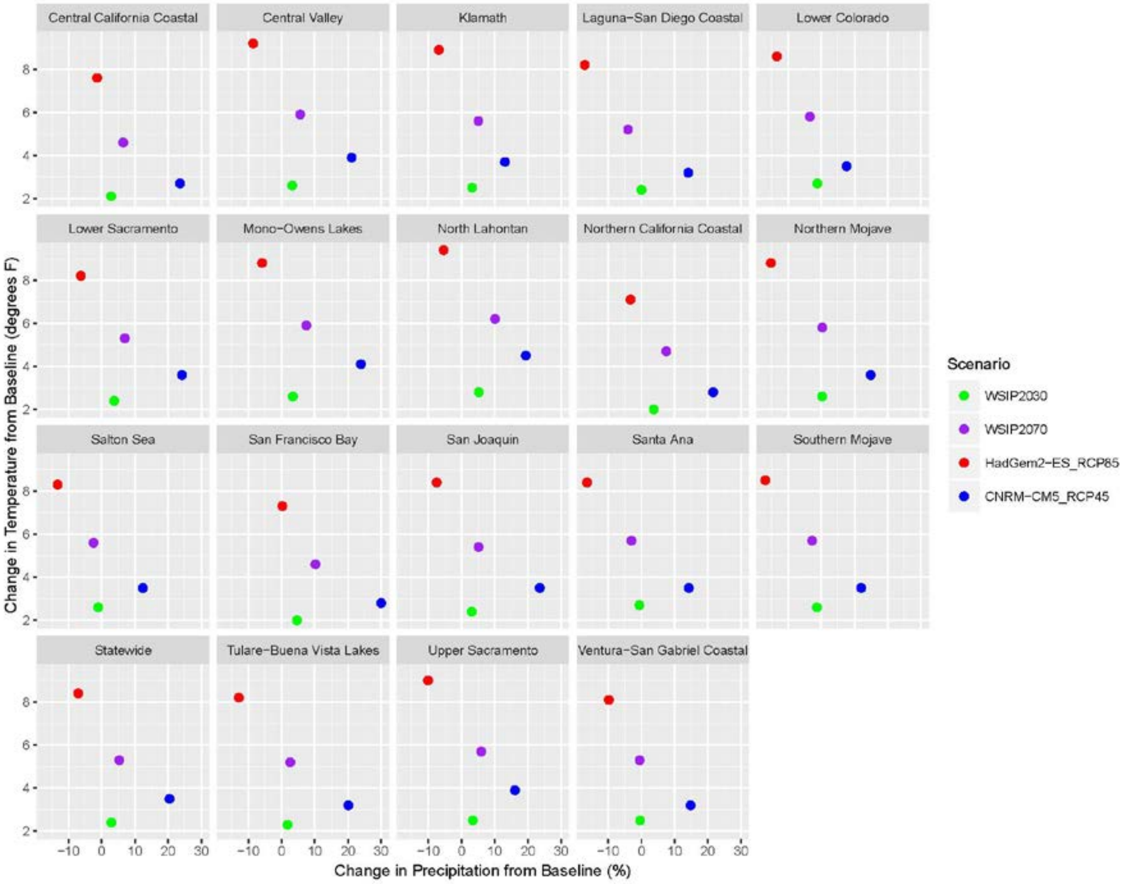

Figure A-3. Percent Change in Precipitation and Temperature Across Scenarios.

Rainfall-Runoff Modeling Using the VIC Model

The VIC Model (Liang et al., 1994, 1996; Nijssen et al., 1997) simulates land-surface-atmosphere exchanges of moisture and energy at each model grid cell. The VIC Model incorporates spatially distributed parameters describing topography, soils, land use, and vegetation classes. It accepts input meteorological data directly from global or national gridded databases or from global climate model projections. To compensate for the coarseness of the discretization, VIC is unique in its incorporation of sub-grid variability to describe variations in the land parameters, as well as precipitation distribution. Figure A-5 shows the hydrologic processes included in the VIC Model.

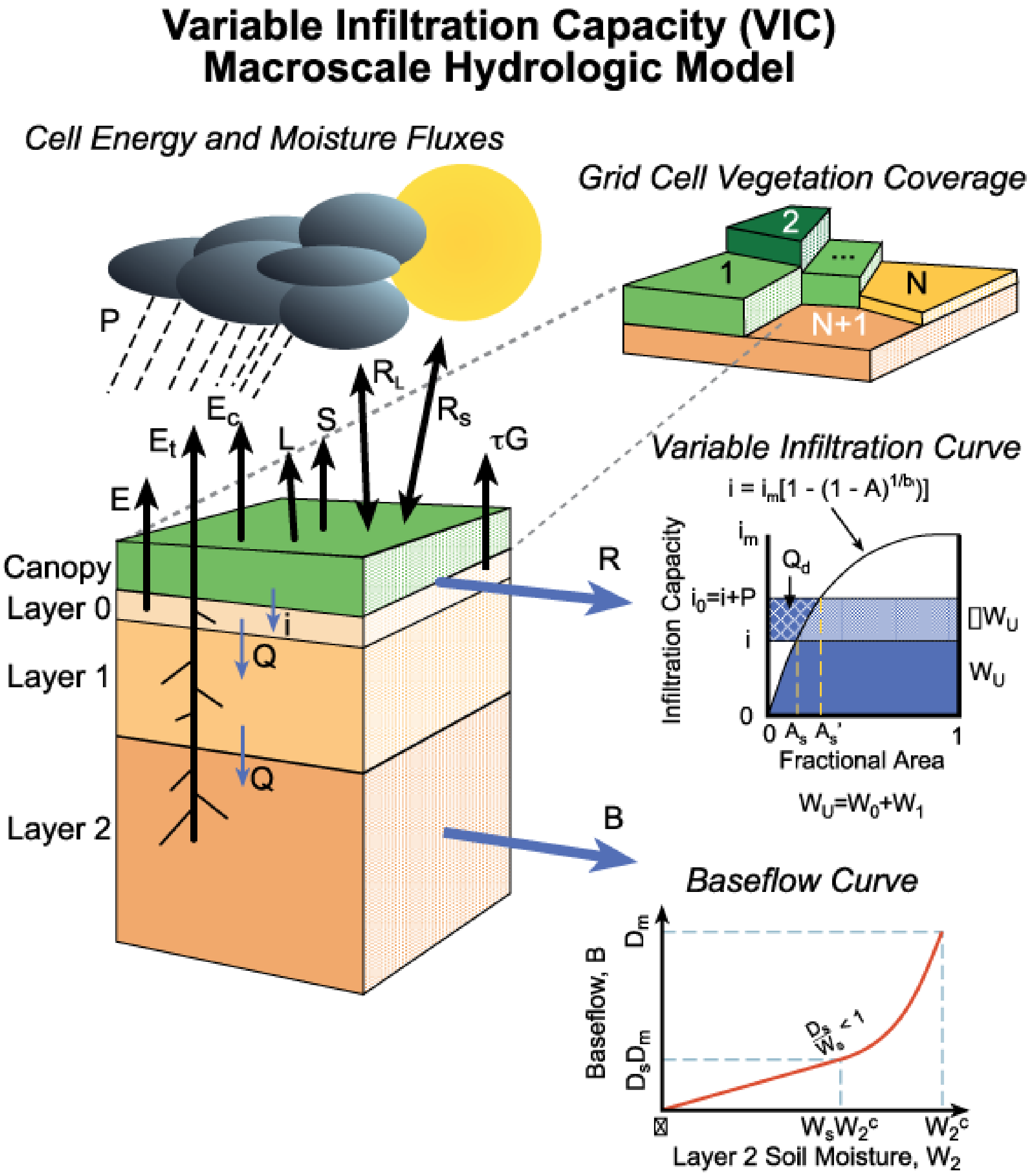

Figure A-5. Hydrologic Processes Included in the VIC Model

Source: University of Washington, 2016

The VIC Model has been applied to many major basins in the United States (U.S.), including large-scale applications to the following:

- California's Central Valley (Liang et al., 1994; Maurer et al., 2002, 2007; Maurer, 2007; Hamlet and Lettenmaier, 2007; Barnett et al., 2008; Cayan et al., 2009; Raff et al., 2009; Dettinger et al., 2011a, 2011b; Das et al., 2011a, 2013; DWR, 2014; Bureau of Reclamation [Reclamation], 2014)
- Colorado River Basin (Christensen and Lettenmaier, 2007; Das et al., 2011b; Vano and Lettenmaier, 2014; Vano et al., 2012, 2014)
- Columbia River Basin (Hamlet and Lettenmaier, 1999; Hamlet et al., 2007)
- Several other basins (Maurer and Lettenmaier, 2003; CH2M HILL, 2008; Livneh et al., 2013)

VIC Model Application for the WSIP

The VIC Model has been configured at 1/16th degrees (approximately 6 km, or 3.75 miles) spatial resolution throughout California. Improvements by Livneh et al. (2013) were used as a preliminary dataset in the VIC Model setup. Parameterization within the model is performed primarily through adjustments to parameters describing the rates of infiltration and base flow as a function of soil properties, as well as the soil layer depths. When simulating in water balance mode, as done for this California application, the model is driven by daily inputs of precipitation, maximum and minimum temperature, and wind speed. The model internally calculates additional meteorological forcings, such as short- and long-wave radiation, relative humidity, vapor pressure, and vapor pressure deficits.

Five elevation bands are included for each 1/16th degree (approximately 6 km, or 3.75 miles) grid cell in the VIC Model to capture the precipitation and snow variability over the grid cell. In addition, the model includes a sub-daily (1-hour) computation to resolve transients in the snow model. The soil column is represented by three soil zones extending downward from the land surface to capture the vertical distribution of soil moisture. The land cover is represented by multiple vegetation types.

Rainfall, snow, infiltration, evapotranspiration, runoff, soil moisture, and base flow are computed over each grid cell on a daily basis for the entire period of simulation. The VIC Model routing tool processes the individual cell runoff and base flow terms, and routes the flow to develop streamflow at various locations in the watershed.

Although the VIC Model contains several sub-grid mechanisms, the coarse grid scale should be noted when considering results and analysis of local-scale phenomenon. The VIC Model is currently best applied for regional-scale hydrologic analyses. The model is reasonable for capturing flow changes in the larger watersheds in the basin, but may have bias at smaller scales due, primarily, to model resolution.

VIC Model Watershed Delineation and Routing Network

A streamflow routing network in the VIC Model at 1/16th degree (approximately 6 km, or 3.75 miles) was developed using ArcMap's Flow Direction and Flow Accumulation tools. The Flow Direction tool first assigns the flow direction for each VIC Model grid cell to its steepest downslope neighbor. Prior to processing the VIC Model grid through this tool, a stream network shapefile was burned into the digital elevation model (DEM) to enhance the performance of the flow direction tool by increasing the slope toward the closest stream. The VIC Model also requires that flow from each grid cell be directed out of the cell and into another one, and is unable to process sinks. Sinks in the DEM were filled to accommodate this. The Flow Accumulation tool then creates a raster dataset of accumulated flow to each cell by accumulating the number of all upstream cells that flow into each downslope cell.

Once the VIC Model grid is processed through these two tools, watershed delineations were determined based on downstream U.S. Geological Survey (USGS) gage locations and were compared to USGS watershed boundaries. Due to the topographic complexity of the high-elevation regions and the coarseness of the VIC Model grid, adjustments were made to the model watershed delineations to more accurately align with USGS watershed boundary delineation.

VIC Model Calibration

The existing VIC Model had previously undergone only limited calibration for monthly streamflow for selected major river basins over the conterminous U.S. (Livneh et al., 2013). For WSIP application, further VIC Model calibration was performed for the 12 upper watershed locations in the Sacramento and San Joaquin River basins. The VIC Model was recalibrated for water years 1970-2003.

Daily VIC Model simulations were performed from 1915 to 2011. The daily runoff and base flow simulated from each grid cell was routed to various river flow locations. For the simulations performed for this application, streamflow was routed to the necessary river flow locations for CalSim-II modeling throughout the Sacramento and San Joaquin River basins. It is important to note that VIC Model routed flows are considered naturalized in that they do not include effects of diversions, imports, storage, or other human management of the water resource.

Bias Correction of VIC Model Results

Even though the VIC Model is calibrated, the model bias still needs to be removed from the model outputs. These biases result from several factors, including spatial and temporal errors in gridded climate forcings, complex groundwater interactions, and other complexities normally inherent to VIC hydrologic model parameter calibration. These steps were followed to correct the biases:

1. Evaluated the monthly and annual bias in VIC Model simulated streamflows as compared to the historical streamflows for each of the flow locations.
2. Developed a quantile map that aligns the historical streamflow CDF with the simulated CDF for each simulated month at each location. For each simulated value, determined the simulated percentile and adjusted the simulated flow to be equal to the historical flow at the same percentile. This method preserves the mean and variance of the unimpaired flows.
3. Rescaled the monthly values (if needed) to align the annual simulated CDF with the historical streamflow CDF. For each simulated annual flow value from Step 2, determined the percentile and adjusted it to be equal to the historical flow at the same percentile. This step confirms that the adjusted streamflows are consistent at the annual scale.

VIC Model Outputs and Limitations

The following key output parameters are produced on a daily and monthly time-step:

- Temperature, precipitation, runoff, base flow, potential evapotranspiration, soil moisture, and snow water equivalent on a grid-cell and watershed basis
- Routed streamflow at major flow locations to the Sacramento and San Joaquin valleys

The regional hydrologic modeling described using the VIC Model is intended to generate changes in inflow magnitude and timing for use in subsequent CalSim-II modeling. While the model contains several sub-grid mechanisms, the coarse grid scale should be noted when considering results and analysis of local-scale phenomenon. The VIC Model is currently best applied for regional-scale hydrologic analyses. Several limitations to long-term gridded meteorology related to spatial-temporal interpolation and bias correction should be considered.

In addition, the inputs to the model do not include transient trends in the vegetation or water management that may affect streamflows; they should only be analyzed from a naturalized flow change standpoint.

Finally, the VIC Model includes three soil zones to capture the vertical movement of soil moisture, but does not explicitly include groundwater. The exclusion of deeper groundwater is not likely a limiting factor in the upper watersheds of the Sacramento and San Joaquin River watersheds that contribute approximately 80 to 90 percent of the runoff to the Delta; however, in the valley floor, groundwater management and surface water regulation is considerable. Water management models, such as CalSim-II, should be used to characterize the heavily managed portions of the system.

Sea-Level Rise

In the past century, global mean sea level has increased by 17 to 21 centimeters (cm) (7 to 8 inches) (IPCC, 2013). Sea level continues to rise due to a combination of melting glaciers and ice sheets, and thermal expansion of seawater as it warms. Global estimates of SLR made in the IPCC 4th Assessment indicate a range of 18 to 59 cm (7.1 to 23.2 inches) this century (IPCC, 2007). Estimates by Rahmstorf (2007) and Vermeer and Rahmstorf (2009) suggest that the SLR may be substantially greater than the IPCC projections. Using empirical models based on the observed relationship between global temperatures and sea levels, which have been shown to better simulate recent, observed trends, these studies indicate a mid-range rise this century of 70 to 100 cm (28 to 39 inches), with a full range of variability of 50 to 140 cm (20 to 55 inches).

Global estimates of SLR made from AR5 indicate a likely range of 26 to 82 cm (10.2 to 32.3 inches) this century (IPCC, 2013). These ranges are derived from CMIP5 climate projections, in combination with process-based models and assessment of glacier and ice sheet contributions. The global SLR projections in the IPCC AR5 (IPCC, 2013) are higher than the projections from the IPCC 4th Assessment Report (AR4) (IPCC, 2007).

Due to the limitations with the current physical models for assessing future SLR, several scientific groups, including the CALFED Bay Delta Program (CALFED) Independent Science Board (ISB), recommend the use of empirical models for short- to medium-term planning (Healy, 2007). Both the CALFED ISB and Climate Action Team 2009 assessments have used the empirical approach developed by Rahmstorf (2007) that projects future SLR rates based on the degree of global warming.

The SLR estimates by the National Research Council (NRC) suggested SLR projections at three future times relative to 2000 (2030, 2050, and 2100), along with upper- and lower-bound projections for San Francisco (NRC, 2012). Their SLR projections range from 4.3 to 29.7 cm by 2030, with a mean SLR of about 14.4 cm. By 2050, the range is from 12.3 to 60.8 cm, with a mean SLR of about 28 cm. And by 2100, the range is from 42.4 to 166.5 cm, with a mean SLR of about 90 cm. The NRC’s projections have been adopted by the California Ocean Protection Council as guidance for incorporating SLR projections into planning and decision making for projects in California.

The 2012 National Oceanic and Atmospheric Administration (NOAA) report on *Global Sea Level Rise Scenarios for the United States National Climate Assessment* includes four global SLR scenarios ranging from 20 to 200 cm (8 inches to 7 feet) by 2100 using mean sea level in 1992 as a baseline (Parris et al., 2012). The SLR projections in the most recent National Climate Assessment report (2014) was informed by the 2012 NOAA sea-level projections (Parris et al., 2012).

In December 2013, the U.S. Army Corps of Engineers (USACE) issued updated guidance on incorporating sea-level change in civil works programs (USACE, 2013). The guidance document reviews the existing literature and suggests use of a range of sea-level change projections, including the high probability of accelerating global SLR. The ranges of future SLR were based on the empirical procedure recommended by the NRC

(1987) and updated for recent conditions. The three scenarios included in the USACE guidance suggest end-of-century SLR in the range of 20 to 150 cm for San Francisco.

By 2030 and 2070, the median range of expected SLR as estimated by the NRC and other sources listed, and as widely accepted within the scientific community, is around 15 and 45 cm, respectively. For this analysis, SLR projections of 15 and 45 cm were selected as representative for 2030 future and 2070 future SLR conditions, respectively, for use in the CalSim-II and DSM2 models.

Development of CalSim-II Models and Datasets

The hydrology of the Central Valley and operation of the CVP and SWP systems are critical elements in any assessment of changed conditions throughout the Central Valley and in the Delta. Changes to system characteristics, such as flow patterns, demands, regulations, Delta configuration will influence the operation of the CVP and SWP reservoirs and export facilities. The operation of these facilities, in turn, influence Delta flows, water quality, river flows, and reservoir storage. The interaction between hydrology, operations, and regulations is not always intuitive, and detailed analysis of this interaction often results in a new understanding of system responses.

Modeling tools are required to approximate these complex interactions under future conditions. CalSim-II is a planning model developed by DWR and Reclamation. It simulates the CVP and SWP and areas tributary to the Delta. CalSim-II provides quantitative hydrologic-based information to those responsible for planning, managing, and operating the CVP and SWP. As the official model of those projects, CalSim-II is typically the system model used for interregional or statewide analysis in California.

Climate and sea-level change is incorporated into CalSim-II in two ways: changes to the input hydrology, and changes to the flow-salinity relationship in the Delta due to SLR. The following methods were used to calculate projected CalSim-II inflow data:

1. For larger watersheds, which constitute the majority of the total inflow volume in the system, CalSim-II inflows were replaced with projected runoff obtained from the VIC Model.
2. For smaller inflows, for which using direct runoff from the VIC Model was not possible, simulated changes in runoff were applied to the CalSim-II inflows and downstream accretions and depletions as a fractional change from the observed inflow patterns at certain gauged locations (simulated future runoff divided by historical runoff). These fractional changes were first applied for every month of the 82-year period consistent with the VIC Model simulated patterns. A second order correction was then applied to confirm that the annual shifts in runoff at each location were consistent with that generated from the VIC Model. Similarly, fractional changes were also used to simulate change in precipitation and temperature as needed for calculation of certain parameters used in CalSim.

3. For larger watersheds where streamflows are heavily impaired, a process was implemented by calculating historical impairment based on observed data, and adding that impairment back onto the VIC Model simulated flows that were bias-corrected to unimpaired at a location upstream of the impairment.
4. Water year types and other indices used in system operation decisions by CalSim-II were regenerated using projected flows, precipitation, or temperature as needed in their respective methods.
5. SLR effects on the flow-salinity response in CalSim-II were incorporated by a separate Artificial Neural Network (ANN) for each climate projection (2030 and 2070).
6. SLR effects were used in the regression equations to estimate the flow split between the Sacramento River and Georgiana Slough at times when the Delta Cross Channel (DCC) is open or closed.

Use of Projected Runoff from the VIC Model for Impaired Streamflows

Impaired streamflows of larger watersheds that constitute the majority of the total inflow volume in the system are listed in Table A-2. As mentioned before, for these locations, CalSim-II inflows were replaced with projected runoff obtained from the VIC Model. The projected runoff was obtained through the hydrologic routing and bias correction process described in previous sections. Bias correction was based on impaired CalSim-II inflows for these locations to capture the level of development modeled in CalSim-II.

Table A-2. River Locations for Upper Watersheds in CalSim-II.

River Locations	CalSim Arc	Basis of Bias Correction
Trinity River at Trinity Lake	I1	CalSim-II inflow[1]
Sacramento River at Shasta Dam	I4	CalSim-II inflow[1]
Feather River at Oroville	I6	CalSim-II inflow[1]
American River North Fork + Middle Fork	I300	Partitioned from American River (I300 + I8) based on monthly ratios (I300/(I300+I8)) in CalSim-II inflow[1]
American River South Fork + Local Flow	I8	Partitioned from American River (I300 + I8) based on monthly ratios (I8/(I300+I8)) in CalSim-II inflow[1]
Cosumnes River at Michigan Bar	I501	CalSim-II inflow[1]
Calaveras River at New Hogan	I92	CalSim-II inflow[1]
Merced River at Lake McClure	I20	CalSim-II inflow[1]
San Joaquin River at Millerton Lake	I18_SJR + I18_FG	CalSim-II inflow[1]
San Joaquin River at Millerton Lake (without Fine Gold Creek)	I18_SJR	Partitioned from San Joaquin River inflow to Millerton Lake (I18) based on monthly ratios in CalSim-II inflow[1]

Table A-2. River Locations for Upper Watersheds in CalSim-II.

River Locations	CalSim Arc	Basis of Bias Correction
Fine Gold Creek	I18_FG	Partitioned from San Joaquin River at Millerton Lake (I18) based on monthly ratios in CalSim-II inflow[1]

[1]CalSim-II inflow data were obtained from the Delivery Capability Report (DCR), 2015 study.

Use of Projected Runoff from the VIC Model for Unimpaired Streamflows

Use of projected runoff from the VIC Model for unimpaired streamflows followed a similar bias-correction scheme as was implemented for impaired streamflow locations (as discussed in previous sections). Because the unimpaired runoff obtained from this step is used to calculate hydrologic indices, and to be consistent with the methodology used to calculate these indices, unimpaired streamflow locations were bias-corrected to unimpaired or full natural flow data[1] for that location.

