Appendix 9.A

Economic Benefits of the BDCP and Take Alternatives

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Acronyms and Abbreviations

ccf	100 cubic feet
CES	constant elasticity of substitution
cfs	cubic feet per second
DWR	California Department of Water Resources
FY	fiscal year
MAF	million acre-feet
MWD	Metropolitan Water District of Southern California
PMP	Positive Mathematical Programming
SANDAG	San Diego Association of Governments
SCAG	Southern California Association of Governments
SDBSIM	Supply–Demand Balance Simulation
SWAP	Statewide Agricultural Production
TDS	total dissolved solids

Appendix 9.A
Introduction and Summary of Findings

This report examines the direct economic benefits of implementing the Bay Delta Conservation Plan (BDCP or the Plan) to the state's urban and agricultural water agencies receiving water supplies from the Central Valley Project (CVP) and the State Water Project (SWP) (the state and federal water contractors). The goal of the BDCP is to provide a comprehensive conservation strategy for the Sacramento–San Joaquin River Delta, designed to restore and protect ecosystem health, water supply, and water quality within a stable regulatory framework.

9.A.1 Proposed Take Alternatives

Chapter 9, *Alternatives to Take*, identifies and analyzes a range of alternatives that may avoid or reduce the level of take of the covered fish and wildlife species likely to result from the BDCP Proposed Action. This report conducts a detailed analysis of the direct economic benefits of these "take alternatives" that vary along a number of dimensions, including the size and type of conveyance facility considered, operating criteria, and the amount of habitat to be restored. The specific take alternatives assessed are the BDCP Proposed Action as well as Take Alternatives A, B, C, D, E, and F as defined in Chapter 9. Take Alternatives G and H would have the same Delta water exports and size of new water conveyance facility as the BDCP Proposed Action, so their benefits are assumed the same. Because detailed water supply data are not available for Take Alternative I, the economic benefits of this scenario are approximated based on the other take alternatives.

As described in Chapter 3, *Conservation Strategy*, the BDCP Proposed Action includes initial operations of the new water conveyance facility that will vary depending on the outcome of the decision tree process. Under this process, scientific evaluations will be conducted to address which specific outflow level is needed in the fall and spring to meet the biological objectives for key covered fish species. For this report, the BDCP Proposed Action is assessed under both ends of the range of four possible initial outflows: the low-outflow scenario and the high-outflow scenario. Results are presented for the BDCP Proposed Action High-Outflow and Low-Outflow Scenarios, as well as the various take alternatives. The take alternatives are evaluated under the high-outflow scenario only.

This report compares economic outcomes under the BDCP Proposed Action to the conditions assumed to exist if the BDCP were not implemented. For purposes of this analysis, the BDCP Proposed Action and each take alternative are evaluated in relation to existing water conveyance (i.e., south Delta facilities) as projected into the future. The operational components of the BDCP are based on existing information and future developments in science and understanding, but have the potential to be implemented even if the BDCP is not. This applies to the existing south Delta facilities and Delta outflow (i.e., high fall and spring outflow) operations. For purposes of understanding a future condition without the BDCP infrastructure, but with the potential future operational constraints, this analysis also uses a comparison scenario that includes the fall and spring outflow (i.e., high outflow scenario of the decision tree) and south Delta operating restrictions of the BDCP (i.e., current biological opinions plus Scenario 6 operations) imposed on existing water conveyance facilities. This comparison scenario is called the Existing Conveyance High-Outflow Scenario. A similar scenario is also introduced that applies the BDCP outflow criteria and south Delta operating restrictions using the low-outflow points on the decision tree (i.e., no Fall X2 and no additional spring outflow). This scenario is called the Existing Conveyance Low-Outflow Scenario. These scenarios are used only in Chapter 9, *Alternatives to Take*, and this appendix and only to provide a reasonable comparison point for the cost practicability analysis of the BDCP Proposed Action. The Existing Conveyance High-Outflow Scenario is the basis for comparison with the BDCP Proposed Action High-Outflow Scenario and each of the take alternatives. Similarly, the Existing Conveyance Low-Outflow Scenario is the basis for comparison with the BDCP Proposed Action Low-Outflow Scenario.

A complete discussion of the method of selecting the BDCP Proposed Action and the take alternatives can be found in Chapter 9, Section 9.1, *Introduction*. A comprehensive description of the BDCP Proposed Action and each take alternative can be found in Chapter 9, Section 9.2, *Descriptions of Take Alternatives.* For reference, Table 9.A-1 summarizes the BDCP Proposed Action and each take alternative as well as the comparative Existing Conveyance High-Outflow and Low-Outflow Scenarios.

Table 9.A-1. Description of Take Alternatives and Existing Conveyance Scenarios

Take Alternative	Take Alternative Description
BDCP Proposed Action	Dual conveyance with Intakes 2, 3, and 5, and up to 9,000 cfs diversion capacity
A: W Canal 15,000 cfs	Dual conveyance with west canal alignment, Intakes W1 through W5, and up to 15,000 cfs diversion capacity
B: Tunnels 6,000 cfs	Dual conveyance with Intakes 1 and 2 and up to 6,000 cfs north Delta diversion capacity
C: Tunnels 15,000 cfs	Dual conveyance with five intakes, and up to 15,000 cfs diversion capacity
D: Tunnels 3,000 cfs	Dual conveyance with Intake 1 with up to 3,000 cfs north Delta diversion capacity; reduce tidal natural communities restoration to 40,000 acres
E: Isolated 15,000 cfs	Isolated conveyance with pipelines and five intake, with up to 15,000 cfs north Delta diversion capacity
F: Through Delta	Through Delta conveyance with Delta channel modifications and different intake locations
G: Less Tidal Restoration	Reduce tidal natural communities restoration to 50,000 acres[a]
H: More Restoration	Increase tidal natural communities restoration to 75,000 acres, seasonally inundated floodplain restoration to 20,000 acres, and channel margin enhancement to 40 linear miles[a]
I: Fixed Spring Outflow	Increase spring outflow to 44,500 cfs
Existing Conveyance Scenario	**Existing Conveyance Scenario Description**
Existing Conveyance High-Outflow Scenario	Existing conveyance with Fall X2, enhanced spring outflow, Scenario 6 Old and Middle River, without San Joaquin River inflow/export ratio
Existing Conveyance Low-Outflow Scenario	Existing conveyance facilities with Scenario 6 operations and no Fall X2 or spring outflow

Note:

[a] Take Alternatives G and H include the same CM1 operating criteria as the BDCP Proposed Action. Although the water supply shown for these take alternatives is the same as for the BDCP Proposed Action, Take Alternatives G and H include different restoration configurations for CM4. These differences in tidal wetland restoration may affect the outflow requirements and therefore may result in different water supply than what is shown in this table.

cfs = cubic feet per second

9.A.1.1 Categories of Benefits

Implementing the BDCP may result in several categories of economic benefits to the state and federal water contractors. These benefits include increased water supply reliability, improved water quality, and reduced seismic risks to Delta water supplies. Each category is assessed under the BDCP Proposed Action and the take alternatives, relative to the appropriate Existing Conveyance High-Outflow and Low-Outflow Scenarios.

Water supply reliability benefits are calculated separately for urban and agricultural water agencies. Urban agency benefits are evaluated using the Supply–Demand Balance Simulation (SDBSIM) model (as developed by The Brattle Group) for 36 major water urban utilities receiving Delta water supplies (Section 9.A.2.2, *Forecasting Supply, Demand, and Shortages*). The value estimation is conducted through a refined econometric approach incorporating observed water price and consumption patterns throughout California.

Water supply reliability benefits for the agricultural sector stem from reductions in groundwater pumping and cost, decreases in fallowing, and increases in net returns from crop production resulting from implementation of the BDCP or a take alternative. These benefits are measured using the Statewide Agricultural Production (SWAP) model (Howitt 1995a)on a regional level for all of the SWP and CVP agricultural water contractors in the Central Valley receiving Delta supplies (Section 9.A.3, *Analysis of Agricultural Water Supply Reliability*).

Implementation of the BDCP will result in **water quality benefits** through reduced salinity levels in the south Delta. Salinity-related benefits are calculated using the Lower Colorado River Basin Water Quality Model (Metropolitan Water District of Southern California and U.S. Bureau of Reclamation. 1999) for the Metropolitan Water District of Southern California (MWD) service areas, and the South Bay Water Quality Model (Bureau of Reclamation 2006) for the Contra Costa and Santa Clara Water District service areas (Section 9.A.5, *Impacts on Water Quality*).

Benefits of reduced seismic risks will result from construction of the conveyance facilities proposed as part of the BDCP (*CM1 Water Facilities and Operation*). With the current water supply infrastructure, large earthquakes in and around the Delta region may cause numerous levees to fail, with the result that some islands will flood. As a result, sea water will be pulled into the Delta, potentially reducing project deliveries for some period of time. During this recovery period, there may be incremental water shortages experienced by urban and agricultural water agencies if they are unable to replace lost Delta supplies.

The benefits of reducing the vulnerability of the Delta's water export system to seismic events are calculated by observing differences in water supplies under no earthquake and post-earthquake conditions across the urban and agricultural sectors for the BDCP Proposed Action High-Outflow and Low-Outflow Scenarios and each take alternative, as well as for the comparative Existing Conveyance High-Outflow and Low-Outflow Scenarios (Section 9.A.6.1, *Post-Earthquake Water Supplies*). The marginal value of water calculated using the SDBSIM and SWAP models is used to value the water supply reduction under each scenario.

9.A.1.2 Summary of Benefits

The economic benefits of the BDCP are calculated to the year 2075 and are expressed as present values. This period of analysis is chosen to reflect the expected 50-year useful life of the new conveyance facilities proposed as part of CM1 (as described in Chapter 8). Table 9.A-2 summarizes the benefits and costs to the contractors receiving SWP deliveries under each take alternative relative to the Existing Conveyance High-Outflow and Low-Outflow Scenarios, respectively. For a balanced comparison, costs in this table are also evaluated to 2075 and expressed in 2012 dollars. For reference, the table also includes the facility size and the level of mean Delta deliveries associated with each scenario.

Table 9.A-2. Summary of State and Federal Water Contractor Economic Benefits and Costs ($ millions)

Alternative or Scenario Description			Total Benefits and Costs[a, b]		
Alternative or Scenario	**Facility Size (cfs)**	**Average Annual Water Deliveries (MAF)**	**Total Benefits[c]**	**Total Costs[d]**	**Net Benefits**
BDCP Proposed Action High-Outflow Scenario	9,000	4.705	$18,011	$13,472	$4,540
BDCP Proposed Action Low-Outflow Scenario[e]	9,000	5.591	$18,826	$13,487	$5,339
A: W Canal 15,000 cfs	15,000	5.009	$23,187	$11,110	$12,076
B: Tunnels 6,000 cfs	6,000	4.487	$14,445	$12,347	$2,098
C: Tunnels 15,000 cfs	15,000	5.009	$23,187	$15,641	$7,545
D: Tunnels: 3,000 cfs	3,000	4.188	$8,923	$10,240	-$1,317
E: Isolated 15,000 cfs	15,000	3.399	-$8,697	$15,711	-$24,407
F: Through Delta	N/A	4.172	$12,060	$5,233	$6,826
G: Less Tidal Restoration	9,000	4.705	$18,011	$13,432	$4,579
H: More Restoration	9,000	4.705	$18,011	$13,505	$4,506
I: Fixed Spring Outflow	9,000	4.338	$13,417	$13,472	-$55
Existing Conveyance High-Outflow Scenario	N/A	3.446			
Existing Conveyance Low-Outflow Scenario	N/A	3.889			

Notes:

[a] Construction is assumed to begin in 2015. BDCP operations are assumed to begin in 2025.

[b] All values are in 2012 $ (millions), and are discounted to present value using 3% real discount rate.

[c] Benefits are calculated out to year 2075.

[d] Costs are calculated out to year 2075.

[e] Benefits for the BDCP Proposed Action Low-Outflow Scenario are calculated relative to the Existing Conveyance Low-Outflow Scenario, which assumes Scenario 6 operations, no Fall X2, no north Delta diversions.

cfs = cubic feet per second; MAF = million acre-feet

The analysis of water supply benefits of the BDCP presented in this report demonstrates that several take alternatives would result in significant net economic benefits to the state and federal water contractors. A large portion of economic benefits arises from the value of increased water supply. These benefits result from higher levels of Delta exports under the take alternatives as compared to the Existing Conveyance High-Outflow and Low-Outflow Scenarios. The increased water supply reliability benefits under the BDCP Proposed Action High-Outflow Scenario, relative to the Existing Conveyance High-Outflow Scenario, for the state and federal projects combined, are expected to be

$15.7 billion, evaluated across the historical hydrology. Under the BDCP Proposed Action Low-Outflow Scenario, water supply benefits are expected to be $16.6 billion.

The BDCP will also result in water quality benefits. By diverting water directly from the Sacramento River, the BDCP will reduce salinity levels and thus improve the quality of Delta water exports. The improved water quality benefits to urban and agricultural users attributed to reduced salinity has a present value of roughly $1.8 billion under the BDCP Proposed Action High-Outflow and Low-Outflow Scenarios.

The BDCP will also reduce the vulnerability of the Delta's water export infrastructure to earthquakes. As discussed above (Section 9.A.1.1., *Categories of Benefits and Analysis Approach*), a large earthquake could compromise water quality, and ultimately, SWP deliveries, resulting in a potential shortage to consumers. The expected welfare benefits of reduced seismic risks to urban and agricultural agencies would be $0.5 billion under the BDCP Proposed Action High-Outflow Scenario and $0.4 billion under the BDCP Proposed Action Low-Outflow Scenario.