Use of Fractional Changes for Climate Data

Fractional changes from the historical observed data based on simulated future climate conditions are used when direct use of future climate is not feasible. Streamflows of smaller watersheds, projected precipitation for use in hydrological index calculations, and projected change in temperature for use in calculating required Old and Middle River flow for modeling purposes are examples of where fractional changes have been used and are described in detail in the following subsections.

Streamflows

The existing VIC Model at 1/16th degree (approximately 6 kilometers [km], or approximately 3.75 miles) spatial resolution is insufficient to produce streamflows with good accuracy at small watersheds. Therefore, for smaller watersheds in the system, climate change ratios were used to adjust CalSim-II inflow data obtained from the 2015 SWP delivery capability study (DWR, 2015). Table A-3 lists these small watersheds. The climate change ratios were computed based on VIC Model simulations using historical, detrended climate forcing and climate change projections.

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[1] Data obtained from California Data Exchange Center (CDEC).

Table A-3. River Locations for Small Watershed Tributaries in CalSim-II.

Tributary	CalSim Arc	Approach
Cow Creek	I10801	Developed climate change ratio, and used as reference for other locations
Battle Creek	I10803	Used climate change ratio developed based on Cow Creek
Cottonwood Creek	I10802	Developed climate change ratio
Deer Creek	I11309	Developed climate change ratio, and used as reference for other locations
Paynes Creek	I11001	Used climate change ratio developed based on Deer Creek
Red Bank Creek	I112	Used climate change ratio developed based on Deer Creek
Antelope Creek	I11307	Used climate change ratio developed based on Deer Creek
Mill Creek	I11308	Used climate change ratio developed based on Deer Creek
Thomes Creek	I11304	Developed climate change ratio, and used as reference for other locations
Elder Creek	I11303	Used climate change ratio based on Thomes Creek
Lewiston inflow	I100	Not modified
Whiskeytown inflow	I3	Developed climate change ratio
Bear river inflow	I285	Developed climate change ratio
Butte Creek	I217	Developed climate change ratio, and used as reference for other locations
Big Chico Creek	I11501	Used climate change ratio developed based on Butte Creek
Kelly Ridge	I200	Not modified
Fresno River inflow to Hensley Lake	I52	Developed climate change ratio, and used as reference for other locations
Chowchilla River inflow to Eastman Lake	I53	Used climate change ratio developed based on Fresno River inflow to Hensley Lake
Inflow to Black Butte	I42	Developed climate change ratio, and used as reference for other locations
Stony Creek inflow East Park	I40	Used climate change ratio developed based on inflow to Black Butte
Inflow to Stony Gorge	I41	Used climate change ratio developed based on inflow to Black Butte

Precipitation

CalSim-II requires runoff forecasts for the Shasta, Feather, and American river basins. In practice, statistical forecast functions are developed based on observed precipitation and runoff. To mimic the same procedure for forecasts that would have occurred in future climate conditions, forecast functions were developed using projected precipitation and runoff. The following steps were taken:

1. Basin-wide average precipitation was computed for each climate scenario.
2. Sensitivity factors for precipitation were calculated in reference to historical data for each climate scenario.

3. Historical precipitation indices were perturbed to obtain estimated precipitation indices under each climate scenario. Sensitivity factors for precipitation indices are calculated as the ratio of climate precipitation to historical precipitation for each basin.
4. Perturbed precipitation index estimates were then used to develop regression equations for forecasted runoff.

Temperature

CalSim-II uses a temperature trigger based on temperature data at the Sacramento Executive Airport (SEA) to establish trigger date requirements for the U.S. Fish and Wildlife (USFWS) Biological Opinion Reasonable and Prudent Alternative Action 3 (BIOP A3) that sets the Old and Middle River flow requirement in spring months. To mimic these modeled trigger dates under future climate, temperature sensitivity factors for each climate scenario were calculated at the VIC Model grid location best representative of SEA. Perturbation was applied to the DCR2015 temperature dataset to establish temperature trigger date requirements under each climate scenario. Sensitivity factors for temperature are calculated as a difference in temperature.

Use of Projected Runoff from the VIC Model for Impaired Streamflows

Projected VIC Model runoff that was bias-corrected to unimpaired flows at the upstream location of impaired streamflow locations were used to re-introduce the impairment that was observed in CalSim-II (Table A-4). Because information on specific local project operations (impairment) at these locations was not available, the impairment was calculated as the difference between the unimpaired historical flow and the CalSim-II inflow time series. The same difference was then applied to projected unimpaired flow to obtain impaired flows in future conditions. This method assumes the local project operations will be the same in future climate conditions and does not account for any adaptation in local project operations because the information on how the local project operations would change is currently not available.

Table A-4. River Locations for Upper Watersheds in CalSim-II.

River Locations	CalSim Arc	Basis of Bias Correction
Yuba River at Smartsville	I230	Unimpaired flows for use of re-impairment method (re-impairment method uses historical impairment included in CalSim-II inflows based on output from the YCWA HEC model)
American River at Folsom	I300 + I8	Unimpaired flows for use of re-impairment method (re-impairment method uses historical impairment included in CalSim-II inflows based on DWR American River HEC3 model)
Mokelumne River	I504	Unimpaired flows into Pardee Reservoir (I90, use input from EBMUDSIM) for use of re-impairment method (re-impairment method uses historical impairment included in CalSim-II inflows at I504 based on output from EBMUD SIM; in this case re-impairment includes other smaller inflow between I90 and I504)
Stanislaus River at New Melones Dam	I10	Unimpaired flows for use of re-impairment method (re-impairment method uses historical impairment included in CalSim-II inflows)
Tuolumne River at New Don Pedro	I81	Unimpaired flows for use of re-impairment method (re-impairment method uses historical impairment included in CalSim-II inflows)

Key:
EBMUD SIM = East Bay Municipal Utility District Simulation
YCWA HEC = Yuba County Water Agency Hydrologic Engineering Center

Updating Water Year Types and Indices

Water year types and other hydrologic indices used in CalSim-II operational decisions were regenerated using the projected flows and temperatures based on VIC Model simulations. These indices and data they use are listed in Table A-5.

Table A-5. Water Year Types and Other Hydrologic Indices Used in CalSim-II.

Item/Index	Input	CalSim-II File Name	Specification	Raw Data	Raw Data Source	CDEC Station Location/ Station used in VIC Model for Projected Flows
Forecasting	Folsom Inflow Forecast	American_Runoff_Forecast.table	Fn (WY precip, known streamflows at the time of forecast)	Unimpaired; Basin Precipitation	CDEC; other DWR	AMF; Folsom Basin Precipitation (Index of Gaged)
	Oroville Inflow Forecast	Feather_Runoff_Forecast.table		Unimpaired; Basin Precipitation	CDEC; other DWR	FTO; Feather Basin Precipitation (Index of Gaged)
	Shasta Inflow Forecast	Sacramento_Runoff_Forecast.table		Unimpaired; Basin Precipitation	CDEC; other DWR	SIS; Shasta Basin Precipitation (Index of Gaged)
Indices for broad regulatory criteria (simulated with perfect foresight in CalSim-II)	8RI	EightRiver.table	Sum of eight stations' monthly flows (SacValleyIndex + SJValleyIndex)	Full Natural Flow	CDEC	AMF, FTO, SBB, YRS, MRC, SJF, SNS, TLG
	X2 Days	x2days.table	Based on 8RI PMI	Full Natural Flow; Table of electrical conductivity requirements	CDEC; Table available in spreadsheet	8RI (previous line)
	SacValley Index	SacValleyIndex.table	Sum of four stations' monthly flows	Full Natural Flow	CDEC	AMF, FTO, SBB, YRS
	Sacramento Index	wytypes.table	Water Quality Control Plan 40-30-30	Full Natural Flow	CDEC	AMF, FTO, SBB, YRS
	San Joaquin Index	wytypes.table	Water Quality Control Plan 60-20-20	Full Natural Flow	CDEC	MRC, SJF, SNS, TLG
	San Joaquin Index	wytypeSJR.table	Water Quality Control Plan 60-20-20	Full Natural Flow	CDEC	MRC, SJF, SNS, TLG
	San Joaquin Index – 5-year average	wytypeSJR5.table	5-year running average of WQCP 60-20-20	Full Natural Flow	CDEC	MRC, SJF, SNS, TLG
Indices and other inputs for Operations policies (with regulatory significance)	Trinity Index	wytypes.table	Based on TNL WY Total	Full Natural Flow	CDEC	TNL
	Shasta Index	wytypes.table	Based on SIS Apr-Jul and WY Totals	Full Natural Flow	CDEC	SIS
	Feather River Index	wytypes.table	Based on FTO Apr-Jul and WY Totals	Full Natural Flow	CDEC	FTO

Table A-5. Water Year Types and Other Hydrologic Indices Used in CalSim-II.

Item/Index	Input	CalSim-II File Name	Specification	Raw Data	Raw Data Source	CDEC Station Location/ Station used in VIC Model for Projected Flows
	UIFR	UIFR.table	Based on AMF Mar-Nov Totals	--	--	AMF
	AmerD893 Index	wytypes.table	Based on AMF Apr-Sep Totals	Full Natural Flow	CDEC	AMF
	Delta Index	Delta_Index.table	Based on Jan-May 8RI	Full Natural Flow	CDEC	AMF, FTO, SBB, YRS, MRC, SJF, SNS, TLG

Key:

BRI = VAN DUZEN R NR BRIDGEVILLE AT GRIZZLY CR

AMF = AMERICAN R AT FOLSOM

Apr-Jul = April through July

Apr-Sep = April through September

FTO = FEATHER RIVER AT OROVILLE

Mar-Nov = March through November

MRC = MERCED R NR MERCED FALLS

SBB = SACRAMENTO RIVER ABV BEND BRIDGE

SIS = SACTO INFLOW-SHASTA

SJF = SAN JOAQUIN RIVER BELOW FRIANT

SNS = STANISLAUS R-GOODWIN

TLG = TUOLUMNE R-LA GRANGE DAM

TNL = TRINITY R AT LEWISTON

WY = wet years

YRS = YUBA RIVER NEAR SMARTVILLE

Incorporating Effects of SLR in CalSim-II through ANN

Determination of flow-salinity relationships in the Delta is critical to both water project operations and ecosystem management. Operation of the CVP and SWP facilities and management of Delta flows often depend on Delta flow needs for salinity standards. Salinity in the Delta cannot be simulated accurately by the simple mass balance routing and coarse time step used in CalSim-II. An ANN has been developed that attempts to mimic the flow-salinity relationships as simulated in DSM2 and provides a rapid transformation of this information into a form usable by CalSim-II (Sandhu et al., 1999). The ANN is implemented in CalSim-II to confirm the operations of the upstream reservoirs and the Delta export pumps satisfy specific salinity requirements in the Delta. A more detailed description of the use of ANNs in the CalSim-II model is provided by Wilbur and Munévar (2001).

The ANN developed by DWR (Sandhu et al., 1999; Seneviratne and Wu, 2007) statistically correlate the salinity results from a particular DSM2 model run to the peripheral flows (Delta inflows, exports, and diversions), gate operations, and an indicator of tidal energy. The ANN is trained on DSM2 results that may represent historical or future conditions using a full circle analysis (Seneviratne and Wu, 2007). For example, a future SLR may significantly affect the hydrodynamics of the system. The ANN is able to represent this new condition by being retrained using the results from the DSM2 model representing the conditions with the SLR.

The current ANN predicts salinity at various locations in the Delta using the following parameters as input:

- Northern inflows
- San Joaquin River inflow
- DCC gate position
- Total exports and diversions
- Net Delta consumptive use
- An indicator of the tidal energy
- San Joaquin River at Vernalis salinity

Northern inflows include Sacramento River at Freeport flow; Yolo Bypass flow; and combined flow from the Mokelumne, Cosumnes, and Calaveras rivers (eastside streams) minus North Bay Aqueduct and Vallejo exports. Total exports and diversions include those at the SWP Banks Pumping Plant, the CVP Jones Pumping Plant, and Contra Costa Water District (CCWD) diversions, including diversions to Los Vaqueros Reservoir. A total of 148 days of values of each of these parameters is included in the correlation, representing an estimate of the length of memory of antecedent conditions in the Delta.

The ANN model approximates DSM2 model-generated salinity at the following key locations for modeling Delta water quality standards:

- X2
- Sacramento River at Emmaton
- San Joaquin River at Jersey Point
- Sacramento River at Collinsville
- Old River at Rock Slough

In addition, the ANN is capable of providing salinity estimates for Clifton Court Forebay, CCWD Alternate Intake Project, and Los Vaqueros diversion locations.

The ANN may not fully capture the dynamics of the Delta under conditions other than those for which it was trained. It is possible that the ANN will exhibit errors for flow regimes beyond those for which it was trained. Therefore, a new ANN is needed for any SLR scenario or any new Delta configuration (physical changes in Delta) that may result in changed flow-salinity relationships in the Delta.

Two ANNs, retrained by the DWR Bay-Delta Modeling staff, each representing one of the two SLR scenarios assumed in the WSIP (15 cm at 2030 and 45 cm at 2070) were used with the two CalSim-II models that represent 2030 and 1070 conditions. ANN retraining involved the following steps:

1. The DSM2 model was corroborated using the UnTRIM model to account for SLR effects, enabling a one-dimensional (1-D) model, DSM2, to approximate changes observed in a three-dimensional (3-D) model, UnTRIM.
2. A range of example long-term CalSim-II scenarios were developed to provide a broad range of boundary conditions for the DSM2 models.
3. Using the grid configuration and the correlations from the corroboration process, several 16-year (water years 1976-1991) DSM2 planning runs were simulated based on the boundary conditions from the identified CalSim-II scenarios to create a training dataset for each new ANN.
4. ANNs were trained using the Delta flows and Delta cross-channel operations from CalSim-II, along with the salinity (electrical conductivity [EC]) results from DSM2 and the Martinez tide.
5. The training dataset was divided into two parts: one was used for training the ANN, and the other for validating.
6. Once the ANN was ready, a full circle analysis was performed to assess the performance of the ANN and confirm similar results were obtained from CalSim-II and DSM2.

A detailed description of the ANN training procedure and the full circle analysis is provided in DWR's 2007 annual report (Seneviratne and Wu, 2007).

Incorporating Effects of SLR in Sacramento River- Georgiana Slough Flow Split

The SLR expected by 2030 or 2070 would change the flow split between Sacramento River and DCC-Georgiana Slough flow. This requires modification of the linear regression equations used to estimate DCC-Georgiana Slough flow in CalSim-II. Table A-6 shows the equations to be used in CalSim-II for each SLR condition. The changes to the regression coefficients are made in the .\common\Delta\Xchannel\xc-gates.wresl file.

Table A-6. Regression Results for DSM2 Monthly Averaged Cross-Delta Flow (Y-axis) versus Sacramento River Flow Upstream of Sutter Slough (X-axis).

#	Scenario	DCC Open		DCC Closed	
		Slope	**Intercept**	**Slope**	**Intercept**
1	Current Conditions DSM2[1]	0.3217	1050.7	0.1321	1086.6
2	15 or 45 cm SLR DSM2[2]	0.3187	1094.6	0.1316	1102.0

Key:
BDCP = Bay Delta Conservation Plan

[1] Regression coefficients from 2009 DSM2 recalibration model.

[2] Regression coefficients from 2009 DSM2 recalibration model under 15- and 45-cm SLR using Bay Delta Conservation Plan 040110 No Action CalSim-II results.

The equations to be used with current sea level are:

*Cross-Delta flow (i.e., DCC flow plus Georg. Sl. Flow) = (slope * Sac Flow) + intercept*

Where:

slope = 0.3217, intercept = 1051 cubic feet per second (cfs) when DCC is open

slope = 0.1321, intercept = 1087 cfs when DCC is closed.

Assuming the Georgianna Slough flow portion would remain the same whether DCC is open or closed, the split between Georgianna Slough and DCC is calculated as:

*Georgianna Sl. Flow = 0.1321*Qsac + 1087 (whether DCC is open or closed)*

and

*DCC Flow = 0.1896*Qsac - 36 when DCC is open*

DCC Flow = 0.0 when DCC is closed

The equation to be used with SLR of 15 or 45 cm are:

*Cross-Delta flow (i.e. DCC flow plus Georg. Sl. Flow) = (slope * Sac Flow) + intercept*

Where

slope = 0.3187, intercept = 1095 cfs when DCC is open

slope = 0.1316, intercept = 1102 cfs when DCC is closed

Assuming the Georgianna Slough flow portion would remain the same whether DCC is open or closed, the split between Georgianna Slough and DCC is calculated as:

*Georgianna Sl. Flow = 0.1316*Qsac + 1102 (whether DCC is open or closed)*

and

*DCC Flow = 0.1871*Qsac - 7 when DCC is open*

DCC Flow = 0.0 when DCC is closed

DSM2 Modeling

Several tools are available to simulate hydrodynamics and water quality in the Delta. Some tools simulate detailed processes with two-dimensional (2-D) or 3-D representation; however, they are computationally intensive and have long runtimes. Other tools approximate certain processes and have short runtimes, while only compromising slightly on the accuracy of the results. For a long-term planning-level analysis, the simulation period should cover a range of hydrologic and tidal conditions to understand the resulting changes than can occur over a number of years. A tool with short run-times but that can simulate the changed hydrodynamics and water quality in the Delta accurately is ideal. DSM2, a 1-D hydrodynamics and water quality model, fits these criteria.

DSM2 has a limited ability to simulate 2-D features, such as open waterbodies (including reservoir, flooded islands, and tidal marshes); and 3-D transport processes, such as gravitational circulation, which is found to increase with SLR in the estuaries. Therefore, DSM2 must be recalibrated or corroborated based on a dataset that accurately represents the conditions in the Delta with SLR. Since the future SLR conditions are hypothetical, the best available approach to estimate the Delta hydrodynamics is to simulate the Delta with higher dimensional models, which can resolve the 3-D processes well. These models generate the datasets needed to corroborate or recalibrate DSM2 under the future conditions so that it can simulate the hydrodynamics and salinity transport with reasonable accuracy.

Figure A-6 shows a schematic of how the hydrodynamics and water quality modeling is formulated under the SLR conditions. UnTRIM Bay-Delta Model, a 3-D hydrodynamics and water quality model, was used to simulate the SLR effects on hydrodynamics and salinity transport under the historical operations in the Delta.

The results from the UnTRIM model were used to corroborate DSM2 so that DSM2 can simulate the effect of SLR consistent with a higher-order model that can better resolve estuarine processes.

The corroborated DSM2 model was used to simulate hydrodynamics and water quality in the Delta by integrating SLR effects over an 82-year period (water years 1922-2003), using the hydrological inputs and exports determined by CalSim-II under the projected operations. It was also used to retrain ANNs to emulate modified flow-salinity relationships in the Delta.

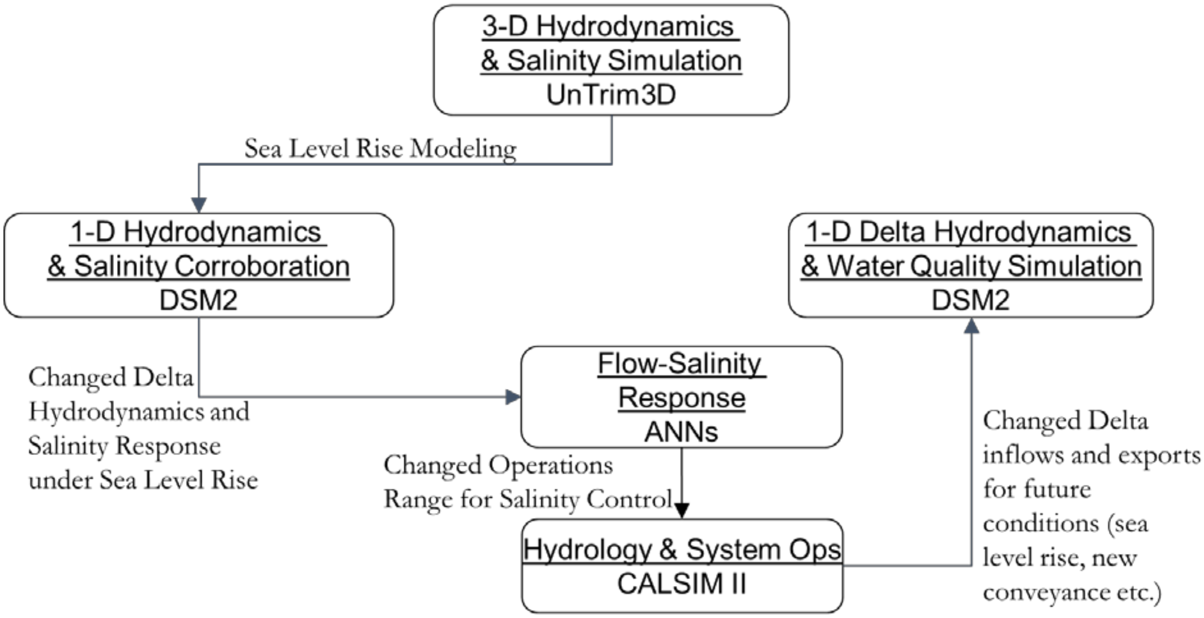

Figure A-6. Delta Hydrodynamics and Water Quality Modeling Methodology under SLR.

Based on the outcome of the SLR corroboration, an updated DSM2 model setup for each of the 2030 and 2070 projections was prepared for use in the WSIP analyses to account for the projected 15- and 45-cm SLR.

Using the results from the UnTRIM models, two correlations were developed to compute the resulting stage and EC at the Martinez location for each SLR scenario. Table A-7 shows the Martinez stage and EC correlations for the 15- and 45-cm SLR scenarios. It also shows the lag in minutes between the baseline stage or EC, and the resulting stage or EC under the scenarios with SLR. The regressed baseline stage or EC time series must be shifted by the respective lag time noted in Table A-7.

As noted earlier, adjusted astronomical tide at Martinez was used as the downstream stage boundary in the DSM2 planning simulation representing the current Delta configuration without SLR. This stage time series was modified using the stage correlation equation identified in Table A-7 for use in planning simulations with 15- and 45-cm SLR. The EC boundary condition in a DSM2 planning simulation was estimated using the G-model based on the monthly net Delta outflow simulated in CalSim-II and the pure astronomical tide (Ateljevich, 2001).

Although the rim flows and exports are patterned on a daily step in DSM2, the operational decisions, including exports, are still on a monthly time step. This means that the net Delta outflow may or may not meet the standards on a daily time step. Therefore, to estimate the EC boundary condition at Martinez, monthly net Delta outflow simulated in CalSim-II was used. For planning simulations with 15- and 45-cm SLR, the EC time series from the G-model was adjusted using the EC correlations for each SLR scenario listed in Table A-7 to account for the anticipated changes at Martinez.

Table A-7. Correlations for Martinez Stage.

Climate Condition	**Martinez Stage (ft NGVD 29)**		**Martinez EC (µS/cm)**	
	Correlation	**Lag (min)**	**Correlation**	**Lag (min)**
2030 Future Condition	Y = 1.0033*X + 0.47	-1	Y = 0.9954*X + 556.3	0
2070 Future Condition	Y = 1.0113*X + 1.4	-2	Y = 0.98*X + 1778.9	-2

Notes:
µS/cm = microSiemens per centimeter
ft = foot
min = minutes
NGVD 29 = National Geodetic Vertical Datum of 1929
X = 2015 Historical Condition Martinez stage or EC
Y = Scenario Martinez stage or EC

Climate Change and SLR Data Provided to Applicants and Potential Use of these Data by Applicants

The following is a list of product archive files included in the November 1, 2016 release:

Without-Project 2030 Future Conditions:

- Climate and VIC results: WSIP_2030_Statewide_Grid_Monthly_9-3-16.zip
- CalSim-II model and output: WSIP_2030_CALSIM_10-24-16.zip
- DSM2 model and output: WSIP_2030_DSM2_10-24-16.zip

Without-Project 2070 Future Conditions:

- Climate and VIC results: WSIP_2070_Statewide_Grid_Monthly_9-3-16.zip
- CalSim-II model and output: WSIP_2070_CALSIM_10-24-16.zip
- DSM2 model and output: WSIP_2070_DSM2_10-24-16.zip

1995 Historical Temperature - Detrended Conditions (reference):

- Climate and VIC results: WSIP_1995_HistTdetrended_Statewide_Grid_Monthly_9-3-16.zip

Use of VIC Model results for models other than CalSim-II can be implemented using similar methodologies as applied to the CalSim-II model. Applicants can choose to implement direct use of VIC Model output or sensitivity factor calculations, or apply a re-impairment scheme when applicable. For use of routed streamflow, a bias-correction scheme should be implemented to remove bias developed during VIC Model calibration. Depending on the use of bias-corrected streamflows, the bias-correction process can be implemented based upon impaired or unimpaired data. At the base level, the VIC Model simulation creates daily outputs. Outputs can then be summarized based on the time frame necessary for implementation into the simulation of model of interest.

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Appendix B
Description of CalSim-II Model

CalSim-II is a water operations planning model developed by DWR and Reclamation. It simulates the SWP and the CVP, and areas tributary to the Sacramento-San Joaquin Delta. CalSim-II provides quantitative, hydrologic-based information to agencies responsible for planning, managing, and operating the SWP and federal CVP. As the official model for those projects, CalSim-II is typically the system model used for any inter-regional or statewide analysis in California. CalSim-II uses descriptive optimization and rules-based simulation techniques to route water through a CVP/SWP system network representation. The network includes over 300 nodes and over 900 arcs (i.e., stream or canal reaches), representing 24 surface water reservoirs and the interconnected flow system.

The CVP, operated by Reclamation and local operating authorities, is composed of 20 reservoirs with a combined storage capacity of more than 11 million acre-feet, 11 power plants, and more than 500 miles of major canals and aqueducts. The SWP, operated and maintained by DWR, is composed of 17 pumping plants, 8 hydroelectric power plants, 32 storage facilities, and more than 660 miles of aqueducts and pipelines. The SWP serves more than two-thirds of the state’s population and approximately 600,000 acres of irrigated farmland in the Feather River area, San Francisco Bay Area, San Joaquin Valley, Central California Coast, and Southern California. The managed facilities provide water supply to contracting agencies, flood control, recreation, fish and wildlife enhancement, power generation, and salinity control in the Sacramento-San Joaquin Delta. The major water facilities in the Central Valley included in CalSim-II are:

- Shasta Lake
- Keswick Reservoir and Red Bluff Diversion Dam on the Sacramento River
- Trinity Lake on the Trinity River
- Whiskeytown Reservoir on Clear Creek
- Lake Oroville and Thermalito Afterbay on the Feather River
- Folsom Lake and Folsom South Canal on the American River
- San Luis Reservoir
- New Melones Lake on the Stanislaus River
- Millerton Lake on the San Joaquin River

CalSim-II operates on a monthly time step from water year 1922 through 2003. It uses historical streamflow data, which have been adjusted to describe existing and future projected conditions, including changes in water and land use that have occurred or may occur in the future. The model simulates the operation of the water resources infrastructure in the Sacramento and San Joaquin river basins on a month-to-month basis during this 82-year period.

CalSim-II models all areas that contribute major flows to the San Francisco Bay. The geographical coverage includes the Sacramento River Valley, the San Joaquin River Valley, the Sacramento-San Joaquin Delta, the Upper Trinity River, and the CVP and SWP service areas.

The model operates the reservoirs and pumping facilities of the SWP and CVP to assure the flow and selected water quality requirements for these systems are met. For a projected condition, the model assumes that facilities, land use, water supply contracts, and regulatory requirements are constant over 82 years from 1922 to 2003, representing a fixed level of development. The model output includes monthly reservoir releases, channel flows, reservoir storage volumes, water diversions, Delta pumping, and parameters describing San Joaquin River and Delta water quality conditions.

Model Mathematics

CalSim-II represents California's water resources system as a linked network of nodes and arcs. CalSim-II routes water through the arcs according to a set of user-defined priorities. CalSim-II uses optimization techniques to route water through the network. A linear programming/mixed integer linear programming (MILP) solver determines an optimal set of decisions for each time period given a set of priority weights and system constraints. The physical description of the system is expressed through a user interface with tables representing the system characteristics. The priority weights and basic constraints are also entered in the system tables.

Hydrology

Reservoir inflows, stream gains, diversion requirements, irrigation efficiencies, return flows, and groundwater operation are all components of the hydrology for CalSim-II.

The monthly time step simulations are conducted over the 82-year period using the adjusted historical rainfall/runoff data. This approach incorporates the important assumption that the next 82 years will have similar rainfall/snowmelt amount, range of variability, and pattern, both within-year and from year to year, as the period 1922 through 2003.

The hydrology used for CalSim-II may be adjusted for the impacts of climate change. Techniques for making these adjustments and datasets available for use with CalSim-II are provided in Appendix A.

Demands

Demands are preprocessed independent of CalSim-II and may vary according to the specified level of development (e.g., 2015, 2030) and according to hydrologic conditions. Demands are typically input to a model as a monthly time series. Demands are classified as CVP, SWP, local project, or non-project. CVP and SWP demands are classified according to water delivery rules and shortage criteria, recognizing priorities of water rights, refuge deliveries, settlement or exchange contracts, and other delivery contract types.

Demands are disaggregated into project demands and non-project demands. Project demands are subject to reduced water allocations based on CVP and SWP contract provisions, while non-project demands are satisfied from sources other than project storage and project conveyance facilities and are reduced as a function of water availability in the absence of project operations.

The demands used for CalSim-II can be adjusted for the impacts of climate change if desired. However, due to the complex response of demands and related water operations associated with climate change, adjustments in demands are not required for the WSIP.

Environmental Water Requirements

Environmental water requirements are included in the model where appropriate, including minimum reservoir storage requirements, minimum in-stream flows, and deliveries to national wildlife refuges and wildlife management areas that are stipulated in current regulatory requirements and discretionary interagency agreements.

Allocation Decisions

CalSim-II uses allocation logic for determining deliveries to north-of-Delta and south-of-Delta CVP and SWP contractors. The delivery logic is intended to simulate actual operations, and uses runoff forecast information that incorporates uncertainty and standardized rule curves (i.e., a water supply index versus a demand index curve). The rule curves relate forecasted water supplies to deliverable demand, and then use deliverable demand to assign subsequent delivery levels to estimate the water available for delivery and carryover storage. Updates of delivery levels occur monthly from January 1 through May 1 for the SWP and March 1 through May 1 for the CVP as runoff forecasts become more certain. The south-of-Delta SWP delivery is determined based on water supply parameters and operational constraints. The CVP system-wide delivery and south-of-Delta delivery are determined similarly using water supply parameters and operational constraints, with specific consideration for export constraints.

Reservoir System Operation

CalSim-II requires operating rules to release flows to meet water demands and water quality standards. Reservoirs are operated using rule curves that represent the desired monthly storage levels according to flood-space filling requirements. The rule curves have been derived from historical hydrologic conditions, and may not be appropriate if there are significant changes to system operations or if there are changes from the historical reservoir inflow hydrology. Reservoirs provide flood control capacity during the high runoff season (i.e., winter and spring), when they need to have flood space available. This flood control space requirement limits the amount of water stored during the wet season and available to deliver for other uses later in the year.

Delta

The State Water Board specifies water quality standards for the Delta. The CVP and SWP share the obligation to meet these standards as defined by the COA. Salinity standards must be converted into flow equivalents to be modeled in CalSim-II. However, flow-salinity relationships in the Delta involve complex dynamics based on the hydraulics of the Delta under different flow levels and durations. CalSim-II uses DWR’s Artificial Neural Network (ANN) model to simulate flow-salinity relationships for the Delta by estimating salinity at water quality stations in the Delta. The ANN model is a set of equations and logic used to approximate the flow-salinity relationships of the more complex DSM2 model. The ANN estimates electrical conductivity at the following four locations for the purpose of modeling Delta water quality standards:

- Old River at Rock Slough
- San Joaquin River at Jersey Point
- Sacramento River at Emmaton
- Sacramento River at Collinsville

For its estimates, the ANN model considers antecedent conditions up to 148 days, and considers a carriage-water effect associated with Delta exports.

CalSim-II passes antecedent (i.e., previous month) flow conditions and known (or estimated) current month flows to an ANN dynamic link library. The dynamic link library returns coefficients for a linear constraint that binds Sacramento River Delta inflows to Delta exports based on a piecewise-linear approximation of the flow-salinity relationship.

Surface Water/Groundwater Interaction

Groundwater has a limited representation in CalSim-II. On the Sacramento Valley floor, groundwater is explicitly modeled in CalSim-II using a multiple-cell approach based on depletion study area boundaries, resulting in 12 groundwater cells in the model. Stream-aquifer interaction, groundwater pumping, recharge from irrigation, and sub-surface flow between groundwater cells are calculated at each time step. All other groundwater flow components are pre-processed and represented in CalSim-II as a fixed time series. In areas of high groundwater elevation, CalSim-II calculates groundwater inflow to the stream as a function of the groundwater head and stream stage. In areas of low groundwater elevation, where the groundwater table lies below the streambed, CalSim-II assumes the stream and aquifer are hydraulic disconnected. In this case, seepage from streams depends only on stream stage.

Regulatory Conditions

The following sections describe common regulatory requirements represented in CalSim-II to reflect the current regulatory environment.

Water Rights

The State Water Board’s Water Quality Control Plan (WQCP) and other applicable water rights decisions, as well as other agreements, are important factors in determining the operations of both the CVP and the SWP.

Historically, approximately 90 percent of the CVP water has been delivered to agricultural users, including to prior water rights holders. Total annual contracts for CVP water exceed 9 million acre-feet per year, including over 1 million acre-feet per year of Friant Division Class II supply, which is generally available only in wet years. The CVP also delivers water from the San Joaquin River to CVP contractors and water rights holders located along the Madera and Friant Kern canals. Water from New Melones

Reservoir is used by water rights holders in the Stanislaus River watershed and CVP contractors located in the northern San Joaquin Valley. In addition, water is conveyed via the Sacramento and American rivers to CVP contractors and water rights holders along the Sacramento and American rivers.

The SWP delivers water to water rights holders in the Feather River Service Area prior to meeting its other contracts. The contract entitlement in CalSim-II for the Feather River Service Area water rights holders downstream of Lake Oroville is 948 TAF per year in non-drought years; this can drop to 630 TAF per year when deficiencies of up to 50 percent are imposed in drought years on some parts of the contract amount. The historical 24-year average annual SWP deliveries to the Feather River Service Area including the senior water rights holders downstream of Lake Oroville are 840 TAF per year. CalSim-II represents this by imposing 50 percent deficiencies in 1977, 1988, and 1991. In non-drought years, the land use-based demand is usually significantly less than the contract entitlement.

Water Service Contracts and Deliveries

The CVP has 253 water service contracts consisting of settlement contracts, agricultural water service contracts, urban water service contracts, and refuge requirements. CVP contracts south of the Sacramento-San Joaquin Delta consist of exchange contracts, agricultural service contracts, and M&I service contracts.

The SWP has 29 long-term contracts for water supply totaling about 4.2 million acre-feet annually, of which about 4.1 million acre-feet are for contracting agencies with service areas south of the Sacramento-San Joaquin Delta. About 70 percent of this amount is the contract entitlement for urban users and the remaining 30 percent for agricultural users. CalSim-II allocations are set per the Monterey Agreement criteria, which imposes any deficiencies equally between agricultural and M&I requests, as a percentage of each contract amount.

Coordinated Operations Agreement

The COA is both an operations agreement and a water rights settlement defined by State Water Board Decision 1485. Decision 1485 ordered the CVP and SWP to guarantee certain conditions for water quality protection for agricultural, M&I, and fish and wildlife uses.

The purpose of the COA is to ensure that the CVP and the SWP each obtain its share of water from the Delta and bear its share of obligations to protect the other beneficial uses of water in the Delta and Sacramento Valley. Coordinated operation by agreed-upon criteria can increase the efficiency of both the CVP and the SWP.

COA sharing formulas are used as constraints in the linear programming formulation within the model. These formulas or constraints ensure that the COA is maintained in the model.

Central Valley Project Improvement Act 3406(b)(2) Operations

According to the 1992 Central Valley Project Improvement Act (CVPIA), the CVP must "dedicate and manage annually 800,000 acre-feet of Central Valley Project yield for the primary purpose of implementing the fish, wildlife, and habitat restoration purposes and measures authorized by this title; to assist the State of California in its efforts to protect the waters of the San Francisco Bay/Sacramento-San Joaquin Delta Estuary; and to help to meet such obligations as may be legally imposed upon the Central Valley Project under State or Federal law following the date of enactment of this title, including but not limited to additional obligations under the Federal Endangered Species Act." This dedicated and managed water, or (b)(2) water as it is called, is water that the USFWS, in consultation with Reclamation and other agencies, has at its disposal to use to meet the primary restoration purposes of CVPIA 3406(b)(2), the CVP's WQCP obligations, and any legal requirements imposed on the CVP after 1992. CVPIA 3406 (b)(2) water may be managed to augment river flows and also to curtail pumping in the Delta to supplement the WQCP requirements.

Decision 1641 Operations

The December 1994 Accord committed the CVP and SWP to a set of Delta habitat protection objectives that were incorporated into the 1995 WQCP and later, along with the Vernalis Adaptive Management Plan, were implemented by Decision 1641. The actions the CVP and SWP took implementing Decision 1641 significantly reduced the export water supply of both projects. Significant elements in the Decision 1641 standards include X2 standards, export/inflow ratios, real-time Delta Cross Channel operation, and San Joaquin flow standards.

Operations Under 2008 USFWS and 2009 NMFS Service Biological Opinions

USFWS Biological Opinion Actions

The USFWS Biological Opinion for delta smelt was released on December 15, 2008, in response to Reclamation's request for formal consultation with the USFWS on the coordinated operations of the CVP and SWP in California. To develop CalSim-II modeling assumptions for the reasonable and prudent alternative (RPA) documented in this Biological Opinion, DWR led a series of meetings that involved members of fisheries and project agencies. This group prepared the assumptions and CalSim-II implementations to represent the RPA in a No Action Alternative CalSim-II simulation. The following actions of the USFWS Biological Opinion RPA have been included in the No Action Alternative CalSim-II simulations:

- Action 1: Adult Delta Smelt migration and entrainment. Impose a fixed duration condition on OMR flow to protect pre-spawning adult delta smelt from entrainment during the first flush, and to provide advantageous hydrodynamic conditions early in the migration period. (RPA Component 1, Action 1 – First Flush)

- Action 2: Adult Delta Smelt migration and entrainment. Manage OMR flow using an adaptive process to tailor protection to changing environmental conditions after Action 1. As in Action 1, the intent is to protect pre-spawning adults from entrainment and, to the extent possible, from adverse hydrodynamic conditions. (RPA Component 1, Action 2)
- Action 3: Entrainment protection of larval and juvenile Delta Smelt. Manage OMR flow to minimize the number of larval delta smelt entrained at the facilities by managing the hydrodynamics in the Central Delta flow levels pumping rates spanning a time sufficient for protection of larval delta smelt. Because protective OMR flow requirements vary over time (especially between years), the action is adaptive and flexible within appropriate constraints. (RPA Component 2)
- Action 4: Estuarine habitat during fall. Improve fall habitat for delta smelt by managing X2 through increasing Delta outflow during fall when the preceding water year was wetter than normal. This will help return ecological conditions of the estuary to that which occurred in the late 1990s when smelt populations were much larger. (RPA Component 3)
- Action 5: Temporary spring Head of Old River barrier and the Temporary Barrier Project. Manage the barriers to minimize entrainment of larval and juvenile delta smelt at Banks and Jones or from being transported into the South and Central Delta, where they could later become entrained. (RPA Component 2)

A detailed description of the assumptions that have been used to model each action is included in the technical memorandum “Representation of U.S. Fish and Wildlife Service Biological Opinion Reasonable and Prudent Alternative Actions for CalSim-II Planning Studies,” prepared by an interagency working group under the direction of the lead agencies (Reclamation, 2015).

NMFS Biological Opinion Salmon Actions

The NMFS Salmon Biological Opinion on long-term operations of the CVP and SWP was released on June 4, 2009. To develop CalSim-II modeling assumptions for the RPAs documented in this Biological Opinion, DWR led a series of meetings that involved members of fisheries and project agencies. This group has prepared the assumptions and CalSim-II implementations to represent the RPA in the No Action Alternative CalSim-II simulations for future planning studies. The following NMFS Biological Opinion RPAs have been included in the No Action Alternative CalSim-II simulations:

- Action I.1.1: Clear Creek spring attraction flows. Use pulse flows in May and June to encourage spring-run movement to upstream Clear Creek habitat for spawning.
- Action I.4: Wilkins Slough operations. Enhance the ability to manage temperatures for anadromous fish below Shasta Dam by operating Wilkins Slough in the manner that best conserves the dam’s cold water pool for summer releases.
- Action II.1: Lower American River flow management. Implement a flow schedule in the Lower American River to provide minimum flows for all steelhead life stages.

- Action III.1.4: Stanislaus River flows below Goodwin Dam. Implement operational criteria for Eastside Division to ensure viability of the steelhead population on the Stanislaus River, and halt or reverse adverse modification of steelhead critical habitat.
- Action IV.1.2: Delta Cross Channel (DCC) gate operations. Modify DCC gate operation to reduce direct and indirect mortality of emigrating juvenile salmonids and green sturgeon in November, December, and January.
- Action IV.2.1: San Joaquin River flow requirements at Vernalis and Delta export restrictions. Increase the inflow to export ratio to reduce the vulnerability of emigrating CV steelhead within the lower San Joaquin River to entrainment into the channels of the South Delta and at the pumps due to the diversion of water by the export facilities in the South Delta. Enhance the likelihood of salmonids successfully exiting the Delta at Chipps Island by creating more suitable hydraulic conditions in the main stem of the San Joaquin River for emigrating fish, including greater net downstream flows.
- Action IV.2.3: Old and Middle river flow management. Reduce the vulnerability of emigrating juvenile winter-run, yearling spring-run, and CV steelhead within the lower Sacramento and San Joaquin rivers to entrainment into the channels of the South Delta and at the pumps due to the diversion of water by the export facilities in the South Delta.

Action I.2.1 is a performance measure rather than an operational action. It calls for a percentage of years to meet certain specified end-of-September and end-of-April storage and temperature criteria resulting from the operation of Lake Shasta. No specific CalSim-II modeling code is implemented to simulate the performance measures identified; CalSim-II results are evaluated to determine performance.

A detailed description of the assumptions that have been used to model each action is included in the technical memorandum “Representation of National Marine Fisheries Service Biological Opinion Reasonable and Prudent Alternative Actions for CalSim-II Planning Studies,” prepared by an interagency working group under the direction of the lead agencies (Reclamation, 2015).

CDFW Incidental Take Permit (ITP) for Longfin Smelt

CDFW has issued an ITP to the SWP for protection of Longfin Smelt under the California Endangered Species Act (CDFW 2009). The permit includes a number of conditions on flow, entrainment, management, salvage, and monitoring. CalSim-II does not include specific SWP operations criteria for these conditions, but for modeling purposes the criteria imposed for the two federal Biological Opinions are considered to provide compliance with the ITP conditions.

Minimum Flow for Navigation — Wilkins Slough

Historical commerce on the Sacramento River resulted in the requirement to maintain minimum flows of 5,000 cfs at Chico Landing to support navigation. No commercial traffic currently travels between Sacramento and Chico Landing, and USACE has not dredged this reach to preserve channel depths since 1972. However, long-time water users diverting from the river have set their pump intakes just below this level. Therefore, the CVP is operated to meet the navigation flow requirement of 5,000 cfs to Wilkins Slough (i.e., the gaging station on the Sacramento River) under all but the most critical water supply conditions to facilitate pumping.

State Water Resources Control Board Water Rights Order 90-05 and Water Rights *Order 91-01*

In 1990 and 1991, the State Water Board issued Water Rights Orders 90-05 and 91-01, modifying Reclamation's water rights for the Sacramento River. The orders included a narrative water temperature objective for the Sacramento River and stated that Reclamation shall operate Keswick and Shasta dams and the Spring Creek Power Plant to meet a daily average water temperature of 56 degrees Fahrenheit at Red Bluff Diversion Dam in the Sacramento River during periods when higher temperatures would be harmful to fisheries.

Under the orders, the water temperature compliance point may be modified when the objective cannot be met at Red Bluff Diversion Dam. In addition, Order 90-05 modified the minimum flow requirements initially established in the 1960 MOA for the Sacramento River below Keswick Dam.

Flood Control

Monthly flood control space requirements are provided by USACE for flood control operation of reservoirs modeled in CalSim-II.

State Water Project Monterey Agreement

The 1994 Monterey Agreement revised the water management strategy of the SWP and its contractors, and eventually led to SWP contract amendments. The Monterey Agreement changed the allocation procedure of SWP deliveries so that cuts would be made proportionally to all SWP contractors, authorized the transfer of 130,000 acre-feet of agricultural contract amounts to M&I contractors, aggregated several contractual obligations for water delivery into one water type (Article 21), and resulted in Kern County Water Agency's assumption of the Kern Water Bank.