Because the ultimate economic benefits of the BDCP depend on factors that cannot be known with certainty (e.g., demand growth, future hydrology, future regulations, climate change, etc.), an exact quantification of the direct benefits of the BDCP is elusive. Nonetheless, given the available evidence, two conclusions seem certain. First, both the BDCP Proposed Action High-Outflow and Low-Outflow Scenarios will result in substantial net benefits to the urban and agricultural water agencies that rely on the Delta for at least a portion of their water supplies. Second, implementing the BDCP will reduce a range of risks that are of great consequence to the public. These risks include the vulnerability to earthquakes in the Delta region that may disrupt water exports for an unknown period of time, gradual, long-term sea level rise that could progressively restrict Delta water exports unless mitigating action is taken, and an increasingly strict regulatory environment under the state and federal Endangered Species Acts that could further restrict exports from the Delta.

9.A.2 Benefits of Increased Urban Water Supply

California's urban water systems are often vulnerable to supply fluctuations. Natural variation in precipitation and runoff leads to changes in water supplies that pose challenges to urban water managers seeking to meet demands for water. These challenges are exacerbated by increasing federal and state regulatory restrictions. Meanwhile, urban water demands in California are projected to grow over the coming decades.

This section documents the water supply benefits resulting from implementation of the BDCP. It describes the likely future pattern of urban water supplies and demands in the SWP service area, and evaluates the economic impacts of water shortages expected to occur assuming implementation of the BDCP Proposed Action or one of the alternatives to take, and if the BDCP is not implemented. In calculating the value of water supply reliability, the analysis considers variations in Delta deliveries, the operation of storage facilities throughout the state, and the role of water supply alternatives such as recycling and desalination.

The analysis of urban water supplies and demands is performed at the individual agency level. Changes in economic welfare are calculated for 36 major water urban utilities receiving Delta water supplies directly or indirectly. These agencies were chosen because they receive the bulk of the SWP urban deliveries and because they have the largest potential to experience changes in welfare as a result of variations in Delta yields. Some of these agencies are members of the Metropolitan Water

District of Southern California, which receives roughly half of all available yields from the SWP. Many of these 36 agencies are wholesalers themselves. For these agencies, it is necessary to model demand and supply conditions in the retail agencies they serve. At the retail level, the analysis described in this Appendix covers nearly 120 individual retail agencies throughout California.

The data requirements of such disaggregated analysis are significant, but this approach is necessary to accurately calculate changes in the welfare of urban water customers as a result of implementing the take alternatives. Water rates vary widely in California, and knowledge of existing rate structures is essential to calculating changes in consumer welfare following water shortages. Further, accurate estimates of the price elasticity of urban water demand are essential to measuring the costs of mandatory conservation. This analysis relies on the most comprehensive set of water price and consumption data available in California. This data set allows for the use of existing rate structures to calculate impacts and to econometrically estimate the price elasticity of demand at the agency level.

It should be emphasized that the analysis is based on water price and consumption levels reported in water utility administrative records. In this respect, the loss assessment has the advantage of being based on actual valuations of water units by residential consumers as opposed to stated preferences or the results of hypothetical optimization scenarios. Finally, the approach explicitly takes into account that water utilities often recover fixed costs through their volumetric rates, which has a significant effect on how ratepayers value supply reliability, as explained later in the analysis.

The remainder of this section on SWP urban water reliability benefits discusses the following topics.

- The current and projected portfolio of water supplies available to beneficiaries of BDCP water supplies.
- The approach used to forecast water supply shortages, including a detailed explanation of the methods used to forecast water supply and demand that may be realized in the future.
- The implications of the supply and demand simulation output, underlining the fact that even with BDCP water supply shortages will likely occur.
- The method employed to measure the costs of shortage, highlighting the necessity of an accurate econometric estimation of demand and consideration of the cost and availability of water supply alternatives.
- A detailed description of the econometric model used to estimate demand.
- The calculation of the value of increased water supply reliability under the BDCP Proposed Actions and each take alternative using demand estimates, baseline data on prices, information on water supply alternatives and forecasted demand measures and shortages.

9.A.2.1 Water Supplies

An important consideration in estimating the costs associated with urban shortages are the various other sources that make up the water resource portfolios of the BDCP beneficiaries. Water supplies available to these water agencies consist of both local and imported supplies.[1] Local supplies are composed of groundwater, groundwater recovery, local surface water, recycled water, desalinated

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[1] Water supply levels mentioned further in this section coincide with the IRPSIM model inputs (Metropolitan Water District of Southern California 2010).

seawater, and water from the Los Angeles Aqueduct. Imported supplies for southern California come from the Colorado River supplies, and the SWP. The major sources of imported water for the portions of the Bay Area included in the SDBSIM come from the San Francisco Public Utilities Commission Regional Water System, the CVP, and the SWP. Individual agencies may have other specific import sources; for example, Zone 7 receives imported water from Byron Bethany Irrigation District.

9.A.2.1.1 Local Supplies

Groundwater is an important source of drinking water for most urban districts served by the SWP. These groundwater supplies can be drawn on in dry years and supplemented during wet years, and so enhance water supply reliability. Groundwater is available in southern California, but is also a supply source in northern California. For instance, Alameda County Water District stores carryover water in local aquifers; they also have groundwater storage accounts in the San Joaquin Valley. There are more than 1.7 million acre-feet (MAF) of groundwater available yearly to the urban water agencies analyzed in this report. These supplies increase to over 1.8 MAF by 2035. Additional supplies come from groundwater recovery, which is contaminated groundwater that is treated for use, and from local surface water. Groundwater recovery supplies remain fairly stable throughout fluctuating weather patterns at a little over 0.1 MAF per year. These supplies approach 0.2 MAF by 2035. Local surface water varies with weather patterns and averages under 0.2 MAF per year across the study area, remaining fairly stable throughout the forecasted years.

Recycled water, or wastewater that has been treated so that it can be used again, has the benefit of being a nearly drought-proof supply. Recycled water is not, however, of sufficient quality to be used for some of the purposes that are most important to water users. For example, recycled water can be used for toilet flushing or other nonpotable uses, but not for drinking. Most recycled water is treated to a disinfected tertiary level, also known as Title 22 standards. Wastewater that has been treated at this level can be tailored to fit specific commercial and industrial nonpotable applications, but this requires a distribution system and storage facilities for the recycled water completely separated from the potable water system, which can be very costly. Wastewater that is treated to an even higher level is known as advanced treated recycled water, and is currently used for industrial applications such as seawater intrusion barriers and groundwater recharge. About 46% of recycled water in California is used for agricultural irrigation, 21% for landscape irrigation, 14% for groundwater recharge, and 19% for all other uses (California Department of Water Resources 2009: Chapter 11). There are less than 0.4 MAF of recycled water available yearly across all the urban water agencies analyzed (Metropolitan Water District of Southern California 2010: 3-4). These supplies are projected to grow more than 0.1 MAF by 2035, reaching almost 0.5 MAF of available recycled supplies.