Documentation and Peer Review

Many sources of information document the CalSim-II Model. The 2008 Operations Criteria and Plan Biological Assessment (Reclamation, 2008) and the Coordinated Long-Term Operations of the Central Valley Project and State Water Project (Reclamation, 2015) provide detailed descriptions and applications of CalSim-II. In addition, two major peer reviews of the model have been conducted to evaluate the applicability of CalSim-II to the CVP/SWP system and California water management (DWR and Reclamation, 2004).

Other documents describing the features and use of CalSim-II are:

- An analysis of an historical operations simulation (DWR, 2003)
- A sensitivity analysis of selected parameters upon model results (DWR, 2005)
- An analysis of the significance of the simulation time step to the estimated SWP delivery amounts (DWR, 2005).
- CALFED Common Model Package (CALFED Bay-Delta Program, 2005)

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Appendix C
Guidance Documents for Benefit-Cost Analysis

Guidance Documents for Benefit-Cost Analysis

Numerous textbooks and documents provide general direction for benefit cost analysis. Five documents specifically related to benefit-cost analysis of water resources projects are summarized below.

Economics and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G)

In 1983, the U.S. Water Resources Council published the P&G. The P&G is the most cited and used economic guidance for water-related projects. It was developed for the water-related projects of Reclamation, USACE, the Tennessee Valley Authority, and USDA's Natural Resources Conservation Service under the Water Resources Development Act (WRDA) of 1974 through Public Law 93-251. Consistency with the P&G, and now, the Principles, Requirements and Guidelines (PR&G) has been critical for most water projects that seek federal cost-sharing participation.

The P&G describes the federal planning process and four accounts that were used to develop and evaluate water resources projects. The accounts were used to quantify and describe the effects of a proposed project from a national perspective, and include: national economic development (NED), environmental quality (EQ), regional economic development (RED), and other social effects (OSE). The NED account was designed to provide quantitative evaluation of a project's benefits and costs from a national perspective. Detailed procedures are included on how to quantify benefits of water supply (i.e., both M&I and irrigation uses), flood damage reduction, navigation, hydropower, and recreation. Quantification methods for benefits to water quality, ecosystem restoration, and emergency response are not provided, although urban water quality is discussed within urban water supply, and some aspects of emergency response are discussed within flood damage. Agencies including Reclamation and USACE have used the P&G as the basis for more detailed and comprehensive policies, directives, and regulations for evaluating benefits and costs of water resources projects.

In Section 2031 of the 2007 WRDA, Congress directed the Secretary of the Army to revise the P&G. During the process of revising the P&G, lead responsibility was reassigned to the Council on Environmental Quality (CEQ). The CEQ released its "Proposed National Objectives, Principles and Standards for Water and Related Resources Implementation Studies" in December 2009. Among the proposed changes to the NED account was a minimum benefit cost ratio of 1.5 for project consideration.

The CEQ's description of proposed changes states that the revised Principles and Standards include a number of important changes that modernize the current approach to water resources development in the United States, which include:

- Achieving Co-Equal Goals: While the 1983 standards placed greatest emphasis on economic development, the new approach calls for development of water resources projects based on sound science that maximize net national economic, environmental, and social benefits.
- Considering Monetary and Non-Monetary Benefits: The revised Principles and Standards consider both monetary and non-monetary benefits to justify and select a project that has the greatest net benefits—regardless of whether those benefits are monetary or non-monetary. The Principles and Standards do not specify how monetary and non-monetary benefits are to be combined or weighed.
- Avoiding the Unwise Use of Floodplains: The decision to modify water resources and floodplains will be based on evaluations of the services gained and lost by such an action. Only those actions that provide a net benefit will be further pursued or recommended for construction. For the first time such evaluations must give full and equal consideration to nonstructural approaches that can solve the flooding problem without adversely impacting floodplain functions.
- Increasing Transparency and “Good Government” Results: The revised Principles and Standards are intended to promote the transparency of the planning and implementation process for water resource development projects in this country.

The Final Principles, Requirements and Guidelines (PR&G) were published in March 2013 (CEQ, 2014). Chapter 2 states:

> *“It is important that potential Federal investments be evaluated for their performance with respect to the Federal Objective using a common framework. Evaluation methods should be designed to ensure that potential Federal investments in water resources are justified by public benefits, particularly in comparison to costs associated with those investments. Such methods should apply an ecosystem services approach in order to appropriately capture all effects (economic, environmental and social) associated with a potential Federal water resources investment.*
>
> *Services and effects of potential interest in water resource evaluations could include, but are not limited to: water quality; nutrient regulation; mitigation of floods and droughts; water supply; aquatic and riparian habitat; maintenance of biodiversity; carbon storage; food and agricultural products; raw materials; transportation; public safety; power generation; recreation; aesthetics; and educational and cultural values. Changes in ecosystem services are measured monetarily and non-monetarily, and include quantified and unquantified effects.*
>
> *Heretofore, Federal investments in water resources have been mostly based on economic performance assessments which largely focus on maximizing net economic development gains and typically involve an unduly narrow benefit-cost comparison of the monetized effects. A narrow focus on monetized or monetizable effects is no longer reflective of our national needs, and from this point forward, both quantified and*

> *unquantified information will form the basis for evaluating and comparing potential Federal investments in water resources to the Federal Objective. This more integrated approach will allow decision makers to view a full range of effects of alternative actions and lead to more socially beneficial investments."*

In 2014, CEQ published updated interagency guidelines to implement the new PR&G (CEQ, 2014). The current direction is for individual agencies such as Reclamation or USACE to develop guidelines that are consistent with the interagency guidelines but provide more detailed direction for project evaluation. The U.S. Department of the Interior (USDI) published procedures for its member agencies, including Reclamation, to use for project evaluation (USDI, 2015).

Economic Analysis Guidebook

DWR published the Economic Analysis Guidebook in 2008 (DWR, 2008). The guidebook states:

> *"Because of its considerable water management partnerships with the federal government, DWR has a policy that all economic analyses conducted for its internal use on programs and projects be fundamentally consistent with the P&G. It is also DWR policy to adopt, maintain, and periodically update its own Economics Analysis Guidebook, which is consistent with the P&G but can also incorporate innovative methods and tools when appropriate."*

State policy for benefit cost analysis has differed from federal policy in several ways. First, the state's analysis perspective focuses on California, and some costs and benefits to the nation may not apply or may be calculated a bit differently for California. Second, the state has used a discount rate of 6 percent, whereas the federal government uses a rate for investment in water resources projects that changes annually based on the cost of federal borrowing. Other than these specific differences, DWR intends that its benefit cost analyses will be consistent with the P&G.

DWR has used the Economic Analysis Guidebook as a basis for economic evaluations required in recent proposals for grant funding from the state. Proposals from local water suppliers and other agencies for integrated regional water management and stormwater flood management grants have require such economic analysis. Guidelines for these grant programs provide specific instructions and calculation templates for applicants.

Guidelines for Preparing Economic Analysis for Water Recycling Projects

De Souza et al. (2011) provides useful information and ideas related to surface storage. In particular, it provides information related to the nexus between financial and economic analysis, and offers useful summaries of benefits information in the appendices. For example, it includes summaries of U.S. studies regarding the value of water quality, ecosystem improvements, and recreation.

Planning Guidance Notebook

Engineer Regulation 1105-2-100 (USACE, 2000) is perhaps the most detailed implementation document for the P&G. This document offers guidance for projects that provide flood damage reduction, ecosystem restoration, and recreation. In addition, some of the guidance for storm damage reduction might apply to emergency response. Also, guidance is provided where water quality and recreation result from ecosystem restoration. It has been used extensively around the nation, and methods should be familiar to federal partners in California.

Guidance for estimating most benefits is provided in Appendix E, Civil Works Missions and Evaluation Procedures. Appendix D, Economic and Social Considerations, provides guidance for “other direct benefits” that “are the incidental effects of a project that increase economic efficiency.”

Bureau of Reclamation Economics Guidebook

In 2010, Reclamation’s Technical Workgroup published the Bureau of Reclamation Economics Guidebook (Reclamation, 2010). Reclamation maintains this detailed economic guidance based on the P&G for internal use. The WSIP guidance references some important parts of this guidance. However, the guidebook is a working document. Any potential users should contact Reclamation to obtain updated guidance.

DWR Handbook for Assessing Value of State Flood Management Investments (HAV)

The HAV (DWR, 2014) provides comprehensive guidance on the principles, concepts, and methods that can be used to evaluate flood management investment in California. It provides a good summary of methods for some benefit types, but it is not comprehensive for others.

For flood risk management benefits, the HAV states that “DWR shall use HEC-FDA to estimate urban IR [inundation reduction] benefits” (page 3-14; parentheses added). The WSIP does not require using any specific model, although HEC-FDA is a widely-accepted tool to use for projects with large, urban flood management components. The HAV can be used as a complete reference for the recommended USACE recreation methods, but USACE's 2015 guidance memorandum (USACE, 2014) provides the same guidance with updated 2015 baseline unit values.

For ecosystem benefits, the HAV details USACE's cost-effectiveness/incremental cost approach. This approach could help to document cost-effectiveness and evaluate costs of feasible alternatives as suggested by this the WSIP technical guidance. The HAV does not provide details on the various willingness-to-pay approaches to ecosystem valuation, and instead refers to DWR's Economic Analysis Guidebook (DWR, 2008).

Determining the Economic Value of Water

Published in 2005 by Resources for the Future Press, Determining the Economic Value of Water is a relatively current guide to benefit-cost analysis of water resources investments (Young, 2005). It provides an excellent discussion of the conceptual basis for different methods for quantifying benefits, and the pros and cons of methods.

Griffin (2006) also covers the fundamentals of economic analysis for water resource policy and projects. The book discusses both economic principles and many of the applied concepts included in this technical reference, including methods to quantify and monetize benefits, cost allocation procedures, discounting, and overall project justification. A new edition has been released in 2016.

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Appendix D
Unit Values for Water

Unit Values for Water

Commission staff has developed unit values for water (in dollars of benefit per acre-foot) that applicants shall use, where applicable, for estimating the willingness-to-pay for water supply and the avoided or alternative cost of water provided for some public benefits by a water storage project. The unit values were developed using two different methods; a statistical analysis of recent water transfers and a structural model of irrigated agricultural production. This approach was originally applied in 2006 (Mann and Hatchett, 2006a; Mann and Hatchett, 2006b) for analysis of environmental water supply costs. The unit values are based on a statistical analysis of water market transaction data from 1992 through 2015, and estimates of unit values of water in agricultural production from SWAP.

Much has changed since the earlier work was completed ten years ago. Actions to protect endangered species have reduced the amount of water that can be exported from the Delta for agricultural and urban use. Commodity prices, and especially rice prices, increased in real terms to record levels in 2009. Real crop price increases should, all else equal, increase the price required for farmers to forego irrigated production and increase the prices bid by farmers for water.

The economic benefits of agricultural water use have also been influenced by continued conversion of annual to perennial crops in the Central Valley. Some perennial crops require a much larger investment per acre than the annual crops they replaced, and land in perennial crops cannot be temporarily idled to reduce water demand in response to reduced water supply or to provide water for transfer to others. San Joaquin Valley acreage in trees, nuts, and grapes increased by almost 300,000 between 2007 and 2012 alone (USDA, 2012). After 2011, California entered an extended period of severe drought that has substantially increased water transfer prices. In 2015, spot market prices reached unprecedented levels. In the future, the Sustainable Groundwater Management Act (SGMA) is expected to increase water scarcity, especially in areas of the San Joaquin Valley, and further increase willingness to pay for water that would be reflected in open market prices.

The unit values are provided for different year types, for different future conditions, and for different locations for the source of the water. The unit values also consider the effects of SGMA after 2040, primarily reduced average annual groundwater supply south-of-Delta, but have not been adjusted for any climate change effects.

To use the unit values for a particular project, an applicant must explain why they apply to the project and, where appropriate, adjust the values based on consumptive use fraction, conveyance costs, and losses required to move the water from the unit values location to the location of demand served by their project. The unit values shall be used consistently across benefit categories for which water delivery or flow is the measure for monetizing benefits and water is provided in similar conditions. Use of unit values could include water supply, but could also include water for ecosystem or other public benefits. In addition, the applicant should demonstrate that beneficiaries of the non-public water supply could commit to paying the cost allocated to them based on the unit values. The unit values do not represent recommended charges to local users of the project's water. Expected project water charges should be based on allocated costs, not directly on benefits. If the project is economical (i.e., the B/C ratio is greater than one) and the cost allocation is completed correctly, planned water charges per unit should be less than the unit values.

Statistical Analysis of Water Market Transactions Analysis Approach

This section documents the analysis of water transfer prices used to support the unit values. A statistical analysis included 350 individual transfer prices and quantities from 1992 to 2015. The water transfer and price information was compiled from a combination of published and unpublished information. Up to 2006, data were compiled from the Water Strategist© (Stratecon, various years). Additional information was drawn from reports of water transfer program activities, including the Environmental Water Account and the Drought Water Bank (Mann and Hatchett, 2006a). The Water Transfer Level Dataset (University of California at Santa Barbara, 2015) was developed from transactions reported in Water Strategist©, which ended publication in 2010. For 2011 through 2015, prices were obtained using publicly available information from newspaper articles, water board minutes, and district publications, and from a graduate thesis from University of California, Davis (Scheer, 2015).

Several different statistical analyses were developed. A preliminary, aggregate analysis was prepared which estimated annual average price (each transfer weighted by its quantity) for the 1992 through 2015 period as a function of annual hydrologic and economic indicators and trends. The aggregate analysis explored and identified important relationships between hydrologic and economic conditions, land use, and water price.

A number of independent hydrologic variables were tested, including the Sacramento Valley Index, the San Joaquin Valley Index, and binary variables (which take the value of one if a condition is met and zero if not) for dry and/or critical years (DWR, 2016). SWP average allocation was provided by DWR (DWR, 2015). The real price of rice (USDA, 2015) was assessed for whether it affected the price required for water transfers. Almond acreage (USDA, 2016) was used as an indicator to assess how agriculture's willingness to pay for or willingness to sell water has been affected by acreage that cannot readily be adjusted to variable water supply conditions.

Hydrologic and water supply indicators were also tested using previous-year (lagged) variables to capture how dry conditions in the previous year affect transfer prices. Rice prices and perennial acreage were also tested as lagged variables. For rice, price expectations when water transfer decisions must be made depends on expected price, which in turn is highly influenced by the price of rice in the previous year. Almond acreage includes non-bearing acreage whose full water use may be felt in the next year. All transfer and rice price data were expressed in real dollars using the Gross National Product Implicit Price deflator (Federal Reserve Bank of St. Louis, 2015).

The aggregate analysis tested the hypothesis that a structural change in the market began in 2013. By 2013, the combination of severe drought and inelastic demand for water, driven by population and perennial crops, sharply increased water transfer prices. A variable was defined as the product between a binary variable (assigned the value zero prior to 2013 and one afterward) and a measure of drought severity, being one divided by the San Joaquin River index.

The aggregate price analysis considered factors that affect average price (weighted by quantities) in each year of the 1992 through 2015 period. No transfers observations were identified for water year 2010-11, a wet year, resulting in 22 available observations.

Variables included in the selected price equation were almond acreage lagged one year, the structural change variable, the San Joaquin River index in the previous year, and rice price lagged one year. Other variables were added but were not significant. These independent variables explained 94 percent of the variation in average annual transfer price. The structural change variable alone accounted for most of the variation in annual water prices. The San Joaquin River index in the previous year was significant, and lagged almond acreage and rice price are both significant, but only at the 10-percent level.

Estmated unit values of water from the preliminary aggregate regression analysis alone are shown in Table D-1. This simulation takes advantage of the 1906 through 2015 hydrology in terms of the San Joaquin Valley index during that entire period. For predicting price, it was assumed that the structural change variable continues into the future in all year types except above normal and wet. Perennial acreage does not continue to increase as it has the previous two decades, so the lagged almond acreage variable holds constant at the 2015 level; this assumption is generally consistent with DWR land use forecasts

Table D-1. Preliminary Simulated Annual Average Water Transfer Prices Using Aggregate Regression Equations

Using 1906 to 2015 Hydrology			**Sacramento Valley**	**San Joaquin**
Year Type	**Average SJV t**	**Average SJV t-1**	**2030 Price**	**2030 Price**
Wet	4.91	3.44	$170	$254
Above Normal	3.49	3.51	$168	$253
Below Normal	2.78	3.20	$282	$366
Dry	2.27	3.96	$293	$377
Critical	1.65	2.56	$367	$451

Independently of this analysis, a master’s thesis published at the University of California at Davis explored factors that affected water transfers and prices in the Sacramento Valley during the recent drought (Scheer, 2015). The thesis work used a survey format to obtain price and quantity information for the 2011 through 2015 period. The analysis included many transfers within the Sacramento Valley that were not included in the preliminary analysis just described. These transfers, which often did not require new permitting, generally had a much lower price than those in the WSIP analysis. Similar to the preliminary WSIP analysis, the thesis found that the water year type in the past year predicts price better than the current year water year type.

A new, combined dataset was created that included all of the data used in the preliminary analysis plus data gathered by Scheer (2015) on temporary transfers from agricultural to M&I use, or to a destination south-of-Delta. A revised regression model used individual observations of transfer quantities and prices, rather than the aggregated weighted average process used in the preliminary analysis. This approach improves on the preliminary analysis in that it uses all the information contained in the observations and can control for variation across regions and across time. A number of improvements were made to the dataset – various binary variables, new explanatory variables, interaction terms, updated data, and various nonlinear (log, quadratic) functional forms – were investigated. Specifically, the following changes were made:

1. The new 2011 to 2015 transfer observations from Sacramento Valley were included in the transfer data set.
2. All transfer observations were assessed for consistency.
3. A series of binary variables were created to control for district (or groups of districts), type of water purchaser or seller, and an identified structural change affecting water shortages. These binary variables identified
    - Sacramento Vallley, San Joaquin Valley, and Kern County buyers or sellers
    - Southern California or Bay Area M&I buyers or sellers
    - Sellers within a rice producing region
    - State or federal agency buyers or sellers
    - Post-2009 transfers, affected by increased water scarcity following the 2009 ESA BiOp, court decision and reduced Delta exports
4. Perennial crop acreage was updated to reflect total Central Valley acreage of orchards, vineyards, and berries. This allowed for the calculation of perennial acreage as a share of total irrigated acreage.
5. The preliminary work suggested that the San Joaquin River Index is a good predictor of price, but the increase in transfer price as the index declined from, say 2 to 1 (critical to very critical) was much more than when price declined from, say 4 to 3. Therefore, a non-linear transformation of the index, being one divided by the index, was used instead.

Results

Results of the analysis are shown in Table D-2 below. The independent variables explain aboout 60 percent of the variation in the real price of transfers (expressed in constant 2015 dollars). The F statistic for the regression equation is significant at better than a 1% level.

The following discussion provides interpretation of some specific regression coefficients to help readers understand the results. If a buyer was an agency buyer (agencyb), expected transfer price was reduced by about $55 per AF. CVP or SWP buyers (cvpb and swpb) both had a significant relationship to price, though opposite in sign. Sales within the Sacramento Vallley (intra_sac_ag) were associated with a lower price, and transfers whose sellers were within the San Joaquin Valley (sjvs) or that represented cross-Delta transfers (CrossDelta) were both associated with a $42 per AF higher price, all else equal.

Table D-2. Results of Revised Regression Analysis of Individual Transfer Prices

Regression Statistics

Multiple R	77.425%
R Square	59.946%
Adjusted R Square	58.979%
Standard Error	107.313
Observations	468

Regression Coefficients, Standard Errors, and t-Statistics

Variable Name	Coefficient	Standard Error	t Stat	P-value
Intercept	-424.101	43.68542	-9.71	0.0000
Agency	-55.550	14.20895	-3.91	0.0001
cvpb	-29.334	14.57718	-2.01	0.0448
swpb	57.034	13.40639	4.25	0.0000
intra_sac_ag	-79.847	16.72242	-4.77	0.0000
sjvs	42.357	15.12096	2.80	0.0053
1/SJVt-1	97.604	45.75155	2.13	0.0334
peren_share	1728.005	165.10103	10.47	0.0000
CrossDelta	42.745	15.37293	2.78	0.0057
1/SJV	58.019	35.18474	1.65	0.0998
cvp_wanger	-0.786	1.46221	-0.54	0.5909
swp_wanger	-1.606	0.84604	-1.90	0.0583

Two hydrologic variables, the inverse of the San Joaquin Valley Index (1/SJV), and the inverse of the lagged San Joaquin Valley Index (1/SJVt-1), are included. The share of perennial acreage in the Central Valley (peren_share) was positively associated with higher transfer prices, and after 2009, the percent CVP and SWP allocations (cvp_wanger and swp_wanger) are associated with lower transfer prices relative to the pre-2009 period.

Table D-3 shows implied unit values of water at 2030 and 2070 conditions, expressed in real 2015 dollars.

Table D-3. Unit Values Using Revised Regression Analysis.

SJV Index	2030		2070	
	Sacramento Valley	San Joaquin Valley	Sacramento Valley	San Joaquin Valley
Wet	$185	$228	$270	$312
Above Normal	$244	$286	$328	$371
Below Normal	$280	$322	$365	$407
Dry	$301	$343	$385	$428
Critical	$351	$393	$436	$478

Water transfer prices predicted for the 2030 condition, shown in Table D-3, are similar to those from the aggregate analysis (Table D-1) except that simulated prices from the aggregate analysis are higher in the critical years and lower in above normal years. For 2070 conditions, the perennial share is allowed to increase from 44.6 to 49.5 percent.The predicted prices for 2070 do not include any effects of SGMA, including increased water scarcity and potential effect on the share of perennial acreage in the future. The SWAP analysis described below was used to assess these factors.

It should be noted that the Table D-1 and D-3 values for critical years reflect an average critical year among those in the 1906 to 2015 hydrology. The severity of drought in 2014 and, even more so in 2015, caused transfer prices to increase well above the critical year average.

SWAP Analysis of Water Values

The SWAP is a calibrated optimization model that can estimate the benefit per AF of changes in water supply to agricultural production for locations in the Central Valley. SWAP was applied to assess the potential unit values of water for the WSIP. Specifically, this analysis used SWAP to estimate willingness to sell water from agricultural regions that have participated as sellers of water in recent years, and the willingness to pay for water by agricultural regions that have purchased water transfers in recent years.

The model included hydrology to reflect the current Biological Opinion, the San Joaquin River Agreement, and in 2070, implementation of SGMA. The analysis evaluated how the implementation of SGMA groundwater safe yield pumping restrictions would affect the unit value of water once such restrictions are implemented. Calibration results from C2VSIM were used to derive an approximation of sustainable yield for purposes of this analysis. C2VSIM does not develop a precise or accurate estimate of sustainable pumping (which is not possible given the current state of knowledge), but rather it provides an assessment of direction and rough magnitude of change that such limits could impose on future average pumping.

Modeling Approach

SWAP version 6.1 was used for the analysis, which was calibrated using crop acreage and water use information from 2010 and crop prices and costs from 2011-12. The model structure is described in Reclamation (2012), and its application to the 2014 drought analysis is described in Howitt et al. (2014). The analysis of unit values uses as its future baseline the no-action alternative in the Draft Environmental Impact Statement for the Coordinated Long-Term Operation of the CVP and SWP (Reclamation, 2015). The no-action alternative includes full implementation of the 2008 USFWS Biological Opinion and the 2009 NMFS Biological Opinion RPAs, in addition to other ongoing and future programs that would be reasonably foreseeable to be implemented by 2030.

In the results summarized below, three year types are represented: an overall average water supply condition, a dry condition, and a critically dry condition. For project water supplies, CALSIM-II results for 2030 were used based on the 2015 analyses (Reclamation, 2015). For local surface supplies, calibration data were used to represent average water year conditions. Critically dry conditions were represented by information gathered and analyzed for the recent 2014 drought impact analysis (Howitt et al., 2014). Dry conditions for local surface supplies were assumed to be the midpoint between the average and the critically dry conditions.

Estimated unit values with SGMA implemented also used CALSIM-II inputs for 2030 level of development, even though full sustainable groundwater conditions are not required until 2040 or later. No recent CALSIM-II No Action run was available representing 2040 or later future conditions. Sustainable pumping limits by region are only rough approximations because careful groundwater modeling of SGMA implementation is not yet available.

Unit values for water were measured as the incremental change in net return to agricultural production as water supply available for irrigation changes by an acre-foot. This measure is more precisely called the marginal value of water. It represents the incremental value of irrigation water to growers, net of any variable cost per AF for delivery by the local water district. For agricultural regions that might be willing to sell water to other regions, or to sell water as an alternative to water provided from a proposed project, marginal value is the willingness to accept payment for giving up a small amount of water. No additional profit over marginal value was included as an inducement to sellers. For agricultural regions that would potentially pay for water provided by a proposed project, marginal value is the willingness to pay for an extra increment of water supply.

SWAP Analysis Detail

SWAP regions that have been active as buyers of water transfers, according to the transfers database, have relatively unreliable surface water supply, and use volumes of groundwater that exceed, on average, the safe yield amount estimated as described above. Imposing safe yield limits on these regions has the potential for affecting crop mix. Annual variability in surface supply, coupled with limits on groundwater pumping, means that perennial crop acreage will, in future, be constrained by what can be irrigated during very dry years using the available surface water plus groundwater recharged during wetter years. Growers cannot and will not bear the cost of removing and replanting perennial crops like orchards and vineyards as water conditions change from year to year.

Therefore, the first step in the analysis of future conditions with SGMA used SWAP to calculate crop mix under critical year conditions. That acreage was used as a constraint on perennial crop acreage in other year types. Specifically, the analysis assumed an average 25-year life of orchards and vines, so that in any single year, one-twenty-fifth of acreage would typically be removed and replaced regardless of year type. Stands that are one year away from replacement were also allowed to be removed if the year is critically dry. The analysis imposed the constraint that perennial crop acreage in non-critical years can be two-twenty-fifths greater than what can be supported by the water supply in a critically dry year. This approach was not intended to be precise, but simply recognized that long run perennial crop mix must be reasonably consistent with variable water supply conditions.

Steps in the analysis to estimate unit values were:

- Calibrate SWAP to 2010 acreage and water supply conditions.
- Evaluate baseline 2030 for average, dry, and critically dry water conditions. Crop demand shifts and real pumping cost increases are incorporated to reflect 2030 conditions.
- Use critical year perennial crop acreage to create upper limits on perennial crop acreage in average and dry conditions. Re-analyze the 2030 average, dry, and critical conditions with the constraints imposed.
- Display the marginal value of water ($ per AF of applied water) by region.
- Repeat steps above with estimated safe yield pumping restrictions in place.
- Summarize results.
- Escalate to 2015 dollar values.

Some SWAP regions have a relatively reliable surface water supply and have been active sellers of water on the transfer market, according to the water transfer database. Even regions that have not been important sellers of water in past could potentially provide water from current uses as an alternative to water provided from a proposed storage project. For these regions, only the consumptively used portion of the water can be sold and transferred out of region or to another use.

SWAP Results

Results are shown in Table D-4 below. For 2030, results are provided without-SGMA pumping limits, and 2030 with-SGMA includes the restrictions. SWAP regions that include Glenn-Colusa Irrigation District, Yuba County Water Agency, Butte County water districts, and Placer County Water Agency have been active in the water transfer market and these SWAP regions were used to represent the Sacramento Valley region. SWAP regions that include Oakdale, South San Joaquin Modesto, Turlock, and Merced Irrigation Districts represent the Eastside San Joaquin region.

SWAP regions used to calculate unit value of water in the Delta export service areas of the Central Valley include Westlands Water District for the CVP and five regions in the Kern County Water Agency service area of Kern County. The Friant service area of the CVP is represented using SWAP regions that include many Friant contractors in Tulare County and a portion of Kern County. All of these regions and their water agencies are used as examples for the analysis; other potential regions could participate in a storage project or provide water for purposes of an alternative cost analysis.

Table D-4. Estimated Unit Values of Water in Central Valley Agricultural Regions from SWAP

Year	**Type**	**Unit Values from SWAP in 2015 $/AF of Applied Water**			
		Sacramento Valley	**Eastside San Joaquin Basin**	**Friant Service Area**	**Delta Export Regions**
2030	AVG	$59	$94	$179	$225
2030	DRY	$92	$142	$199	$226
2030	CRIT	$189	$265	$232	$326
2030 w/SGMA	AVG	$63	$274	$230	$519
2030 w/SGMA	DRY	$94	$330	$366	$674
2030 w/SGMA	CRIT	$197	$515	$790	$1,056

Notes:

- No adjustment for Delta carriage losses (outflow or water quality requirements) or conveyance losses have been made.
- Unit values may need to be converted to $/AF of consumptive use, depending on how and where the water is used.
- No additional profit or transactions costs over marginal value has been included as an inducement to sellers.

Proposed Unit Values of Water Supply

Unit values calculated by SWAP were used for comparison to those from the water transfer analysis and to project values for future conditions with safe yield limits imposed by SGMA. This section describes how the two analyses are combined to develop the proposed unit values.

Table D-5 shows results from the transfer price regression analysis alongside comparable estimates from SWAP. The values in Table D-4 above are on an applied water basis – that is, in dollars per acre-foot of applied irrigation water. However, water provided for agricultural use by a proposed water storage project would have value not just in its initial application, but also as return flow (non-consumptively used water) is used by others. In addition, water provided from existing uses for water transfers or instream flow generally is restricted to prevent harm to third party uses of the water. The effective value per acre-foot transferred to another use should account for that value to third parties.

To account for the total value of new water supply, and the effective value of water provided for instream flow or other uses, the values for Sacramento Valley, Eastside San Joaquin, and Friant displayed in Table D-5 are shown on a consumptive use basis. Unit values for the Delta Export region are not adjusted to a consumptive use basis because a relatively small fraction of applied water is reused. Reasons are that application efficiency is relatively high in these areas and part of the non-consumptive use returns to degraded shallow groundwater. Applicants should consider actual reuse fractions in areas receiving or providing water in order to calculate the appropriate effective value per acre-foot.

Even with adjustment for consumptive use fraction, most 2030 unit values estimated from SWAP are less than those from the water transfer analysis. The SWAP analysis does not consider the willingness to pay for water by all buyers, or transactions costs; rather, it can be interpreted as the minimum price sellers should be willing to take. Therefore, the estimated market prices might be expected to be higher than the SWAP values as is the case. For the San Joaquin Basin, the values are provided on an applied water basis.

Table D-5. Comparing Water Transfer Unit Values from Transfer Price Regressions to SWAP Unit Values

Year Type	**Unit Value Estimates (in 2015 $/AF)**									
	Sacramento Valley			**San Joaquin**						
		Comparable from SWAP			**Comparable from SWAP**					
	Table D-3 2030 unit value	**2030 (CU)**	**2045 and later, with SGMA (CU)**	**Table D-3 2030 unit value**	**Delta Export 2030 (AW)**	**East San Joaq 2030 (CU)**	**Friant 2030 (CU)**	**2045 and later, with SGMA**		
								Delta Export (AW)	**East San Joaq (CU)**	**Friant (CU)**
Wet	$185			$228						
Above Normal	$244	$138	$143	$286	$225	$133	$251	$519	$388	$321
Below Normal	$280			$322						
Dry	$301	$248	$256	$343	$226	$201	$278	$674	$466	$512
Critical	$351	$338	$347	$393	$326	$375	$324	$1,056	$728	$1,105

Notes

- AW indicates SWAP estimates per acre-foot of applied water
- CU indicates SWAP estimates per acre-foot of consumptive use

Table D-6 provides the unit values for water supply based on this information, rounded to the nearest $5 per acre-foot due to the uncertainty inherent in the analysis. For 2030, for the Sacramento Valley and Delta Export regions, the average of the transfer price and the SWAP price is suggested for years that have both. For example, for the critical year type in the Sacramento Valley, the average of the transfer price regression and the SWAP result is used: ($351+$338) / 2 = $345 per acre-foot. The transfer price analysis provides information regarding wet and below normal years that is not provided by

SWAP. The ratio of the transfer prices in below normal to dry years times the dry year unit value is used to calculate the below normal unit value, and the ratio of the wet to above normal transfer price, times the above normal unit value is used to calculate the wet year unit value for 2030.

The Delta Export values for 2030 are calculated similarly. The transfer price analysis could not identify unique estimates for transfers from the East San Joaquin region, so the above normal, dry and critical values are those from the SWAP analysis in Table D-5. The water transfer price analysis for San Joaquin transfers in general provides information regarding how the wet and below normal values differ from the above normal and dry values, respectively.

For 2045 and after, the unit values use estimates from SWAP to calculate the difference between with and without SGMA conditions. For the above normal, dry and critical condition, the unit values are those in 2030 without SGMA, times the ratio of the with-SGMA and without-SGMA SWAP results. For example, for the above normal year in Sacramento Valley, Table D-5 shows the SWAP ratio of with-SGMA to without-SGMA value as $143/$138. This ratio is applied to the 2030 value of $191, so 191*(143/138) = $198 ($200 per acre-foot after rounding). The values for the wet and below normal years are again developed using information for those year types from the water transfer analysis.

The unit values by year type in Table D-6 do not include any influence of climate change. Much of the climate change effect should be captured by a shift in the distribution of water year types, but there could be additional effect that is not captured, for example, if years classified as critical got even drier.

Table D-6. Unit Values of Water for WSIP, by Year Type, Future Condition, and Region.

Type	Sacramento Valley (in $/AF of consumptive use)	Delta Export (in $/AF of applied water)	Eastside San Joaquin Basin (in $/AF of consumptive use)	Friant Service Area (in $/AF of consumptive use)
2030 Conditions (2015 Dollars)				
Wet	$145	$205	$105	$200
Above Normal	$190	$255	$135	$250
Below Normal	$255	$265	$190	$260
Dry	$275	$285	$200	$280
Critical	$345	$360	$375	$325
2045 and later conditions with SGMA (2015 Dollars)				
Wet	$150	$415	$310	$255
Above Normal	$200	$520	$390	$320
Below Normal	$265	$635	$435	$480
Dry	$285	$675	$465	$510
Critical	$355	$1,055	$730	$1,105

Table D-6. Unit Values of Water for WSIP, by Year Type, Future Condition, and Region.

Type	Sacramento Valley (in $/AF of consumptive use)	Delta Export (in $/AF of applied water)	Eastside San Joaquin Basin (in $/AF of consumptive use)	Friant Service Area (in $/AF of consumptive use)

Notes

Applicants will need to develop their own estimates for water-related benefits not covered by the regions provided here.

To use these unit values, adjustments may need to be made depending on the source of water and location of use. For example, if the source of water is Sacramento Valley but the purchaser is in the Delta Export region, adjustment for Delta carriage losses (outflow or water quality requirements) or conveyance losses must be considered. Applicants are responsible for any adjustments to account for such losses. In addition, accommodation may be needed to account for the value of surface return flow that would be reused.

The unit values of water are based on estimates that do not, in general, incorporate third party economic costs. See section 5.3.6 of this Technical Reference for a discussion of such costs and how applicants may consider them.

Finally, the unit values that are shown in Table D-6 are in dollars per AF of consumptive use to represent the value of an acre-foot in both its initial use and in its value as return flow (except for the Delta Export region as explained above). Applicants should make their own estimates of the actual reuse to calculate appropriate total value per AF. In some cases, using the value per AF of consumptive use may be appropriate. For example, suppose an instream water quality benefit would be provided by a proposed project’s release from storage. The applicant wishes to monetize the benefit as the alternative cost of purchasing the same water from existing agricultural uses, but in order to avoid harm to local users of the return flow, only the consumptive use portion can be purchased.

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Appendix E
Methods, Data, and Sources for Monetizing Ecosystem Benefits

Methods, Data, and Sources for Monetizing Ecosystem Benefits

This appendix provides information and representative data regarding avoided cost, alternative cost and willingness-to-pay estimates for ecosystem benefits. Information is provided regarding:

- Alternative costs of habitat measures
- Recovery goals and costs for special-status species
- Contingent valuation and benefits transfer studies for Central Valley salmonids

First, the attachment shows examples of alternative cost measures where water supply is not the only potential physical measure of habitat provided. For example, wetlands and riparian areas might be created by water supply, but they could also be provided by acquiring and protecting existing wetland and riparian areas. Temperature reduction might be provided by more releases from a cold-water pool, but temperature might also be reduced by shading or by a temperature control device. The examples themselves may not be representative of conditions in a specific study area, but they show the approach and types of information that might be helpful.

Under the ESA, recovery plans must include costs, and the alternative cost of the recovery action could be used as a measure of benefit. Furthermore, recovery plans are generally not a compliance obligation, so recovery plans are useful in showing some specific ecosystem improvements that might qualify for funding.

Finally, this appendix details the potential application of contingent valuation and benefits transfers to California salmonids. This discussion supports the recommendations for valuing salmonids in Section 5.4.2.

Alternative Cost of Habitat Measures

Wetlands and Riparian Areas

No known database exists that compiles recent wetland acquisition and improvement costs. Where wetlands will be protected, improved, or created, applicants should identify similar wetland acquisitions or improvements as close to the project improvements as possible. The following recent wetland restoration projects show a variety of project types that provide alternative cost information representative of information that might be used:

- Pitkin Marsh. This 27-acre site on Highway 116 cost almost $1 million under a financial deal approved in August 2007 by the Sonoma County supervisors. Acquisition cost was about $37,000 per acre. More information about this project can be found at http://www.sonomalandtrust.org/news_room/press_coverage.html
- Sears Point Wetlands. The Sonoma Land Trust recently helped purchase lands for wetland restoration and has begun implementing restoration plans. The Sonoma

Land Trust acquired 2,327 acres of Sears Point wetlands in 2005 for about $20 million, including tidal marsh, seasonal wetlands and uplands. An additional $18 million is planned for restoration, recreation and other improvements. Total costs are about $14,200 per acre. More information about the project can be found at: http://www.pressdemocrat.com/csp/mediapool/sites/PressDemocrat/News/story.csp?cid=2371129&sid=555&fid=181

- Haire Ranch. The Sonoma Land Trust coordinated the purchase of the 1,092-acre Haire Ranch on Skaggs Island in December 2013. The cost was $8.3 million, or about $8,300 per acre. More information about the project can be found at: http://www.sonomalandtrust.org/news_room/press_coverage.html
- Cullinan Ranch. The 2010 National Coastal Wetland Conservation Grant Program Project provided $1 million for the Cullinan Ranch Restoration Project to restore 1,575 acres of vital estuarine tidal salt marsh and uplands at the San Pablo Bay National Wildlife Refuge in north San Francisco Bay. These funds leverage $6,282,940 in non-federal cost share, so the total cost per acre was $4,624. More information about the project can be found at http://www.fws.gov/coastal/CoastalGrants/docs/2010_Coastal_Grants_Project_Descriptions_State_Order.pdf and http://www.restorecullinan.info/home.htm
- San Francisco Wetland Ecosystem Restoration Program. The Wetland Ecosystem Restoration Program, proposed as a project for funding the San Francisco Bay Area 2011 IRWM, cost $25.668 million, would "create or significantly restore" 2,300 acres of coastal wetlands. The project costs $11,160 per acre.

Table E-1 summarizes information from these projects.

Table E-1. Representative Recent Costs of Wetlands Acquisition and Restoration

Name	Location	Type	Acres	Cost in dollars/acre
Pitkin Marsh	Sonoma County	Freshwater, rare species	27	$37,000
Sears Point	Sonoma County	tidal marsh, seasonal wetlands and uplands	2,327	$14,200
Haire Ranch	Sonoma County	diked baylands to wetlands	1,092, enables 4,400 restored	$8,300
Cullinan Ranch	Solano County	tidal salt marsh and uplands	1,575	$4,624
Wetland Ecosystem Restoration Program		Coastal wetlands	2,300	$11,160

Some additional information about wetland projects are their costs are provided at:

http://wsfrprograms.fws.gov/Subpages/GrantPrograms/

Table E-2 is a reproduction of the Coughlin et al. (2006) table of wetland acquisition prices up to the mid-2000s.

Table E-2. Representative Costs for Wetlands from Coughlin et al. (2006)

Name	Area acres	Price in Dollars/Acre	Date	County
Cargill Salt Flats	16,000	$8,181	2002	Alameda/Santa Clara
Ormond Beach	276	$46,739	2005	Oxnard/San Diego
San Elijo Lagoon	8	$125,000	2004	San Diego
Highway 37 Marsh	2,327	$8,637	2004	Marin/Sonoma
Rancho Santa Fe	15	$24,500	2004	San Diego
Bolsa Chica	880	$28,400	2004	Orange
Ormond Beach	500	$46,000	2004	Ventura
Santa Ana River	83	$69,500	2004	Los Angeles
San Dieguito River	132	$37,200	2004	San Diego
Huntington Beach	17	$44,000	2004	Orange

Table E-3 is a reproduction of the Coughlin et al. (2006) table of riparian land acquisition prices up to the mid-2000s.

Table E-3. Representative Costs for Riparian Lands, from Coughlin et al. (2006)

Name	Area acres	Price in Dollars/Acre	Date	County
Stornetta Ranch	1,132	$6,796	2004	Mendocino
Garcia River Forest	24,000	$750	2004	Mendocino
Monte Vista Ranch	4,056	$3,920	2005	San Diego
Santa Clara River	377	$1,525	2005	Ventura
Homer Ranch	1,837	$817	2004	Tulare
Gilroy Hot Springs	242	$9,917	2003	Santa Clara
Arroyo Seco	1,675	$1,731	2002	Monterey
Mount Hamilton	61,000	$311	1998	Santa Clara
Howard Ranch	12,360	$1,100	1999	Sacramento
San Pasqual Valley	75	$21,218	2004	San Diego
Santa Ysabel West	1,512	$1,984	1999	San Diego
Joughin Ranch	1,733	$4,155	2003	Los Angeles
Ahmanson Ranch	2,983	$50,285	2003	Los Angeles
Palo Corona Ranch	9,898	$3,738	2002	Carmel
Garcia River Watershed	23,780	$1,409	2004	Mendocino

Land purchase might be used for part of the costs of wetland habitat creation. The American Society of Farm Managers and Rural Appraisers provides current land rent and price estimates for California regions and for subregions within each of these regions by crop type (American Society of Farm Managers and Rural Appraisers, 2009). Prices are estimated by consensus of appraisers operating in each region. American Society of Farm Managers and Rural Appraisers data are available for most regions of the state with agricultural land. If agricultural land acquisition costs are used, the analysis should use sales from properties that are comparable to the area affected by the project. Costs of converting or restoring the agricultural land to the proposed type of ecosystem land use would be additional to the land cost and must be included if using this approach.

Salmon Habitat Improvements

Thomson and Pinkerton (2008) provide references for habitat restoration costs of salmon recovery planning. For each restoration activity, one or more tables are provided that include cost estimates for that activity by location, year, project scale, cost per scale unit, and data source. Restoration activities and costs covered by the report are:

- Fish ladders
- Fish passage at stream crossings — culvert replacement/improvement
- Fish screening of diversions
- Instream barrier modification — modification of fish passage barriers in the stream channel and along the streambank (tide gates, sandbars, dams, other non-culvert barriers)
- Instream habitat restoration — enhancement of stream channel and streambank habitat (instream structures, spawning gravel supplementation, floodplain tributary reconnection, side channel reconnection, wetland/floodplain restoration, levee evaluation/repair/setback)
- Riparian restoration — restoration of area, including fencing, between the fence and middle of stream (e.g., livestock exclusion, revegetation)
- Streambank stabilization — stabilization of eroding, collapsing of otherwise de-stabilized banks
- Upland watershed restoration — largely pertains to upslope erosion control (e.g., road decommissioning/upgrade, landslide/gully stabilization, upslope planting)
- Tailwater management
- Water conservation — e.g., ditch lining, piping
- Water purchase/lease
- Habitat acquisition and conservation easement
- Monitoring status and trends — monitoring of baseline conditions and status/trends in habitat, watershed processes and/or populations.

- Monitoring watershed restoration — monitoring to determine if project treatments were constructed correctly and as planned, effectiveness monitoring to determine if restoration has produced desired habitat conditions and/or watershed processes, and validation monitoring to determine if hypothesized responses of habitat, watershed processes and/or populations to restoration were correct
- Watershed evaluation, assessment and planning — developing watershed plans with site-specific, prioritized recommendations for restoration of salmon/steelhead habitat. Includes partial assessments (e.g., road erosion surveys, stream surveys).
- Watershed organizational support and assistance — organizational support to local watershed groups and development/maintenance of databases that facilitate organizational aspects of restoration
- Cooperative fish rearing
- Water measuring devices — e.g., head gate
- Wildlife management — e.g., control of exotic species such as pike minnow
- Research — general research on productivity (e.g., life cycle monitoring/analysis), spatial structure (fish distribution surveys), genetic diversity (laboratory analysis of tissue samples), and estimation of abundance.