Seawater desalination is another supply that is relied upon during drought periods. Although desalination encompasses various methods of removing salt from water in an attempt to convert the water into a usable state, the main process used in California is reverse osmosis. This process is not only used to treat seawater and brackish water, but can also be used to treat polluted and impaired waters as an advanced treatment to produce high-quality recycled water (California Department of Water Resources 2009: Chapter 9). Projected seawater desalination supplies to the urban agencies included in the analysis are limited to less than 0.1 MAF annually from Poseidon Resources' Carlsbad Desalination Plant in San Diego County.

Locally-controlled surface supply projects are also available to some urban water agencies. The Los Angeles Aqueduct, operated by the Los Angeles Department of Water and Power, provides water to the City of Los Angeles. From 1995 to 2000, the Los Angeles Aqueduct supplied 63% of the city's water supply. From 2001 through 2004, however, this amount decreased to only 34%. As of 2007, deliveries through the Los Angeles Aqueduct accounted for slightly less than 0.3 MAF of the City of Los Angeles' water supply. Deliveries from the Los Angeles Aqueduct have declined over the last 20 years due to environmental restrictions and are forecasted to average about 0.2 MAF per year in the future.

9.A.2.1.2 Imported Supplies

The urban agencies included in the analysis import water supplies from the SWP, Colorado River Aqueduct (Colorado River), the CVP, and the San Francisco Public Utilities Commission Regional Water System (Tuolomne River). The analysis of BDCP benefits takes these supplies as exogenous but considers their effect when calculating excess demands at the retail level. The Colorado River Aqueduct is operated by MWD. Forecasts of Colorado River supplies are evaluated through the use of the Bureau of Reclamation's Colorado River Simulation System Colorado River Aqueduct forecast. The Colorado River Aqueduct supply deliveries to MWD consist of base supplies and optional program supplies. There are roughly 0.8 MAF of base supplies and 0.1 MAF of the optional program supplies, totaling 0,9 MAF of combined Colorado River Aqueduct supplies. By 2035, base supplies are forecasted to grow to 0.9 MAF and optional program supplies are forecasted to grow to roughly 0.2 to 0.3 MAF. Thus, there will be 1.0 to 1.1 MAF of Colorado River Aqueduct supplies available to MWD in 2035. The level of Colorado River Aqueduct optional program supplies fluctuates with the level of SWP supplies available.

There are several other sources of imported water available to urban agencies included in SDBSIM. In the Bay Area, the San Francisco Public Utility Company's regional water system delivers water from the Tuolomne River to the San Francisco Bay Area. Some of San Francisco's wholesale customers also receive SWP and CVP supplies directly or indirectly. The only urban agency modeled that receives CVP water is Santa Clara Valley Water District with an annual CVP delivery of over 0.1 MAF. Other imported water supplies include Yuba Accord purchases, the San Bernardino Minimum Purchase transfer, and Zone 7's transfer with Byron-Bethany Irrigation District.

The SWP is the most important source of imported water for the urban agencies included in the SDBSIM. SWP deliveries to these agencies consist of both Table A and Article 21 supplies. Table A supply is a contracted quantity that totals roughly 2.6 MAF per year across all the urban member agencies in the model (California Department of Water Resources 2013). Article 21 deliveries are unscheduled water that is available in wet years, and is essentially the surplus water that remains after all operational, water quality, and Delta requirements are met.

Estimates of future SWP deliveries from the Delta are forecasted using the California Department of Water Resources' CALSIM II model, a generalized water resource simulation that generates hydrologic time series forecasts of large, complex river basins. This model relies on early long-term water demand forecasts for the year 2020 and an extended record of runoff patterns. Data produced using CALSIM II are used to estimate the water to be exported from the Delta and distributed to SWP contractors. Forecasted levels of SWP deliveries are discussed in detail in a following section (Section 9.A.2.2.1, *Forecasting Annual Supplies*).

9.A.2.2 Forecasting Supply, Demand, and Shortages

The first step toward valuing the water supply benefits of the BDCP and the take alternatives is to identify the associated patterns of urban water shortages relative to those occurring under the Existing Conveyance High-Outflow Scenario and the Existing Conveyance Low-Outflow Scenario. These calculations are performed using the SDBSIM, which is a probabilistic water portfolio simulation model that apportions and values shortages on an agency level (as developed by The Brattle Group). The SDBSIM evaluates water shortages in each sector[2] given demand levels over time and water supply forecasts for each of the SWP agencies. The model runs 83 different trials for each agency by rotating through a historical hydrologic sequence. The shortage and demand outputs are then used to calculate the value of losses to consumers associated with a shortage given a constant elasticity of demand and avoided marginal cost of service. The water supplies considered in the SDBSIM consist of the local and imported supplies discussed in the preceding section. The water demands considered in the SDBSIM are based on an econometric forecast model, discussed in detail in the subsequent section. For the purposes of this report, the SDBSIM incorporates the 26 MWD water agencies along with Alameda County, Antelope Valley-East Kern, Castaic Lake, City of Santa Maria, Mojave, Palmdale, San Bernardino Valley, San Gorgonio, Santa Clara Valley Water District and Zone 7.

The SDBSIM uses an indexed sequential Monte Carlo simulation method to measure the supply-demand balance outcomes for forecasted years given the pattern of historical hydrologic conditions between years 1922 and 2004. It adjusts the demand and supplies of a forecasted year given a past year of hydrologic conditions, then takes the next sequential forecasted year and adjusts the demand and supplies for that year given the next sequential historical hydrologic year conditions, and so on. For example, the SDBSIM would adjust the forecasted demand and supplies for the year 2012 given the hydrologic conditions of the year 1922, and adjust the forecasted demand and supplies of year 2013 given the hydrologic conditions of year 1923, and so on. By preserving the series of climate patterns, or *hydrologic trace*, the model is able to capture the operation of storage resources that are drawn upon and refilled over the forecast horizon given a probabilistic sequence of hydrologic conditions. The model then starts over and shifts the hydrologic year by one for each forecasted year. That is, it will adjust the 2012 forecast given the 1923 historical hydrologic conditions, and accordingly will adjust 2013 given 1924 conditions, and so forth. This shifting process is done 83 times such that each forecasted year is evaluated under each hydrologic condition, while still preserving the order of the hydrologic conditions, resulting in 83 different reliability outcomes for each forecast year. The model considers the hydrologic conditions of 2004 to be followed by those of year 1922. Thus, when forecasting using a trace that starts with a late hydrologic year, it simply loops back around to the beginning of the climate cycle.

For each year, the SDBSIM compares the forecasted demand to the sum of available projected local supplies and imported supplies less conservation savings in order to assess the disparity between the amount of water desired and the amount that can be provided. If a shortage exists, the SDBSIM may release additional supplies from storage or transfer programs until supply and demand are balanced or until these supplies are exhausted. A net shortage for the year results if the gap between supplies and demands is too large to be balanced by storage and transfer programs. If a surplus exists, the SDBSIM may allocate surplus water to various storage accounts until all storage capacity

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[2] All sectors are composed of single-family residential, multifamily residential, commercial/industrial/institutional, and agriculture.

is used; any remaining surplus supplies are considered unused or “wasted” and are not available for use in subsequent years of the forecast. The remainder of this subsection details the supply and demand forecasts used in the SDBSIM.