Allen et al. (2004) provide references for salmonid habitat costs including stream restoration, riparian restoration, road improvements, floodplain restoration, and fish protection facilities.

Recovery Goals and Costs for Special-Status Species

A variety of sources are available that document special-status fish recovery goals and costs of fish recovery actions and improvements. For Central Valley winter-run salmon and steelhead, the most recent recovery plan was produced in 2014 (NMFS, 2014). Table E-4 summarizes the status and recovery goals for the covered fish. In total, at least 1,500 escaping winter-run Chinook salmon, with at least 500 in each of three populations, would be needed for Endangered Species Act (ESA) recovery. For winter-run Chinook, all of the populations would be in the Basalt and Porous Lava diversity group.

Table E-4. Extinction Risk and Recovery Goals for Winter Run Salmon, Spring Run Salmon and Steelhead Trout

Extinction Risk	Minimum Escapement/ Population	Winter Run	Spring Run	Steelhead	Catastrophic Events in Last 10 years	Hatchery Influence
		Total Number of Populations to Recover				
		3	9	9		
		Total Escapement Goal, evenly distributed among populations				
High	N<50	N<150	N<450	N<450		High
Medium	50<N<500	150<N<1500	450<N<4500	450<N<4500	none	Med

Table E-4. Extinction Risk and Recovery Goals for Winter Run Salmon, Spring Run Salmon and Steelhead Trout

Extinction Risk	**Minimum Escapement/ Population**	**Winter Run**	**Spring Run**	**Steelhead**	**Catastrophic Events in Last 10 years**	**Hatchery Influence**
		Total Number of Populations to Recover				
		3	9	9		
		Total Escapement Goal, evenly distributed among populations				
Low	N>500	N>1500	N>4500	N>4500	none	Low
Recovery	N>500	N>1500	N>4500	N>4500	none	Low
	Additional populations		More populations maintained at medium risk or better		none	Low

Central Valley steelhead trout and spring-run Chinook salmon each require at least 500 escaping adults in nine populations each, or at least 4,500 escaping fish, with additional fish in other populations, each with 50 to 500 individuals. For both of these species, two populations would be in the Basalt and Porous Lava diversity group, one in Northwestern California, four in Northern Sierra, and two in the Southern Sierra.

It is unlikely that any one water storage project would provide substantial help with recovery for all of the species' populations slated for recovery. For spring-run salmon and steelhead trout, the nine populations for each species are spread around the Central Valley. The recovery targets will require that new populations be established for each species. Even for winter-run Chinook salmon, only one out of the three populations, the one in the mainstem Sacramento River, currently exists. Two other habitats, the McCloud River and Battle Creek populations, are classified as primary:

> *"Primary areas for reintroductions are areas where there is a known high likelihood of success based on species-specific life history needs, and available habitat quality and quantity."* (NMFS, 2014 p. iv)

The populations proposed for recovery, and their re-introduction plans and priorities, are shown in Tables 3-4 through 3-6 of the recovery plan.

The 2014 recovery plan provides detailed tables of recovery plan actions and expected costs. Actions covered in the document are listed by watershed. Most could potentially be affected by a WSIP-funded project. Table E-5 lists some recovery actions and the costs provided.

Table E-5. Central Valley Winter Run Salmon, Spring Run Salmon and Steelhead Selected Recovery Actions and Related Costs from 2014 Recovery Plan

Region/Action	**Million $, One-Time Cost Unless Noted**
Central Valley	
Ecosystem based management approach	$9.6

Table E-5. Central Valley Winter Run Salmon, Spring Run Salmon and Steelhead Selected Recovery Actions and Related Costs from 2014 Recovery Plan

Region/Action	Million $, One-Time Cost Unless Noted
Enforcement poaching, stream alterations, pollution	$60.0
Central Valley Steelhead Monitoring Plan	$7.5
Evaluate and implement actions for invasive species	$551.0
Coordinate operations and transfers for fish	$5.0
Assess opportunities for re-introductions above big dams	$5.0
San Francisco, San Pablo and Suisun Bay	
Wastewater and stormwater capture/management	$3,331.0
Complex portfolio of habitats	$100.0
San Francisco Estuary Partnership Comprehensive Conservation Management Plan	$60-$80
Agricultural drainage management	$20 to $110 per acre
Reduce anthropogenic inputs of NH4 to achieve concentrations below 4 µmol L-1 (Sacramento Regional Wastewater Treatment Plant)	$1,000 to $2,000
Evaluate and implement predator control actions	$0 to $75
Quantify predation on juvenile salmonids	$0.2 to $0.4
Identify and manage predation hot spots	$0.038 per site
Educational outreach	$0.4
Marine mammal predation studies	$1.5
Delta	
Reduce hydrodynamic and biological impacts of exporting water through Jones and Banks	$8,600 to $14,500 plus $85.0 annual
Landscape scale ecological restoration	$600 to $13,000
Targeted smolt research and monitoring	$627.0
New South Delta floodplain habitat for San Joaquin River salmonids	$950.0
Prospect Island Tidal Habitat Restoration Project	$32.0
Southport Floodplain Restoration Project	$55 to $160
Dutch Slough Tidal Marsh Restoration Project	$25 to $30
Projects to reduce predation at weirs, diversions, etc.	$50.0
McCormack Williamson Tract Integrated Flood Management	$10.0
Lindsay Barker Slough	$0.4 to $3.4
Reconnect Elk Slough to the Sacramento River	$5.2
Grizzly Slough Floodplain and Riparian Habitat	$0.25 to $4.0
Screen Delta Diversions	$20.0
Implement Actions for Invasive Aquatic Species	$551.0
Sacramento River	

Table E-5. Central Valley Winter Run Salmon, Spring Run Salmon and Steelhead Selected Recovery Actions and Related Costs from 2014 Recovery Plan

Region/Action	Million $, One-Time Cost Unless Noted
Reintroduce winter run, spring run and steelhead salmon above Shasta Dam through pilot reintroduction phase	$50.2
Restore and maintain diverse riparian and floodplains	$42.1
M&T Ranch adequately screened	$9.5
Flow management plan below Shasta, Keswick	$0.7
Gravel augmentation plan	$2.3
Secondary winter run Chinook trapping for Livingston National Fish Hatchery	$27.4 plus $0.14 to $0.69 annual
O&M Lewiston and Whiskeytown Temperature Control Curtains	$0.15 annual
Whiskeytown replacement every 15 years	$3.5
Lewiston if needed	$1.5
Adult fish rescues	$0.1 in 2013
Restore current lake Red Bluff footprint to riparian	up to $6.75
Clear Creek	
Clear Creek floodplain, riparian, instream habitat	$5.0
Feather River	
Reintroduce spring run and steelhead salmon above Oroville Dam	$50.2
Yuba River	
Reintroduce spring run and steelhead salmon above Englebright	$50.2
American River	
Reintroduce spring run and steelhead salmon above Folsom	$50.2
Gravel management	$5.0
Wood management	$1.2
Mokelumne	
Reintroduce steelhead above dams	$20.2
San Joaquin River	
Develop and implement flow regime	$16.9
Wastewater and stormwater capture/management	Up to $0.1 each
Reintroduce steelhead above Friant Dam	$50.2

Few studies of restoration actions include both the expected amount of improvement for aquatic species and the costs. DWR (2015) provides engineering and cost estimates for Delta actions intended to reduce juvenile salmonid exposure to Delta export facilities. The report concludes:

> *"Based on current information that was evaluated by the TWG, if there is a demonstrated need to implement an engineering option at one or more of the five junctions, the following are the currently preferred options for implementation:*
>
> - *Georgiana Slough – Bio-Acoustic Fish Fence (BAFF)*
> - *Threemile Slough – BAFF*
> - *Head of Old River – Floating Fish Guidance System*
> - *Turner Cut – BAFF*
> - *Columbia Cut – BAFF"*

With costs and protection efficiencies, the cost per unit of protection can be estimated. For Georgianna Slough, for example, the BAFF reduced entrainment from about 24 to 12 percent (p. 3-11). The cost comparison on page ES-7 of the report shows that the present worth cost of this BAFF was $25.6 million dollars. Therefore, the present worth cost of reducing salmonid entrainment by 1 percent is roughly $2 million.

The existing recovery plan for Delta smelt and other resident fishes (1996) "is out of date. We are currently working on a new plan" (USFWS, 2015). The new plan might be available in 2017. If it is available before WSIP applications are due, there may be useful cost information.

California Department of Fish and Game and DWR (2005) shows costs of actions to increase populations of Delta smelt. Table E-6 summarizes expected costs. Total one-time cost for all of these actions was expected to be about $100 to $125 million, not including new Delta conveyance, plus $40 to $85 million in annual costs, mostly for Environmental Water Account purchases to reduce entrainment.

Table E-6. Delta smelt related costs from 2005 Delta Smelt Action Plan

Action	Description/Source	Million $ Annual Cost	Million $ One-Time Cost
Interagency Ecological Program	Estuary monitoring and research program conducted by six federal and three state agencies. Includes longfin smelt, threadfin shad, and other pelagics.	$13.5	
Additional funds to augment IEP		$1.7	
Future POD work	Page viii of the Action Plan	$5.0	
Delta Regional Ecosystem Restoration Imp. Plan	Funds are for approved ERP monitoring projects		$3.0
Suisun Marsh Actions	Currently approved restoration projects and up to an		
	Additional $5 million for future projects '05 to '08		$10.0
Increase Food Web Productivity	Freshwater and brackish tidal marsh and seasonal floodplains		$5 to $30

Table E-6. Delta smelt related costs from 2005 Delta Smelt Action Plan

Action	Description/Source	Million $ Annual Cost	Million $ One-Time Cost
Reduce Entrainment at Power Plants	Gunderbooms	$0.6	$7.0
Environmental Water Account Equivalent	Historic cost. May includes actions for all fish	$20 to $64	
Environmental Water Account Decision-Making for Export Curtailments	More rapid response to critical time-sensitive issues	Additional Environmental Water Account cost	
Alternative conveyance		Could be billions	
Modified Barrier Installation at Head of Old River	Look for SDIP draft EIS/R Would save $2 million annually in temporary barrier costs?		$75.0
Contaminants Management			$0.2 to $0.5
Control of Invasive Species			unknown
TOTAL	Not including modified conveyance	$40.8 to $84.8	$100.2 to $125.5

The Draft Environmental Impact Statement for the Coordinated Long-Term Operation of the Central Valley Project and the State Water Project (Reclamation, 2015) compares delta smelt entrainment and water supply under long-term operating alternatives. Analysis of trade-offs between entrainment and the value of water supply could be developed based on information provided in the impact statement.

Market Prices

Market price techniques in this context refer to the use of market price as the measure of gross willingness-to-pay per unit for the public benefit. Market prices should be used to value goods that are sold in competitive markets. Market price techniques can often be applied to estimate use values, but usually cannot be used to estimate non-use values. For California, ecosystem services sold in competitive markets include commercial fall-run salmon and recreational charter and guide services for salmon and steelhead.

Many ecosystem services have value because they are inputs in a production process or they are end-user products that are bought and sold in reasonably competitive markets.

For commercial fishing, Engineer Regulation 1105-2-100 (USACE, 2000) provides this guidance:

> *"Estimate the harvest of the exploited stocks. Estimate the seasonally corrected current price of the harvested species and the total cost of harvesting in each of the relevant years if a plan is undertaken. Calculate the ex-vessel value of the harvest (output) for each alternative plan and for the without plan condition. Determine the harvesting costs, for the level of catch (output) identified by each alternative plan and the without plan condition. Compute the benefit as the value of the change in harvest less the change in harvesting cost from the without plan condition to the with plan condition."*

Data related to the recreational and commercial catch of salmon is provided by the Pacific Fisheries Management Council (PFMC) (PFMC, 2016a). Recreational fishing benefits from fishing for native fish can be counted as an ecosystem benefit.

Hedonic Pricing Method

Hedonic pricing refers to techniques that use observed market prices to estimate the value of specific attributes of a good or service. In the case of public benefits, real estate values can sometimes be used to estimate at least some of the value of the public benefit. The prices of real estate and information about the public benefits attributes of the real estate can be used to infer the value of the attributes. The method is appropriate where an important share of the public benefit is captured by landowners and where the benefit for these lands is large enough to be measurable by comparison to similar lands that do not enjoy the public benefit.

A hedonic price equation is estimated using statistical methods from a cross section of sales and attribute data for properties in a given property market. The hedonic price equation calculates a property's price as a function of its attributes. In this context, the analysis would include public benefit attributes such as presence or amount of ecosystem services or recreational amenities, water quality measures, amount of waterfront, or incidence of flood damage. Coefficients in the hedonic price equation can be used to estimate the share of property value attributable to the public benefit. Additional use values and non-use values usually apply for people who do not receive the property related benefit, and their benefits must be estimated separately, taking care not to double-count benefits.

Revealed Preference Studies

Revealed preference methods use observed behavior, but not market purchases of the good itself, to infer willingness to pay. Travel cost models value recreation use based on distance travelled; more distance travelled implies a higher willingness-to-pay. Votes for an initiative that raises taxes to fund public benefits imply willingness-to-pay. Voluntary contributions to environmental causes or to the provision of public benefits suggest willingness-to-pay. Preferences are also revealed by behaviors that seek to avert, avoid, or insure against damages or costs. Examples include purchases of bottled water, home water filters, and flood insurance. The costs of such behaviors indicate willingness-to-pay. Revealed preference methods can be used for use and non-use values, but some “free-riders” may never act on their non-use values; for example, they may never give to environmental charities even though they value endangered species because they are satisfied that enough others are already giving.

Revealed preference methods can be used for certain ecosystem benefits. Recreation and water quality benefits are discussed in their respective sections. The method requires that individuals will be aware of the benefits they will receive. This is sometimes not the case when benefits are distributed over a large population because the improvement per capita is small.

Survey-Based Methods

Survey-based methods seek to estimate willingness-to-pay by using questionnaires. Contingent valuation uses a questionnaire to ask people if they would be willing to pay, or if they would pay, for some hypothetical improvements. Willingness-to-pay can also be derived from questions regarding whether the respondent would vote for a measure that would increase taxes to finance specified improvements. Conjoint analysis asks individuals about attributes of goods and uses rankings to infer value. Survey-based methods may be important for obtaining information on amount of use where data are not routinely collected. In particular, much recreation use is not counted through observed market sales, so surveys are often used to count visitors, determine their characteristics, and build use-estimating or travel cost models.

Contingent valuation and survey methods are controversial methods in economics. Many studies have cast doubt on the validity of survey methods for accurately eliciting willingness to pay (Hausman, 2012; Diamond and Hausman, 1994; Neill et al., 1994). These studies do not question that people place some value on the good in question, but on the ability of a survey to elicit reliable answers. It is clear that survey methods must be carefully designed to avoid bias. Additional issues arise in extrapolating survey results to the larger population.

Survey-based methods for ecosystem benefits are widely used in economics, primarily because ecosystem values often have multiple attributes and a large non-use component. Few other methods are available to estimate non-use values. A number of California applications are discussed below.

Reclamation’s Economic Guidebook does not mention non-use values as part of the value of fish and wildlife, nor does it suggest use of survey-based methods. Fish and wildlife values include commercial, recreational, or non-consumptive use such as bird watching. USACE guidance specifically discourages use of survey-based methods for ecosystem values.

Reclamation (Reclamation Technical Service Center, 2008) recently reviewed the state of science for non-use valuation and recommended (p. 62):

> *"… a study only be considered for nonuse valuation if T&E (threatened and endangered) species are involved and significantly affected (the significance determination should be made by study team biologists)*

But later:

> *"… the decision was made to forgo pursuing a site- and study-specific nonuse value survey and simply exclude quantification of nonuse values from the feasibility-level BCA. Instead, a qualitative discussion of nonuse values will be included in the feasibility study/EIS."*

Benefit Transfer

Benefit transfer is the technique of interpolating or extrapolating benefit estimates from studies done for other similar locations or resources and then applying those values to the proposed project, for which such studies have not been performed. The term has been most widely applied to transfer of results from survey based methods, but the same procedures and problems generally apply for other methods as well. Benefit transfer methods have recently been summarized (Wilson and Hoehn, 2006; Rosenberger and Loomis, 2001; Johnston et. al., 2015).

Benefit transfer usually invokes many issues involving comparability. The available benefit estimate may need to be adjusted for differences in time, location, quantities, and qualities between the original benefit estimate and the subject project, including species, size, productivity, aesthetics, inflation, location, and demographic differences. Benefit transfer has great potential for error, but it is often used because it is inexpensive or because no other information is available.

Benefit transfer methods are often used for ecosystem valuation. The Beneficial Use Values Database (BUVD), maintained at the University of California Davis, provides many studies that might be used for benefit transfer (Larson and Lew, 2011). A useful discussion of benefit transfer methods is also provided in Ghermandi et al. (2008).

The Benefit Transfer and Recreation Use Estimating Model Toolkit (Toolkit) is another resource (Loomis and Richardson, 2008). The Toolkit is available through the Agricultural and Resource Economics Department of Colorado State University. The Toolkit consists of several spreadsheet tables, templates, and models that estimate values for wildlife recreation, common wildlife habitats, and threatened and endangered species. Technical documentation provides guidance selecting appropriate benefit transfer methods and visitor use estimating models. Benefit transfer examples are also included in the technical documentation.

The spreadsheet tables, templates, and models include the following

- Use values for fish and wildlife
- Use values per day of hunting, fishing, and viewing
- Use and non-use values per acre of habitat
- Use and non-use values per household of threatened and endangered species

The use and non-use values include average values, databases of the individual studies, and meta-analysis equations to tailor the benefit transfer to specific study sites.

Visitor characteristics for hunting, fishing, and wildlife viewing are available for National Wildlife Refuges, Wildlife Management Areas, and private, state, and federal lands in California (for example, Sexton et al., 2012). The visitor use estimates might be used with values per visitor day to undertake recreation benefit transfer studies.

Links to some other, potentially useful databases, valid as of June 2016, are provided below:

- http://www.environment.nsw.gov.au/publications/evri.htm
- http://www.environment.nsw.gov.au/envalueapp/
- https://www.evri.ca/Global/Splash.aspx
- http://www.ecosystemvaluation.org/links.htm

Benefits Transfers Using Contingent Valuation Studies for Anadromous Salmonids

In the last 20 years, more than a half dozen contingent valuation studies have estimated the use and non-use value of west coast anadromous salmonids (i.e., salmon and steelhead trout). Hanemann et al. (1991) estimated the willingness-to-pay of California, Nevada, Oregon, and Washington state households for restoring salmonid runs to the upper San Joaquin River. This study introduced the double-bounded, or double referendum survey format. Respondents were offered an increase of about 15,000 fish from a base of about 100 (Loomis, 1999). The statistical analysis estimated a point estimate of willingness-to-pay from the double-bounded model of $181 per household. Adjusting for inflation to 2015, and multiplying by 15 million households expected by 2030, the benefit per fish worked out to be about $300,000.

Since then, this format has been tested and scrutinized for its potential bias. Most recently, Kim et al. (2012) summarized a large amount of literature that criticized the double referendum survey format:

> *"… the double referendum method has been criticized because it suffers from various forms of response bias… including starting-point bias, in which responses to the follow-up question depend on the initial bid amount offered… shifting-effect bias, in which the respondent interprets a*

> *change in the offered price to be a signal of altered quality of the project… and strategic bias, in which respondents see the new bid amount as a signal that they can bargain over the price…"*

Given these uncertainties, and because the study is now 25 years old, results from the Hanemann et al. (1991) study are not recommended for a direct application to the WSIP (though see Hanemann's more recent survey and results discussed below).

Olsen et al. (1991) estimated the willingness-to-pay of households in the Pacific Northwest for increases in salmon and steelhead fisheries in the Columbia River Basin. This study is not discussed further because the more recent Layton et al. (1999) study, see below, covers the same general area and provides similar results.

Bell et al. (2003) conducted a study that proposed an improvement of coho salmon populations in Washington coastal communities, but the improvements were not expressed in population numbers. Rather, increases in allowable catch were shown. Payments for 5 years were assumed. This study is not considered for additional analysis for WSIP because the primary metric of improvement was catch. The main species of interest in California are endangered or threatened, and catch is a minor share of potential economic value.

Four additional studies provide more recent or potentially more comparable information.

Loomis (1996) estimated the willingness-to-pay of households across the nation for an increase in salmonid populations based on the removal of dams on the Elwha River in Washington State. In this study, the population increment was 300,000 fish. Payments for 10 years were assumed. The mean annual 1994 willingness to pay per household was $59 in Clallam County, a rural coastal county on the Olympic Peninsula, $73 for the rest of Washington, and $68 for households in the rest of the United States. The fish population increases proposed in the survey questions included 200,000 pink salmon, a species not often sought for sport or food, plus chum, another less-sought after species, both which are not proposed for recovery in California. Only one population increase, 300,000 Chinook salmon, was proposed for a species relevant to California. The recovery goals for California salmon and steelhead are 1,500 to 4,500 fish (Table C-2), roughly two orders of magnitude less than the numbers posited in the Elwha study. Therefore, there would seem to be little basis for a benefits transfer to the substantially different populations in California.

The Klamath River Basin Restoration Nonuse Valuation Study (Mansfield et al., 2012) attempted to elicit total willingness-to-pay for fishery improvements in the Klamath River, California and Oregon. The fish species of concern were Coho and Chinook salmon, steelhead trout, and shortnose and Lost River sucker. The survey instrument showed "numbers of wild Chinook salmon and steelhead trout" and "risk of extinction for suckers and Coho salmon," Respondents were asked if they would pay a fixed amount ($12, $48, $90 or $168 per household for 20 years) for improvements, which were "increasing numbers of wild Chinook salmon and steelhead trout" (30 percent, 100 percent or 150 percent) and "lower risk of extinction for suckers and Coho salmon" (varying from very high to low).

Page ES-10 of their report describes the statistical results. Apparently, these important attributes of the plan accounted for “a modest share of the total value of the plan.” Stated differently, different levels of fish populations did not have an important influence on stated willingness-to-pay. Similar to many contingent valuation studies, many votes might represent a general approval or disapproval with the concept of an “Action Plan” or with ecosystem restoration as a concept, rather than a calculated willingness-to-pay based on levels of fish or extinction risk. Contingent valuation results often show a surprising lack of response to scale, a drawback that has been called “embedding” (McFadden, 1994; Hausman, 2012).