9.A.2.2.1 Forecasting Annual Supplies

Future hydrologic conditions are highly uncertain. For example, it is unknown if a major drought like the one experienced in 1924 or 1977 will occur in 2025 or 2050. The timing of such extreme weather patterns may have a significant effect on the value of infrastructure that secures water supply reliability. The advantage of SDBSIM’s indexed sequential Monte Carlo simulation method is that it can account for supply uncertainty by considering 83 different sets of forecasted hydrologic time series data and the corresponding supply availability. As suggested earlier, each time series of supply data represents a possible draw from historical hydrological conditions. For example, one SDBSIM simulation uses as input the annual hydrologic conditions from 1922 to 1960, another SDBSIM simulation uses as input from 1923 to 1961. In subsequent simulations, each year from 1924 to 2004 is considered as the starting year to initialize supply conditions in 2012.[3] In this way, water supply availability between 2012 and 2050 is computed under a wide range of potential hydrologic conditions. Thus, the model produces probabilistic water supply availability given a distribution of potential hydrologic conditions, while also having the ability to predict supply under certain hydrologic conditions.

As described, each alternative has 83 simulated total SWP deliveries in each year, and these simulations correspond to the range of historical hydrologic conditions from 1922 to 2004. Figure 9.A-1 considers the range of total SWP deliveries for the Existing Conveyance High-Outflow Scenario and each take alternative in the year 2020, and shows the percentage of the 83 simulations in which different levels of deliveries are exceeded. For example, the Existing Conveyance High-Outflow Scenario, indicated with a black line, shows that about 29% of the 83 simulations had total SWP deliveries in year 2020 exceeding 2.0 MAF. Meanwhile, under the BDCP Proposed Action High-Outflow Scenario, the total SWP deliveries in year 2020 exceed 2.0 MAF for approximately 65% of the simulations. Said differently, Delta deliveries reach a level of 2.0 MAF more than twice as often under the BDCP Proposed Action High-Outflow Scenario than they would under the Existing Conveyance High-Outflow Scenario. This indicates that the water supply under the BDCP Proposed Action High-Outflow Scenario is more reliable than under the Existing Conveyance High-Outflow Scenario. As seen in Figure 9.A-1, the SWP deliveries become more reliable than the Existing Conveyance High-Outflow Scenario under all of the alternative scenarios, with the exception of Take Alternative E. Although not mapped, Take Alternatives G and H have the same SWP deliveries as portrayed for the BDCP Proposed Action High-Outflow Scenario. Take Alternative I SWP deliveries fall somewhere roughly between Take Alternative D and the BDCP Proposed Action High-Outflow Scenario.

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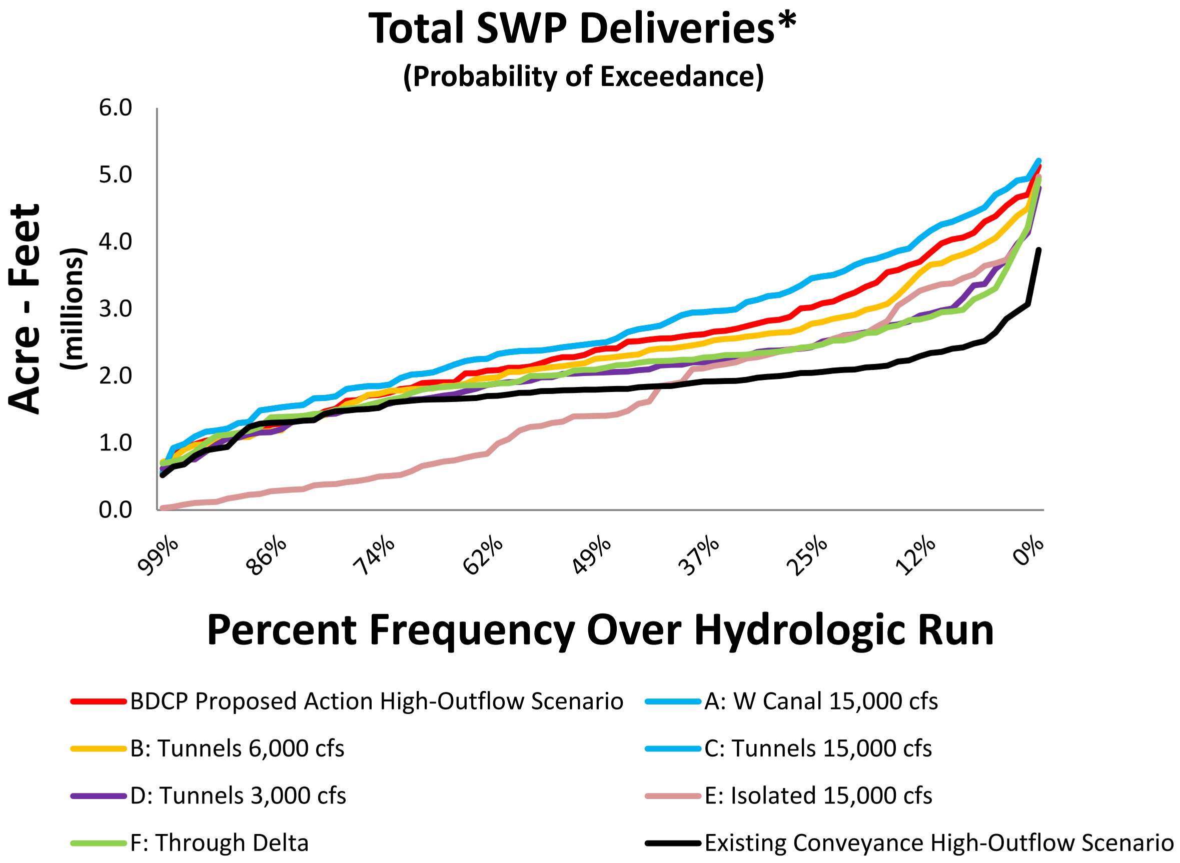
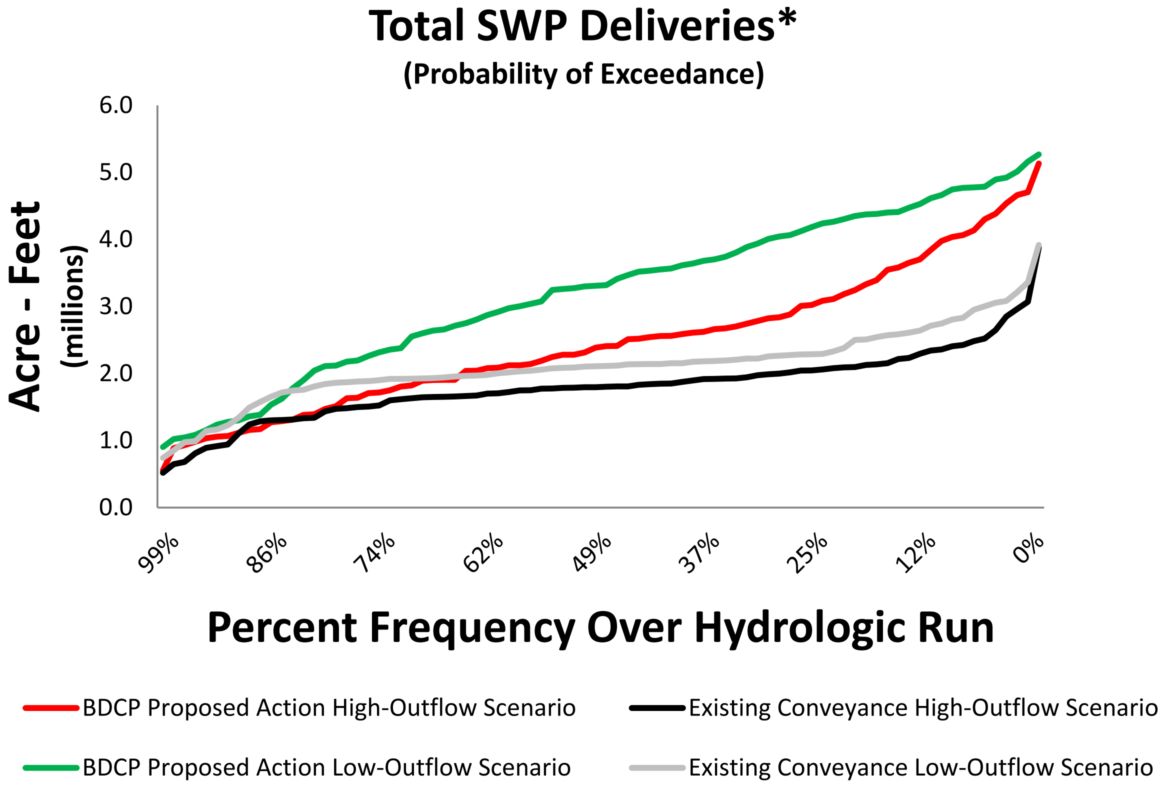
[3] The ordering of years for historical hydrologic data is preserved because there is dependence in conditions across years. Hydrologic data does not exist beyond 2004. When a simulation requires a time series of hydrologic input data beyond 2004, the time series reverts back to 1922 as the year of hydrologic conditions following 2004.



Note: Total SWP deliveries in this graph only include Table A, Article 21, and Carryover.

Figure 9.A-1. Total SWP Deliveries, High-Outflow Scenarios

Figure 9.A-2 demonstrates the same information as Figure 9.A-1, but compares the BDCP Proposed Action High-Outflow and Low-Outflow Scenarios with the Existing Conveyance High-Outflow and Low-Outflow Scenarios. The Existing Conveyance Low-Outflow Scenario is expected to deliver 2.0 MAF of water almost 62% of the time, while BDCP Proposed Action Low-Outflow Scenario is expected to deliver 2.0 MAF of water about 83% of the time. It is also seen that the BDCP Proposed Action Low-Outflow Scenario yields higher exports in general than the Existing Conveyance Low-Outflow Scenario. Total SWP deliveries exceed 3.0 MAF about 60% of the time under the BDCP Proposed Action Low-Outflow Scenario, whereas deliveries exceeded 3.0 MAF only 7% of the time under the Existing Conveyance Low-Outflow Scenario.



Note: Total SWP deliveries in this graph only include Table A, Article 21, and Carryover.

Figure 9.A-2. Total SWP Deliveries, BDCP Proposed Action and Existing Conveyance High-Outflow and Low-Outflow Scenarios

9.A.2.2.2 Forecasting Demand

Water demand is projected individually for each of the 36 urban agencies included in the SDBSIM using disaggregated econometric models, which capture the impacts of long-term socioeconomic trends on retail demands at the water agency level.[4] These models incorporate projections of demographic and economic covariates that are either forecasted by the agencies themselves or provided by the regional planning agencies Southern California Association of Governments (SCAG) and San Diego Association of Governments (SANDAG) (Metropolitan Water District of Southern California 2010).[5] Projections of the covariates are then used to forecast water demand, after which the demand forecasts are adjusted according to expected implementation of conservation programs by individual water agencies. The models forecast demand in 5-year intervals for each of the

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[4] The demand for the MWD agencies are forecasted using the MWD – MAIN model. Demands for each of the remaining SWP agencies are forecasted by the agencies.

[5] The underlying figures of the 2010 MWD-MAIN models, with the exception of water rates, rely on the SCAG's 2007 Regional Transportation Plan (RTP-07) and SANDAG's Series 12 Forecast.

following sectors: unmetered users, single family residential, multifamily residential, and commercial/industrial/institutional users. Linear interpolations are generated for the interim years; this procedure results in annual forecasts by sector for each of the urban water agencies.

The following is a discussion of the roles of population size, household size, employment, income, retail rates and conservation in forecasting water demand. This subsection is concluded with a summary and discussion of the resulting water demand forecasts.

9.A.2.2.2.1 Population and Household Projections

Projected population growth is a key component of forecasting demand. The urban areas that will benefit from the BDCP are expected to experience an average population growth of roughly 19% from 2010 to 2030. It is worth noting that southern California population projections have decreased over the last 20 years due to more conservative projections of employment growth, lower estimates of future birth rates, and updated official population counts, among other factors. If these lower population growth projections underestimate population growth then this would result in conservative demand projections.

The number of single-family and multifamily households is a main driver of many of the water demand forecasts because the residential sector usually accounts for the majority of total retail municipal and industrial demands. In the MWD service areas, single-family households are expected to increase by 16%, from 3.7 to 4.3 million by 2035, while multifamily households are expected to increase by 25%, from 2.4 to 3.0 million by 2035 (Figure 9.A-3). Within these areas, overall households are anticipated to increase by 20%, from 6.1 million in 2010 to 7.3 million in 2035. Currently, single- family households represent 61% of all households; however, by 2035, the rapid growth of multifamily households will shift the single-family share to 59%. Because the proportion of single- family homes is decreasing relative to the multifamily proportion, and the household size of single families is typically higher, the average household size is projected to decline.

Changes in the percentage of single-person households and the age structure of the region's projected population also contribute to this drop in household size. This is a reversal of historical trends, reported by California Department of Finance statistics, where average household size was relatively stable during the 1990s and increased rapidly in the later 1990s, partially explained by the population growing at a faster rate than available housing supply. The current decline in average household size, along with the decrease in outdoor water use, which is usually lower in multifamily households, leads to lower average water use overall.

Housing density, expressed as units per acre, is another element of the water demand forecast model. There is a housing trend of moving toward multifamily homes, which offer higher housing density; thus, the overall density will increase accordingly. In addition, there is a trend toward Smart Growth or New Urbanist developments, which are single-family homes built on limited lot sizes, increasing the density for single-family homes. Older built-out communities are also expected to increase in housing density as a result of subdivided lots, infill, and rezoning. The limited landscaping associated with high-density housing is anticipated to lead to a decline in water demand per housing unit. It is important to note that the impact of changing housing density on water demand is largely dependent on the rate at which the agency is growing. The faster the agency grows, the more the change in housing density affects the water demand estimates.