Simulation using regression equations were used in the study to estimate willingness to pay for specified scenarios. Action Plan 1 proposed to increase numbers of wild Chinook salmon and steelhead trout by 30 percent, reduce risk of extinction of Coho salmon from high to moderate, and reduce risk of sucker extinction from very high to high. The restricted sample removed surveys where respondents strongly agreed that “It is important to restore the Klamath River Basin no matter what it costs” (pages 7 to 14). Using the restricted sample, the annual willingness-to-pay for households in the 12-county region for 20 years was estimated to be $121.85 per year, and for the rest of California and Oregon, $213.03 (Table ES-7, page ES-12). The small confidence interval around this estimate reflects a significant willingness-to-pay for Action Plan 1.

However, Tables 7-9 through 7-14 and 8-2 and 8-3 of the study suggest that the important attributes of the plan can account for only a small share of the total willingness to pay. In Tables 7-9 through 7-14, coefficients on salmon and steelhead population size, and on Coho risk of extinction, are often not significant. In Table 8-2, the reduced Coho extinction risk from high to moderate accounted for only about $50 of willingness to pay, with a large confidence interval, and in Table 8-3, the population increase from 30,000 more to 100,000 more apparently did not contribute positively to the willingness to pay, and improvement from 30,000 more to 150,000 more contributed just $10.59 to the willingness to pay, and the confidence interval ranged from -$28 to $50. The annual willingness-to-pay for 20 years for households for just the Coho risk of extinction improvement (from high to moderate) in the 12-county region was $37.75 per year, and for the rest of California and Oregon, was $49.10 (Table ES-7, page ES-12), both with large confidence intervals.

In summary, the Klamath Survey might provide usable willingness to pay estimates for reduced Coho extinction risk, but with low confidence. However, based on Table 8-3, we cannot reliably assign any willingness to pay to the population increases for Chinook and steelhead based on this study. Comparable Central Valley special status species are generally Chinook salmon and steelhead, not Coho. This is another reason why this study may be unreliable as a basis for benefits transfer to California.

For projects applying for WSIP finding, a desirable benefits transfer study would provide willingness to pay estimates that could be applied to different baseline populations and population increments. The Klamath study does not provide a useful basis for benefits transfer for Chinook salmon and steelhead because there was no consistently significant positive relationship between population levels and willingness to pay.

In another recent study involving salmonids in the Pacific Northwest, respondents were asked to value increases in fish populations in Washington (Layton et al., 1999). Useful results relative to the California case are provided for the Columbia River migratory fish and for Puget Sound migratory fish, using a high baseline fish population in 20 years (assumed to be recent population levels) and a low baseline where future populations would be a quarter of the size (Columbia) or half (Puget Sound) of what they are now. In this study, respondents seemed to provide values highly dependent on the overall size of the improvement. Unlike the Mansfield et al. study, the statistical estimates on population increase were very significant. Reclamation (Reclamation Technical Service Center, 2008) has also reviewed this study for its potential application to valuing salmonids in the Yakima River basin.

Willingness to pay values can be simulated using the Layton et al. equation (7) (page 15) which is based on their preferred modified logarithmic specification. This allows an implicit average value per fish to be estimated using the willingness to pay at the 5 percent improvement. The study assumed payments for 20 years. This calculation can easily be changed to be consistent with WSIP assumptions regarding constant dollar year, planning horizon, and discount rate. The household willingness to pay can also be adjusted for the response rate (68 percent) assuming that non-respondents have no willingness to pay.

For the smallest baseline population in the study (Eastern Washington and Columbia River Migratory Fish, 500,000 fish) the 5 percent increment is 25,000 fish. The annual 2000 willingness to pay per household for this improvement for 20 years is estimated to be $7.80. The equivalent annual value of $7.80 for 20 years, if paid over 100 years, is $4.01 (using a real 3.5 percent discount rate). With about 15 million households in California by 2030, a response rate of 68 percent, and escalating the values by 42 percent to account for inflation between 2000 and 2015, the value of each of the 25,000 fish would be $2,335 per year for 100 years. Rounding provides a value of about $2,500 per fish.

This result from the Layton et al. study is reasonably representative for escapement of non-listed, fall-run Chinook salmon in California. Numbers of these fish are roughly 500,000 per year (PFMC, 2016b), similar to the baseline CM population used by Layton et al. In keeping with the original study, the representative value derived above can be applied to adults entering freshwater (as opposed to spawners). Helvoigt and Charlton (2009) reviewed use values of commercial and recreationally caught fish. Based on the combination of these studies, a t total value of $3,000 per fish entering fresh water should be sufficient to cover commercial and sport values as well as the additional ecological and non-use values.

For special-status salmon and steelhead runs, a number of arguments can be made for different willingness to pay values per fish. Most importantly, the baseline populations for special-status species in California are generally much smaller. From Table C-2, the recovery goal for winter-run Chinook salmon is 1,500 adults, and for spring-run Chinook and Central Valley steelhead, 4,500 adults. Generally, the status of these fish and the smaller baselines should result in a much higher value per fish compared to what the Layton et al., estimate suggests. That study provides a good basis for benefits transfer for species with large populations, but does not apply well for the range of baseline special-status species populations and improvements likely to be provided by California projects applying for WSIP funding.

For this purpose, a more recent and local study by Hanemann (2005) provides an alternative that is update to his earlier work on the San Joaquin River. The survey instrument asked:

> *"I would like to ask you a couple questions regarding a potential bond measure that may be on the ballot in an upcoming election. The San Joaquin River, one of four major rivers in the San Joaquin Valley, is the second longest river in California. Since the late 1940s most of the water that once flowed in, almost 150 miles of the San Joaquin River downstream of the Friant Dam (near Fresno), has been diverted – and 60 miles of the river now go completely dry in most years. Whereas there used to be tens of thousands of salmon in this stretch of river, these salmon runs have been completely destroyed, along with much of the river habitat for other fish, birds, and wildlife.*
>
> *There is currently a proposal to increase water flows in the San Joaquin River in order to restore the salmon runs, which would include sufficient water to maintain a continuous flowing river in almost all years. Additional benefits would include increased habitat for other San Joaquin Valley fish and wildlife, and increased recreational opportunities such as canoeing and rafting."*

Results found that 11.9 million California households would be willing to pay an average of $137 to $162 per household annually, or $1.6 billion to $1.7 billion annually for the proposed improvement.

From the survey language above, the proposal would "restore the salmon runs" which "used to be tens of thousands." It is hard to say exactly how respondents would have interpreted this scenario. If the range of potential improvement perceived was 20,000 to 50,000 fish, then the apparent willingness to pay per fish, for 15 million households, is $41,000 to $122,000.[2] The median of these values is roughly $80,000 per fish. If this value per fish is extended to the size of recovered populations, it suggests that each of 15 million 2030 households would be willing to pay $8 per year for winter run Chinook salmon recovery, and $24 per year for recovery of spring run Chinook salmon or central valley steelhead, or a total of $56 per year for recovery of all three species.

Many benefits transfer studies use contingent valuation results to extrapolate to other fish populations. Benefits transfer studies, because they are based on the existing contingent valuation studies previously discussed, do not add empirical content, and they generally do not address the small population sizes in the California case.

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[2] 15,000,000*137/50000 to 15,000,000*162/20000 equals $41,100 to $121,500.

Weber (2015) reviews the available information from contingent valuation studies to consider a potential benefits transfer to the Willamette River in Oregon. Results show the large potential variation in benefits per household ($47 to $4,370) when using a range of reasonable benefits transfer methods. The author recommends structural benefits transfer as opposed to meta-analysis, and provides a reference list.

Loomis and Richardson (2008) provide technical documentation for a benefits transfer model for recreation, species, and habitats. A salmon meta-analysis developed a statistical analysis using all of the studies above except the more recent Klamath basin study. The resulting equation was:

$$\text{Willingness to pay} = 0.843577P - .001182P^2$$

Where

Willingness to pay is household willingness to pay, per year, for percent increases in salmon populations, and

P is percent increase in salmon population.

So, for example, a 5 percent increase in salmon population would provide an annual increase in household willingness to pay of $4.19. This value is similar to the willingness to pay for a 5 percent improvement from the Layton et al. (1999) study where the baseline was 500,000 fish. Another meta-analysis (Loomis and Richardson, 2009) was applied to rare species. This model calculated willingness to pay estimates that were about double those of the 2008 study (Weber, 2015).

Loomis (1999) developed a benefits transfer equation that estimated willingness-to-pay per household based on fish population size using results from Loomis (1996), Olsen et al. (1991) and Hanemann et al. (1991). The valuation equation suggested, for a population of 4,000 fish, a willingness-to-pay of over $1 million per fish. Helvoigt and Charlton (2009) used this same benefits transfer method to value non-use benefits of salmon in the Rogue River in Oregon.

These benefits transfer studies, or a new benefit transfer analysis using an existing contingent valuation study, shall only be used with justification based on the specific proposed salmonid benefit. None of the studies just described used survey results where respondents were asked to value small population increments added to small populations, as would be applicable for most species of interest in California. Hanemann (2005) provides the most recent study in California for species proposed for recovery in the Central Valley. Benefits transfers based on this study, using the implied unit value of $100,000 per escapement, may be applicable for Central Valley listed salmonids. See Section 5.4.2 for additional discussion.

In a study regarding the value of preserving natural habitats unrelated to salmonids, the State Water Board considered changes in water diverted for use in Southern California from streams flowing into Mono Lake. Reduced flows into the lake were affecting resident and migratory birds. California households received a mail survey asking whether they would pay more on their water bill to restore flows to the lake. The average willingness-to-pay per household was estimated to be $156 per year. This supported the idea that the general public's interest in increased water in Mono Lake could be an important part of the water allocation decision.

The state hired a consulting firm to conduct a more in-depth survey. The survey included images showing the lake at different water levels and provided information about effects of lake levels on different bird species. Survey respondents were asked how they would vote in a hypothetical referendum. This study also suggested that the benefits of a moderately high (but not the highest) lake level were greater than the costs.

A benefits transfer analysis should consider the willingness to pay of non-respondents. The Klamath River Basin Restoration Nonuse Valuation Study had a response rate of 32.8 percent (Mansfield et al., 2012). The researchers found that the "non-respondents may have been systematically different" so they aggregated "over a portion of households equal to the proportion of the sample that returned the survey" (See page ES-13 of the study). Stated differently, the willingness to pay was not aggregated over the entire population of households in the region; the willingness to pay of non-respondents was assumed to be zero. This convention should be applied for any use of benefits transfer to estimate benefits for WSIP.

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Appendix F

Economic Models for Evaluating Public Benefits

Economic Models for Evaluating Public Benefits

This appendix covers some economic models that might be used to help monetize public benefits. Applicants are not required to use the models described.

Ecosystem Improvement

No relevant, practical economic models of general application are known. Specific studies that may be used, where appropriate and justified, to estimate benefit values for salmonids are described in Appendix E.

Water Quality

Lower Colorado River Basin Water Quality Model

This model estimates benefits of source water salinity reductions for urban water supplies. The Lower Colorado River Basin Water Quality Model was developed by Reclamation (Lower Colorado Region) and Metropolitan in 1998. This model was updated as part of Metropolitan's and Reclamation's 1999 Salinity Management Study. The current version of the model maintained by DWR was updated with population data from DWR, and costs have been updated to 2007 levels. Most salinity costs are the reduced life of appliances and infrastructure, treatment costs, and degradation of groundwater resources. Metropolitan and Reclamation's Salinity Management Study (1999) contains a complete reference of the data and their source material.

Additional SWP water generally reduces south coast salinity costs because SWP water is less saline than most other south coast water supplies. The model inputs from CalSim-II and DSM2 are SWP East and West Branch deliveries and TDS of these deliveries in mg/L, respectively. Some water diverted at Banks Pumping Plant is conveyed directly to Southern California; other supplies are mixed in San Luis Reservoir with water diverted at Jones Pumping Plant. Salinity inputs from the California Aqueduct should be calculated at a point south of San Luis Reservoir.

Lower Colorado River Basin Water Quality Model divides Metropolitan's service area into 15 subareas. The division of the south coast region into subareas provides detail regarding sources of water and salts in each area. This detail is necessary because each region obtains very different shares of supply from different sources; and some sources, the Colorado River and groundwater in particular, have higher salinity than others.

The model is large and complex. Mann (2011) used regression analysis to develop an equation that can estimate south coast salinity benefits from changes in SWP supplies and salinity. The Lower Colorado River Basin Water Quality Model was run for export salinities ranging from 160 to 280 mg/l, and with SWP water supplies ranging from 9,000 to 190,000 AF to obtain 177 observations for a regression analysis. Economic cost was estimated as a function of the level of SWP supply and TDS in mg/l. The regression equation with the best fit is:

$$\text{Cost} = 4948 - 0.2526\text{SWP} + .16458\text{TDS} + 0.00066147(\text{SWP}*\text{TDS})$$

Where

Cost = Million 2010 $ south coast salinity cost,

SWP = TAF of SWP supplies, and

TDS = mg/l salinity of SWP supply

This functional form provided an R-squared of 0.992 and an adjusted R-squared of 0.984. This equation can be used to approximate salinity reduction benefits from changes in south coast SWP supplies; estimates should be updated to 2015 dollars using factors provided elsewhere in this Technical Reference.

Bay Area Water Quality Model

The Bay Area Water Quality Model estimates benefits of source water salinity reductions for urban water supplies in the portion of the Bay Area region from Contra Costa County south to Santa Clara County. The model was developed and used for the economic evaluation of a proposed expansion of Los Vaqueros Reservoir (Reclamation, 2006).

Separate calculations are provided for Contra Costa Water District and another region consisting of Alameda County Water District, Zone 7, and Santa Clara Valley Water District. The model inputs include water supply to the South Bay Aqueduct and Contra Costa Canal (provided by CalSim-II) and chloride concentrations in mg/L from DSM2. For Contra Costa Water District, water quality estimates are based on diversion volume and water quality at Old River and Rock Slough. For the other areas, water quality is based on diversion volume and salinity at Banks Pumping Plant. In the districts receiving SWP water, water quality is a function of other supplies as well as SWP imported supplies.

This model calculates residential benefits only. Input data on the percent of households having certain appliances such as water softeners, and the initial cost of the appliances, are required. Data on the salinity of supplies obtained through Contra Costa Water District's intakes, through the South Bay aqueduct, and through the San Felipe system must be developed for alternatives. The model also requires the average salinity of any other non-project supplies.

Agricultural Salinity Model

This model estimates benefits from a reduction in salinity of agricultural water deliveries south of the Delta. SWP and CVP deliveries to south-of-Delta agricultural users are allocated to a large geographic area that supports numerous crops and irrigation methods. Some of these areas are salt- and drainage affected and have limitations for virtually all crops. Crop production in these areas requires careful irrigation management and leaching of salts. Other irrigated areas are not drainage affected (as yet), but sensitive crops such as orchards and vegetables still require that growers maintain adequate leaching to prevent salt from accumulating in the root zone. The savings in irrigation water used for leaching is calculated for each of these areas south of Delta based on the crops grown and their salt sensitivities.

Water saved as a result of growers applying a smaller leaching requirement is assumed to be available for other irrigation use within the area. The benefit of the water saved is the unit value of water for irrigation in that area times the volume saved. Because the saved water would have been delivered to farms anyway, neither the project (SWP or CVP) nor the local district incurs any additional cost of delivery. Therefore, the marginal value of irrigation water is an appropriate measure of the benefit of an AF of water not needed for leaching and therefore available to meet other crop water uses. The saved water could be used to reduce groundwater pumping, to reduce land fallowing, or for both. The SWAP Model is typically used to estimate the value of water for irrigation (see Appendix D)

The CalSim-II and DSM2 models are used to estimate TDS and electrical conductivity of water pumped by the SWP and CVP facilities. Jones PP supplies water to the Delta Mendota Canal, which is the primary source of CVP water delivered into the Grasslands salinity analysis area. Banks Pumping Plant supplies water to the California Aqueduct, which either delivers it directly to contractors or conveys it to San Luis Reservoir, from which it is delivered to contractors. The other salinity analysis areas receive their Delta supply from this source.

Flood Damage Reduction

A number of different models are available to assist with flood damage benefits estimation; some examples are discussed below.

HEC-FDA

The most widely used model for urban flood damage reduction is probably the USACE's HEC-FDA (USACE, 2011). The HEC-FDA software provides the capability to perform an integrated hydrologic engineering and economic analysis. It can estimate direct flood damage losses by category (e.g., single family residential, multi-family residential, commercial, and industrial).

According to DWR (2010), advantages of using HEC-FDA include the following:

- USACE developed and uses the software.
- Uncertainty is directly incorporated into the analysis using Monte Carlo simulation, which explicitly accounts for uncertainty in key parameters and relationships.
- Levee failure assumptions (probabilities based on water surface elevations below top-of-levee) can be entered into the analysis.
- Although designed for urban flood damage analyses, it can be applied to agricultural analyses.

- The model develops the stage-damage functions using structural inventories that are directly input into the software; or stage-damage functions can be developed outside of the software and then directly input into it.
- Project performance statistics (annual exceedance probability, long-term risk, and conditional non-exceedance) are outputs that can be used for determining "levels of protection."

Disadvantages of using HEC-FDA include the following:

- Training is typically required.
- HEC-FDA is data intensive, requiring hydrologic, hydraulic, geotechnical (if levees are present), and economic data.
- HEC-FDA is not GIS-based.

The USACE HEC-FDA model was recently applied for a project near Hamilton City, California (USACE, 2004). An existing private levee, although not constructed to any formal engineering standards, provided flood protection to the town and surrounding area. Since Shasta Dam was constructed in 1945, flood fighting was necessary in 5 years to prevent flooding, and flood damage occurred in 1 year. Glenn County built a backup levee about 1,000 feet long to protect the community in the event that toe erosion caused failure at the northern end of the private levee.

A HEC-FDA application was completed in 2001 and again in 2003. The more detailed 2003 application included site-specific hydrology and hydraulics and disaggregated impact areas and analysis zones. The economic analysis included a structure inventory, structure valuation using the Marshall and Swift valuation service with assumed contents of 50 percent, generic depth-damage relationships using Economics Guidance Memorandum 01-03, an automobile depth-damage curve, crop damages, and levee failure assumptions. Uncertainty was included by use of Monte Carlo simulation. Benefits for seven levee setback alternatives were estimated, and benefit cost measures were provided.

HEC-FIA

HEC has developed Flood Impact Analysis (HEC-FIA) to estimate direct urban and agricultural damage and loss of life that would occur if existing USACE projects had not been built. HEC-FIA estimates are provided to Congress to help document the achievements of existing USACE projects. EAD estimates are not provided by HEC-FIA, but event damage estimates from HEC-FIA can be input into HEC-FDA and other models to obtain EAD estimates.

In California, USACE has developed HEC-FIA data for areas protected by federal levees in the Delta (USACE, 1999) for the 1995 and 1997 flood events. The USACE found that "HEC-FIA did approximate the damage values and location of damage for the Sacramento and San Joaquin River Systems."

HAZUS-MH

FEMA developed a model called HAZUS MH (MH stands for multi-hazard), or just HAZUS for short. This software is a nationally applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods, and hurricanes. HAZUS uses GIS technology to estimate physical, economic, and social impacts of disasters. It graphically illustrates the limits of identified high risk locations due to earthquake, hurricane, and floods. Users can then visualize the spatial relationships between populations and other more permanently fixed geographic assets or resources for the specific hazard being modeled, a crucial function in the pre-disaster planning process.

HAZUS is used for mitigation and recovery as well as preparedness and response. Government planners, GIS specialists, and emergency managers use HAZUS to determine losses and the most beneficial mitigation approaches to take to minimize them. HAZUS can be used in the assessment step in the mitigation planning process, which is the foundation for a community’s long-term strategy to reduce disaster losses and break the cycle of disaster damage, reconstruction, and repeated damage. Being ready will aid in recovery after a natural disaster.

HAZUS contains a flood loss estimation model that includes flood hazard analysis and flood loss estimation modules for riverine and coastal analyses. The flood hazard analysis module uses characteristics such as frequency, discharge, and ground elevation to estimate flood depth, flood elevation, and flow velocity. The loss estimation module estimates direct and indirect economic losses using the results of the flood hazard analysis and structural inventories. HAZUS-MH analyses can be conducted at different levels of rigor (FEMA, 2016).

According to DWR (2010), advantages of using HAZUS include the following:

- It is GIS-based
- It can be adapted to different analysis levels depending upon user-input data; default values are available for “reconnaissance” studies
- The availability of default values allows for analyses that otherwise could not be conducted because of the lack of local data

Disadvantages of using HAZUS include the following:

- Users are required to have ArcGIS software and expertise
- It does not directly incorporate uncertainty (as opposed to risk), although this can be addressed by sensitivity analyses
- It may not have adequate geographic coverage for all potential flood damage categories. Potential users must determine its data coverage and augment if needed.

FEMA Mitigation BCA Toolkit

FEMA developed the Mitigation BCA Toolkit specifically for use by local and state agencies applying for funding to several mitigation grant programs. The software is menu-driven and is therefore relatively easy to use. Default data are provided for many variables (e.g., the value of contents as a percentage of structural value), although local data can be input into the model. The software then computes net benefits and the benefit cost ratio. The software comes with extensive online resources, including training.

Disadvantages include the following:

- It does not directly incorporate uncertainty
- The discount factor is fixed at 7 percent, which FEMA uses, and cannot be changed

F-RAM

Consultants to DWR have developed a spreadsheet model F-RAM to estimate flood damage. This model develops loss-probability curves for with- and without-project conditions based upon hydrologic and hydraulic data, probability of levee failure data, structural and crop inventories, and depth-damage curves. Damage categories include crops, roads, and residential, commercial, and industrial properties; however, other categories can be added. The model is flexible in that many of the analysis assumptions and parameters can be changed (e.g., structural foundation heights, unit replacement values, and depreciation factors; depth-damage curves; discount rates; analysis period; and other indirect damage “adjustment factors”).

Advantages of using F-RAM include the following:

- It can provide relatively quick estimates of EADs depending upon the availability of input data
- It can be adapted to different analysis levels depending upon the quality of the input data
- It incorporates probability of levee failure
- Users can easily see data inputs and calculations (i.e., it is transparent)

Disadvantages of using F-RAM include the following:

- It does not directly incorporate uncertainty in inputs or other parameter values
- The model has not been widely reviewed or approved by federal agencies

F-RAM does not account for some damages that might be important:

- Loss of net revenues in commercial and industrial enterprises

- Costs of flooding disruption to utilities (gas, electricity, water, sewerage, telecommunications and postal services)
- Amount or value of loss of life
- Costs imposed on public services, such as education and health services
- Damages to public gardens, and recreation assets

Recreation

Existing methods for estimating recreation use are summarized in Section 4.8 Recreation, and methods for estimating economic value of recreation are discussed in Section 5.4.5 Recreation. The section below provides a statistical model of surface storage recreation visitation that applicants may use to estimate recreation use at a proposed surface water reservoir.