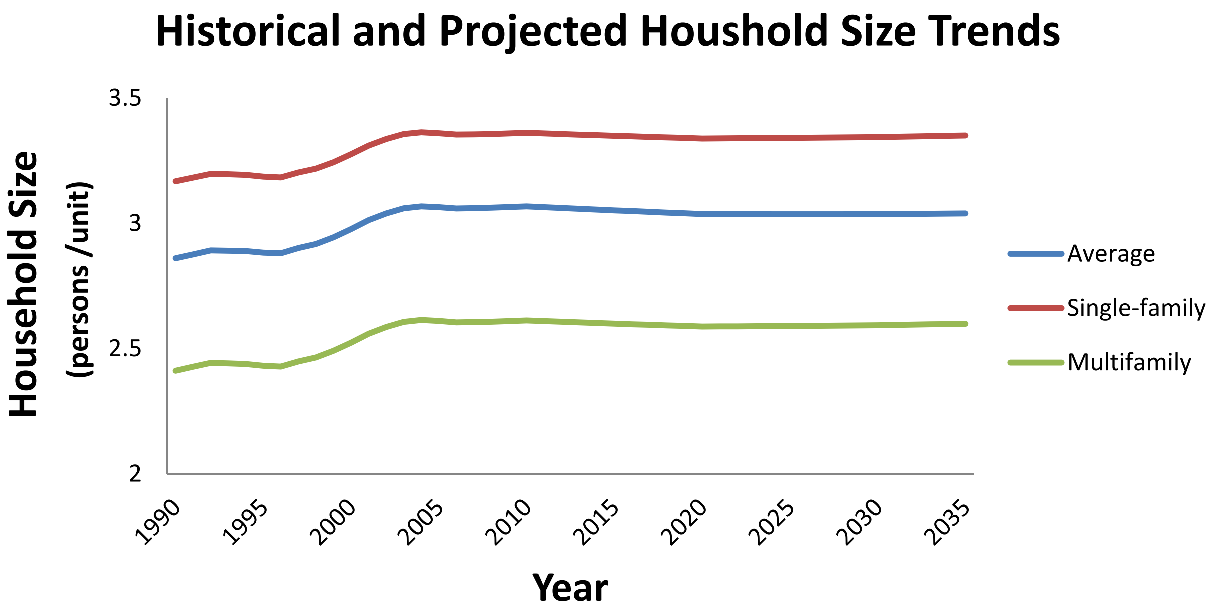

Figure 9.A-3. Historical and Projected Household Size Trends

9.A.2.2.2.2 Employment Projections

Total employment[6] and the mix of growing industries are driving forces behind many of the commercial, institutional, and industrial water demand forecasts. In the last 20 years, California has experienced a large shift from the manufacturing industry to an economy relying on service-related employment and the high-tech industries (Figure 9.A-4). This change was especially felt in southern California during the recessions of the early 1990s, when almost 300,000 manufacturing jobs were lost, while the service employment sector held steady and experienced modest growth. By the late 1990s, California's economy began to recover because of growth in high-tech and service-related employment. The economy was then hit with arguably the greatest recession since the Great Depression, causing an estimated statewide unemployment rate of 12.4% by January 2010. The impacts of the recession are expected to be felt for a number of years to come.

Consistent with recent history, the rate of change in both the service and manufacturing employment sectors are forecasted at a more conservative pace. However, the overall increase in employment leads to general growth in commercial and industrial water demand. Meanwhile, the shift toward the service industry, which inherently requires less water than manufacturing, suggests a decrease in water use per employee.

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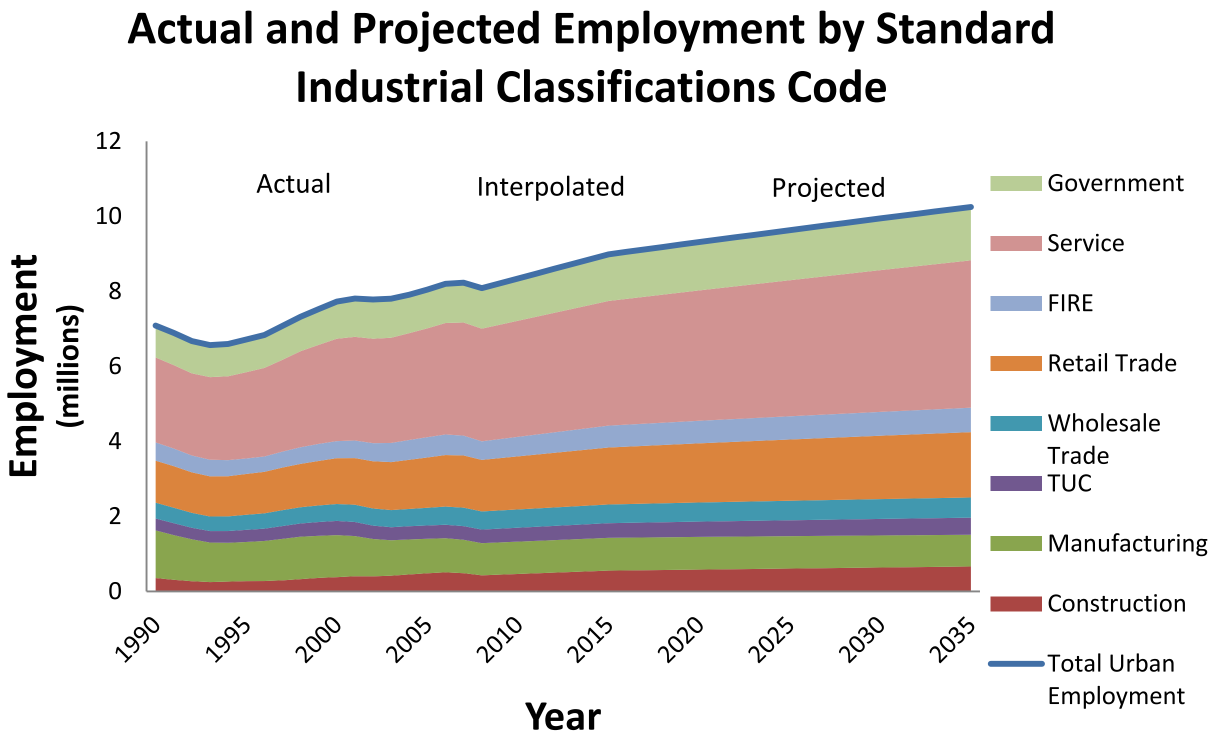
[6] Because SCAG and SANDAG employment projections were developed before the 2007 recession, these statistics are likely to overstate employment, especially in the short term. Caution is therefore necessary when considering the material in this section.



Note: The employment projections are interpolated from July 2009 to July 2014. This graph only includes southern California employment.