WSIP Recreation Visitation Model

This section documents a model of surface storage recreation visitation based on monthly July 2001 through December 2015 visitation data for seven California State Park units where surface water recreation on reservoirs is the primary attraction. The statistical model is a set of regression equations that predict total monthly day visits and total monthly camping visits based on the reservoir and park characteristics. The estimates do not provide monetary benefits associated with the visitation.

California State Parks compiles daily visitation data of varying quality and makes estimates of monthly visitation for their annual reports. A visit is defined as any person entering a State Park. One person entering three parks in one day would be counted as three visits, and a camping visit is the equivalent of two or more days. State Parks has standardized estimating methods, but visitation estimates may not be consistently calculated over time and across the different sites. For example, cars may be counted or estimated but persons per car are based on brief subsamples and estimates of varying frequency and accuracy. More detail is provided in State Parks’ annual Statistical Report (e.g., California State Parks, 2015), produced for each Fiscal Year.

Data for all California State Parks was reviewed to select a sample of parks where a reservoir is the primary attraction. Some State Parks are operated by concessionaires or other agencies and visitation data is not as readily available. California State Parks (2016) provided monthly visitation data for July 2001 through December 2015 for these seven units that we selected:

- Lake Oroville State Recreation Area (SRA)
- Folsom Lake SRA
- San Luis Reservoir SRA
- Turlock Lake SRA
- Millerton Lake SRA

- Lake Perris SRA
- Silverwood Lake SRA

The general form of the visitation equation is

$$
\begin{aligned}
(1)\ \text{Visitation}_m = {} & \beta_0 \cdot A + \beta_1 \cdot A^2 + \beta_2 \cdot F_m + \beta_3 \cdot P + \beta_4 \cdot S + \beta_5 \cdot B + \beta_6 \cdot C \\
& + \beta_7 \cdot W_{SU} + \beta_8 \cdot W_{SP} + \beta_9 \cdot W_{FA} \\
& + \beta_{10\text{-}15} \cdot W_{SU}(A^2 + F_m + P + S + B + C) \\
& + \beta_{16\text{-}21} \cdot W_{SP}(A^2 + F_m + P + S + B + C) \\
& + \beta_{22\text{-}27} \cdot W_{FA}(A^2 + F_m + P + S + B + C) + \beta_{28} \cdot G
\end{aligned}
$$

Where:

Visitation_m = day visits or camping visits during the month m

A = maximum surface acreage of the reservoir, in acres

F_m = the average storage during the month m as a percent of maximum

P = the 2010 population residing within 60 miles of the facility, in thousands

S = the maximum (when full) acreage of substitute reservoirs within 30 miles

B = the number of boat lanes

C = the number of campsites (only in camping equation)

W represents a set of binary variables (0 or 1) for seasons. Spring, W_{SP}, is April or May, summer, W_{SU}, is June through September, and fall, W_{FA}, is October and November.

G = the real annual average price of gasoline

β_0 - β_{28} are regression coefficients

This functional form uses the binary variables as intercept and slope shifters to estimate one equation rather than separate equations for individual months or groups of months. Four groups of months were selected based on preliminary analysis that found that the months within each group predicted similar levels of visitation, all else equal.

The relationship between visitation and maximum surface acreage is quadratic, with the expectation that each additional acre will raise visitation but at a decreasing rate. Therefore, the coefficient estimate β_0 in (1) is expected to be positive and β_1 is expected to be negative. This relationship can also be estimated with a transformed visitation variable. The dependent variable used in the following regression uses visitation per maximum surface acre, shown in (2).

(2) $\text{Visitation}_m/A = \beta_0 + \beta_1 A + \ldots$

Only the independent variables that include acreage in equation (1) were transformed. The statistical analysis includes two visitation regressions: monthly day visits per maximum reservoir surface acre and monthly camping visits per maximum surface acre. The explanatory, or independent variables, are:

1. Maximum surface acreage. Visitation is expected to increase with maximum surface acreage, but at a decreasing rate. The maximum surface acreage includes all lake surface within each State Park: Folsom includes Lake Natoma, Oroville includes Thermalito forebay and afterbay, and San Luis includes O'Neill Forebay and Los Banos Detention Reservoir.

2. Average storage in the main reservoir at the middle of each month as a percent of capacity (0 < Percent < 100). Data are from CDEC (DWR, 2016). The amount of storage as a share of maximum is expected to increase visits per acre. This variable should capture the effect of loss of boat lanes as reservoir storage declines.

3. 2010 population within 60 miles, in thousands. Local population, which can be estimated from census data, is associated with more visits and more visits per acre. The population within a radius of a reservoir can be estimated using online map tools which locate and count census populations. The center of the area is measured at the dam, or at the primary parking facility if much different.

4. Maximum (when full) surface acreage of substitute reservoirs within 30 miles. The sum of the maximum surface acreage of other reservoirs in the region is expected to decrease visits per acre. This acreage is also estimated from the dam, or at the primary parking facility, using online mapping tools to locate substitute facilities. Only lakes that are generally suitable and large enough for power boating were included. Their maximum surface acreage is generally from DWR (2014).

5. Number of campsites. Number of camp visits and visitation per maximum surface acre should be positively related to number of campsites. Data are from the State Parks annual statistical reports (California State Parks, 2004 to 2015), except DWR (2000) is used for the number of campsites without moorage or boat-in facilities. Campsite numbers change over the period for two of the seven facilities. For four facilities, the number of total sites including boat-in and moorage sites is used for the summer period (June through September), but only campground sites are used for the other seasons. Number of campsites is not included in the day visitation per maximum surface acreage regression because day visits should not be affected by camping facilities.

6. Number of boat launch lanes. Camp and day visitation per maximum surface acre should be positively related to number of boat launch lanes. Data are from

Fraser (2016), DWR (2000), and, for Oroville, from two websites.[3] Data were checked by visual inspection of aerial photographs.

7. The real price of gasoline. Data are calculated from the state weekly average price of gasoline from the California Energy Commission (2016) indexed by the California CPI to 2015 dollars.

8. Seasonal Variables. The four seasons were specified as following: winter: December-March; spring: April-May; summer: June-September; fall: October-November. This grouping of months was selected based on preliminary analysis using data for individual months.

9. Interaction between seasonal binary variables and other independent variables were included to allow season to affect the response of visitation to other variables.

Other variables were tested but not included. Unemployment data and a binary variable to represent 2008 and 2009 (impacts from the recession) were not statistically significant. A time trend was also tested but was not statistically significant. Different measurements of population were tested. Conceptually, it should be possible to estimate participation rates separately for populations within a range of distances. Population within 20 miles and the additional population from 20 to 60 miles were tested. This disaggregation did not provide additional explanation of visitation.

Independent variables of reservoir characteristics that do not vary by month, and also change relatively little over the years, are shown in Table F-1 below.

Table F-1. Data for Visitation Regression Analysis That Do Not Vary By Month

Location	Max Surface Acreage	Substitute Acreage within 30 Miles	1000's of Population within 60 Miles	Campsites[1, 2]	Boat Lanes[1]
Folsom	11,950	2,050	3,041	150, 197	67
Millerton	4,900	12,592	1,483	173, 234	26
Oroville	20,737	13,292	1,071	312, 1765	84
Perris	2,340	13,200	10,916	450	12
San Luis	15,720	0	3,724	194, 196	22
Silverwood	990	3,429	12,418	149	8
Turlock	3,260	50,167	1,599	63	3

[1] Some campsite and lane numbers change slightly over the period of analysis

[2] The first number is October through May, the second is June through September

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[3] Oroville has 71 boat lanes plus 13 at Thermalito. http://www.lakeoroville.net/boating-overview.htm

http://www.water.ca.gov/recreation/locations/oroville/recreation.cfm

The California State Parks monthly visitation data included 1218 observations (seven facilities from July 2001 through 2015). The data included seven observations of zero for monthly day visitation and eight observations of zero for camping visits. These might be due to the respective parks' closure, visitor monitoring was canceled, or data was simply nor recorded or not kept. These observations of zero were not included in the analysis.

Results of the day visitation and camp visitation analysis are shown below in Tables F-2 and F-3, respectively. The analysis shows that almost 80% of the variation in visitation per maximum surface acreage across the facilities and months is explained by the independent variables.

Table F-2. Dependent Variable: Monthly Day Visits per Maximum Surface Acreage

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	5.8475770	1.1621830	5.032	0
Percent full	0.0353250	0.0079520	4.442	0.00000
Max surface acres	-0.0001020	0.0000275	-3.727	0.00020
Boat lanes	0.0512670	0.0053190	9.639	0.00000
Population 60mi	0.0004470	0.0000581	7.696	0.00000
Substitute acres	0.0000012	0.0000100	0.118	0.90610
Summer	-2.4052540	2.1980070	-1.094	0.27410
Spring	1.2661990	2.3032310	0.550	0.58260
Fall	-0.3457190	1.1304340	-0.306	0.75980
Summer*percent	0.0577690	0.0221770	2.605	0.00930
Spring*percent	0.0216570	0.0250850	0.863	0.38810
Fall*percent	-0.0073300	0.0148410	-0.494	0.62150
Summer*acreage	-0.0010790	0.0000751	-14.371	0.00000
Spring*acreage	-0.0007210	0.0000831	-8.680	0.00000
Fall*acreage	0.0000151	0.0000467	0.323	0.74660
Summer*lanes	0.2308750	0.0140640	16.415	0.00000
Spring*lanes	0.1544260	0.0145520	10.612	0.00000
Fall*lanes	-0.0099650	0.0100680	-0.990	0.32250
Summer*pop60	0.0029900	0.0001760	16.944	0.00000
Spring*pop60	0.0015160	0.0002060	7.350	0.00000
Fall*pop60	0.0002680	0.0001020	2.618	0.00900
Summer*subacres	-0.0000023	0.0000264	-0.086	0.93180
Spring*subacres	-0.0000316	0.0000288	-1.096	0.27340
Fall*subacres	0.0000136	0.0000163	0.835	0.40360

Table F-2. Dependent Variable: Monthly Day Visits per Maximum Surface Acreage

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Petrolyear	-2.2151940	0.3007810	-7.365	0.00000
R-squared	0.81902	Mean of dependent variable		10.06451
Adjusted R-squared	0.81536	Std. Dev. of dependent variable		14.37562
Std. Error of regression	6.17724	Observations		1211
F-statistic	223.63050	Prob of F-statistic		0.0000

Table F-3. Dependent Variable: Monthly Camping Visits Per Maximum Surface Acreage

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.8497630	0.3006410	2.827	4.80E-03
Percent full	0.0054520	0.0015960	3.416	0.00070
Max surface acres	-0.0000341	0.0000053	-6.397	0.00000
Boat lanes	0.0000500	0.0000147	3.409	0.00070
Population 60mi	0.0000018	0.0000015	1.194	0.23280
Substitute acres	-0.0172530	0.4091530	-0.042	0.96640
Summer	-1.6345800	0.4072860	-4.013	0.00010
Spring	-0.7072540	0.3381390	-2.092	0.03670
Fall	0.0035410	0.0005290	6.688	0.00000
Campsites	0.0350930	0.0059390	5.909	0.00000
Summer*percent	0.0215120	0.0048320	4.452	0.00000
Spring*percent	0.0132050	0.0051320	2.573	0.01020
Fall*percent	-0.0002970	0.0000176	-16.883	0.00000
Summer*acreage	-0.0001200	0.0000175	-6.850	0.00000
Spring*acreage	0.0000043	0.0000130	0.328	0.74300
Fall*acreage	0.0006920	0.0000434	15.965	0.00000
Summer*pop60	0.0003940	0.0000652	6.051	0.00000
Spring*pop60	0.0001310	0.0000434	3.022	0.00260
Fall*pop60	-0.0000339	0.0000047	-7.226	0.00000
Summer*subacres	0.0000053	0.0000044	1.208	0.22740
Spring*subacres	0.0000084	0.0000040	2.126	0.03370
Fall*subacres	-0.0004370	0.0005540	-0.789	0.43050
Summer*campsites	0.0006650	0.0018110	0.367	0.71340
Spring*campsites	-0.0007840	0.0013550	-0.579	0.56290

Table F-3. Dependent Variable: Monthly Camping Visits Per Maximum Surface Acreage				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
Fall*campsites	-0.0012990	0.0010510	-1.236	0.21660
Summer*lanes	-0.0087420	0.0032270	-2.709	0.00680
Spring*lanes	0.0207990	0.0043080	4.828	0.00000
Fall*lanes	-0.0028380	0.0037520	-0.756	0.44950
Petrolyear	-0.4147160	0.0855330	-4.849	0.00000
R-squared	0.80494	Mean of dependent variable		1.93471
Adjusted R-squared	0.80031	Std. Dev. of dependent variable		3.83206
Std. Error of regression	1.71242	Observations		1210
F-statistic	174.0507	Prob of F-statistic		0.0000

Only summer, spring, and fall months have associated binary variables (winter visitation is represented in the overall constant term). As a result, during winter months, all variables associated with the other three seasons have no effect on estimated visitation per acre. For spring months, all variables with the word “spring” in the variable name have non-zero values and also affect the estimated visitation per acre, and similarly for summer and fall. To see the effect of, for example, maximum acreage during the summer, add the coefficients for MAX SURFACE ACRES and SUMMER*ACREAGE.

The maximum acreage of a facility is generally associated with less visitation per maximum acre. Table F-2 shows that, for day visits, this effect is not significant in the fall. However, the maximum acreage is strongly significant in spring and summer when most visitation occurs. For camp visits, the effect (-0.0000341) is negative in winter, spring and summer, but acreage is positively associated with visits per acre in the fall (-0.0000341 + 0.0006920).

The monthly storage as a percent of maximum, regional population, and number of boat lanes are all generally associated with more visitation per acre. For day visits in the fall, the total effect per one percent increase in storage is positive (0.035325 - 0.00733) even though the slope shifter (the cross-effect between the fall season and percent full) is negative (-0.00733). The number of boat lanes is positively related to day visits per acre.

The acreage of other reservoirs within 30 miles does not significantly affect day visitation per acre in most periods. However, the variable is retained because the effect, though small, is believed to be real. The net effect of more substitute acres on visits per acre is negative in every period except for day visits in fall (0.0000012 + 0.0000136).

The number of campsites has positive effects on camp visits per acre in all seasons. In winter, a campsite is associated with 0.0351 more camp visits per acre, and the size of this effect does not change much in the other seasons.

As a validation test, the model was used to predict historical visitation at New Melones Lake. Visitation and campsite data for 2004 through 2007 were obtained from

Reclamation (2011), and the number of boat lanes were estimated from aerial photographs. Data on monthly storage, storage capacity and maximum acreage were obtained from DWR and CDEC (DWR, 2014; DWR, 2016). Table F-4 shows that the model estimated about 17 percent less than the actual average visitation. Most of this difference could be attributable to high gasoline prices experienced in 2007 and summer of 2008. Apparently, visitation at New Melones did not decline as much as expected during these high gasoline price conditions.

Table F-4. Predicted Visitation per Maximum Acre at New Melones Compared to Actual

Year	Predicted Camp Visits per Acre	Predicted Day Visits per acre	Predicted Total Annual	Actual Total Annual	Difference	Percent Difference
2004	-0.5	53.4	53.0	56.0	3.0	5.4%
2005	5.4	60.8	66.2	54.5	-11.7	-21.5%
2006	6.8	60.6	67.4	63.4	-4.0	-6.3%
2007	-0.6	40.8	40.2	58.5	18.2	31.2%
2008	-6.7	20.3	13.6	58.1	44.5	76.6%

Notes:
Actual visitation from Reclamation (2011)
Average % Difference from 2004-2008 28.6%

As part of a recreation market study, the WSIP recreation model is one method for predicting visitation at a proposed surface storage reservoir that is within the range of reservoir size used to estimate the visitation model - one and a half square miles of surface area or greater (see Table F-1). Also, to be applicable, the proposed reservoir should include campsites and facilities to enable private boating. If these characteristics apply, applicants can use the model to predict 1) visitation at the proposed reservoir, and 2) loss of visitation at existing facilities within 30 miles. To predict visitation at the proposed reservoir, an applicant would estimate visitation per maximum acre for the proposed reservoir and then multiply by the maximum acres. The applicant should ensure that recreation facilities are properly planned for the reservoir; facilities should include a suitable mix in relation to the size of the reservoir and expected visitation even if those facilities are not included in the WSIP visitation model. A real gasoline price of $3.27, the average of monthly gas prices in the analysis, can be used to project visitation for future with-project conditions.

Visitation at proposed reservoirs that are much different from those in the State Parks data set should be estimated using different methods, and results should be compared to other, similar facilities where data are available.

To use the WSIP visitation model for estimating economic benefits, the number of visits must be associated with a number of recreation days that can be valued using the Army Corps of Engineers Unit Values. Visits are not the same as a recreation day. When using the WSIP model for visitation, a day visit may be assumed to be one recreation day, and a camping visit may be assumed to last an average of three recreation days.

In summary, the visitation regression model provides a reasonable method that applicants may use to estimate recreational use at a similar proposed surface reservoir. However, the test validation using data from New Melones Reservoir indicates that the model somewhat under-predicts visitation for that particular site.

If available time and budget are available, it is recommended that applicants proposing a large surface reservoir use their recreation facilities plan and a market analysis to estimate visitation. The market analysis should consider the amount of visitation at other, similar facilities. For small proposed reservoirs, and where recreation benefits are not a large share of public benefits, visitation can be estimated based on visits per surface area for similar small local reservoirs.

Emergency Response

No relevant, practical models are known.

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Appendix G
Discounting and Discount Rates

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Discounting and Discount Rates

The discount rate is a real (inflation-free) interest rate that allows all benefits and costs occurring in future years to be compared and combined. If two projects use different discount rates, their benefits and costs are weighed differently and therefore they cannot be compared fairly.

Some discount rates applied to public investments are displayed in Table E-1. Economists have developed three fundamental approaches regarding how to implement discounting: the social rate of time preference, the social opportunity cost of capital, and the shadow price of capital. In general, the social rate of time preference tends to provide the lowest discount rate (i.e., 1 to 4 percent) although some economists propose long-term, inter-generational rates that are near zero. The social opportunity cost of capital tends to provide the highest rates at perhaps 5 to 8 percent.

Table G-1. Options for Discount Rate

Option Name	Description	Current value	Advantages	Disadvantages
DWR Rate	Has been used by DWR for state project evaluations for years	6 percent[1]	Precedent in DWR grant programs; may approximate opportunity cost of capital	No recent, formal documentation or update.
FEMA Rate	Rate for Pre-Disaster Mitigation grant program	7 percent	Compliance with OMB BCA guidelines, intended to be based on the marginal opportunity cost of private investment per OMB Circular A-94	OMB Circular A-94 BCA rate not changed since 1992.
WRDA rate	Rate for federal water projects	3.375 percent[2]	Consistency with federal feasibility studies; related to federal cost of capital	Changes very slowly over time, so lags changes in federal cost of capital[4]
California cost of borrowing, Legislative Analyst's Office Proposition 1	Legislative Analyst's Office assumed a nominal rate of just over 5 percent	About 3 percent[3]	Reflects state costs of capital	Not known how Legislative Analyst's Office developed[4]
California cost of borrowing, independent	Develop a rate based on California bond interest costs	3.5 percent (tentative)	Reflects state costs of capital	Must be calculated – no publication to use as standard reference[4]

1. The DWR rate of 6 percent was based generally on an estimate of the opportunity cost of capital.
2. Discounting methods for the federal Water Resource Development Projects are specified by the WRDA. The rate is based on a mix of federal Treasury bond yields, but the annual change in the rate is capped. During periods of rapid change in interest rates, the WRDA rate can diverge from the federal cost of capital by a substantial amount.
3. The California Legislative Analyst's Office (2014) prepared an analysis of borrowing costs for Proposition 1. After adjusting for an estimated expected long-term inflation rate of 2 percent, the real rate is 3 percent.
4. These rates can be heavily influenced by short and medium term federal monetary policy (e.g., quantitative easing).

California's appropriate discount rate for evaluating public benefits of water projects should not be based on the private opportunity cost of capital. First, repayment of general obligation bonds does not draw money out of the private sector because no new tax revenue is made available when the public passes a bond measure. Rather, bond repayment diverts existing tax revenue from other state-funded programs. Second, most bond buyers are likely to be out of state, so the opportunity cost of their investments do not matter from a state perspective.

The real interest rate at which California General Obligation bonds are sold is arguably the most realistic basis for the State's cost of capital and therefore the appropriate discount rate for public benefits. The WSIP technical team conducted a review of recent bond costs to estimate the likely nominal rate for State bonds. Since 2008, the state has paid an average of 3.22 percent for revenue bonds. The current 30-year general obligation bond rate has ranged from about 3.0 to 3.5 percent during 2015 (California State Treasurer, 2015). Several adjustments to this rate are appropriate.

- First, the bonds will not be sold immediately and then might be sold over a period of 10 years. Current bond rates reflect expansionary monetary policy (low Federal Reserve interest rates). Recent expectations by the Federal Reserve Board of Governors (Federal Reserve Board of Governors, 2015) indicate that longer-term federal funds rates could rise by 2 to 3 percentage points by 2017. In response, bond rates are expected to increase over the next several years.
- Second, the state's borrowing rate reflects investors' (bond buyers') assessment of the risk that they will be repaid by the state. However, the risk that taxpayers take in investing in public benefits of water storage projects is likely to be greater than that, considering the significant uncertainties about future hydrologic, economic, climate, and ecosystem conditions. Therefore, the WSIP team believes that an appropriate discount rate, though based on the State's real borrowing rate, should be higher to reflect the larger risk of achieving the future public benefits.
- The nominal rate must be adjusted for expected inflation. The Federal Reserve Bank of Cleveland reports that its latest estimate of 10-year expected inflation is 1.88 percent, and its estimate of 30-year expected inflation is 2.2 percent (Federal Reserve Bank of Cleveland, 2015). The Federal Reserve Board of Governors (Federal Reserve Board of Governors, 2015) expects inflation to be about 2 percent in the long run.

Commission staff has considered these factors of expected inflation, changes in monetary policy that the Federal Reserve Board has signaled, and the inherent risk in future levels of public benefits, and recommends that, for purposes of allocating costs and calculating expected return on investment, all public and non-public benefits and costs must be evaluated using a real discount rate of 3.5 percent.

Applicants may need to use a different interest rate for some financial calculations related to non-public benefits. This private rate should be based on the applicant's borrowing costs to finance the private share of construction costs, reduced for expected inflation of 2 percent.

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