Figure 9.A-4. Actual and Projected Employment by Standard Industrial Classification Code

9.A.2.2.2.3 Income Projections

Most of the demand forecast models account for the role of income growth; Figure 9.A-5 shows the median household income projections out to 2035 for a subset of the counties in the forecast models. Empirically, the elasticity of income is positive: an increase in household income translates into an increase in water demand. The intuition for this relation is that wealthier individuals have a less restrictive budget, which allows them to use water more intensively in each of its uses, and water can be used within the household in new ways (e.g., installation of lawn sprinkler system). As incomes grow, holding other factors constant, household water consumption will likely increase.

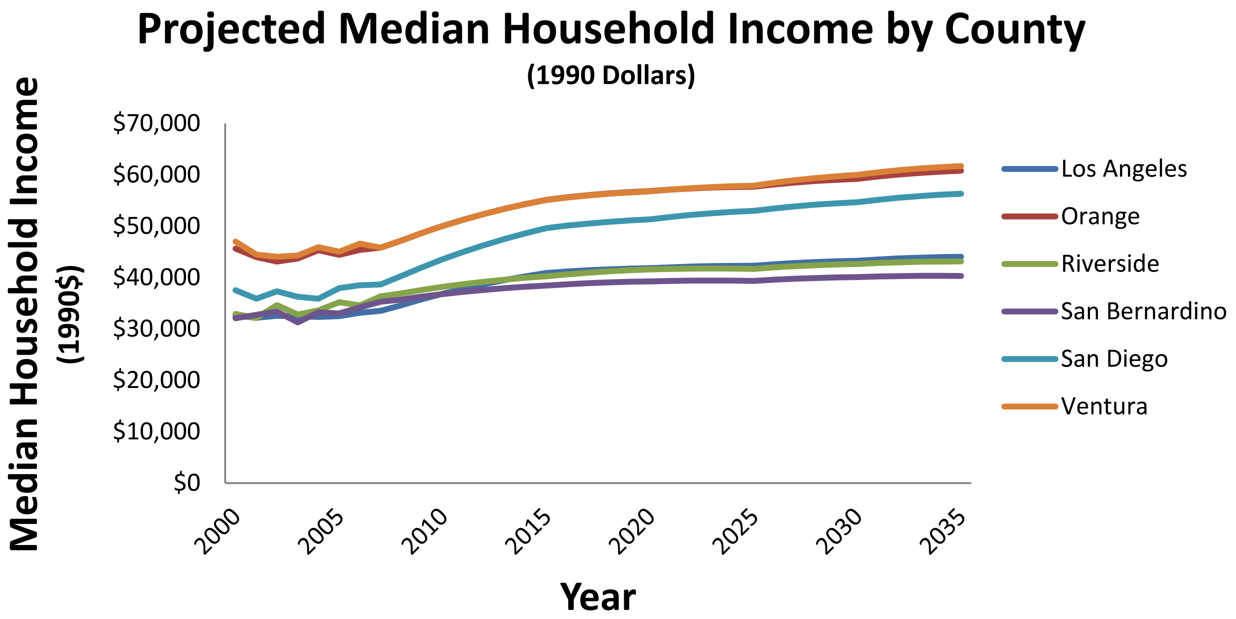


Figure 9.A-5. Projected Median Household Income by County

9.A.2.2.2.4 Retail Water Rates

Water rates are an essential component of many of the water demand projections, and are expected to experience growth over the coming decades. The water rates used to forecast demand in the MWD service areas are assumed to increase at 4.4% per year, or 2.4% in real terms (Figure 9.A-6). This is a conservative annual growth estimate compared to MWD's average annual rate increases of 7.5% in 2011 and 2012.

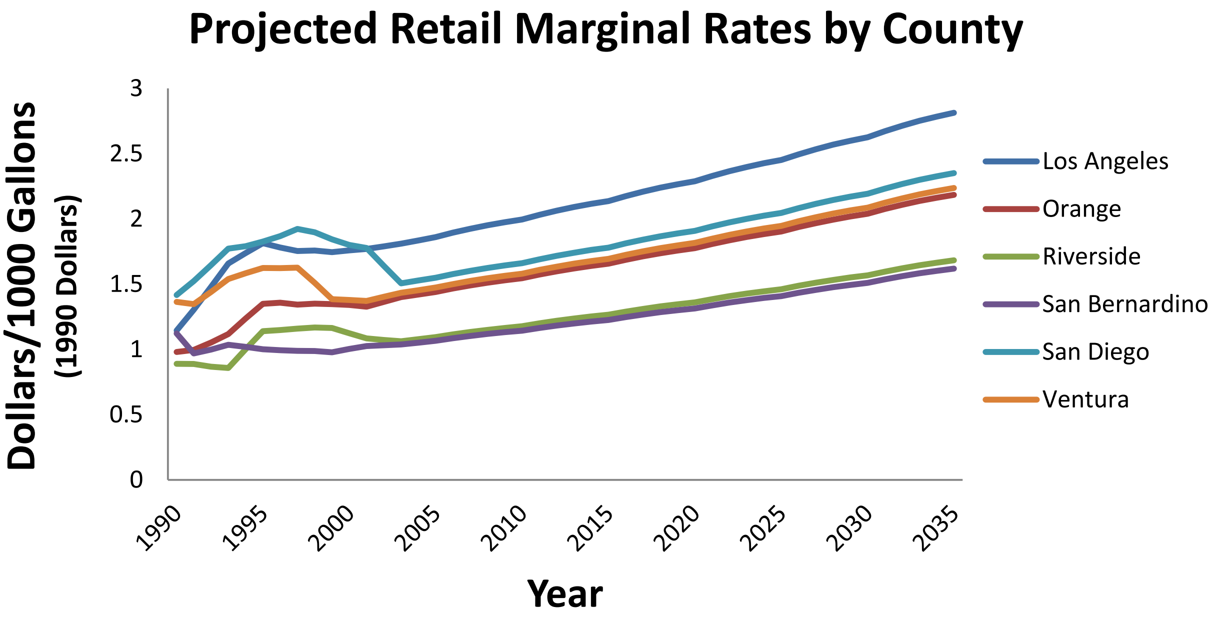


Figure 9.A-6. Projected Retail Marginal Rates by County

9.A.2.2.2.5 Conservation

The majority of demand projections obtained from the demand forecast models are adjusted to account for projected conservation savings stemming from three major sources: active conservation, code-based conservation, and price-effect conservation. Active conservation is the direct result of conservation programs implemented by the water agencies, such as the implementation of best management practices. Code-based conservation is water saving resulting from changes in water efficiency requirements for plumbing fixtures in plumbing codes. Price-effect conservation is the water savings induced by changes in the real price of water. This effect is accounted for using the coefficient on water rates in the water demand forecast models.

Unmetered savings are a by-product of the three sources of conservation savings. Because unmetered water use is calculated as a percentage of overall water demand, as conservation leads to lower demand, unmetered water use is in turn lowered. The reduction in unmetered use is considered a fourth source of conservation.

Conservation savings are expected to surpass 1 MAF by 2025 (Figure 9.A-7). Almost 70% of the estimated conservation savings are from active and plumbing code savings, while close to 23% is due to price-effect savings and about 7% due to savings of unmetered water use.

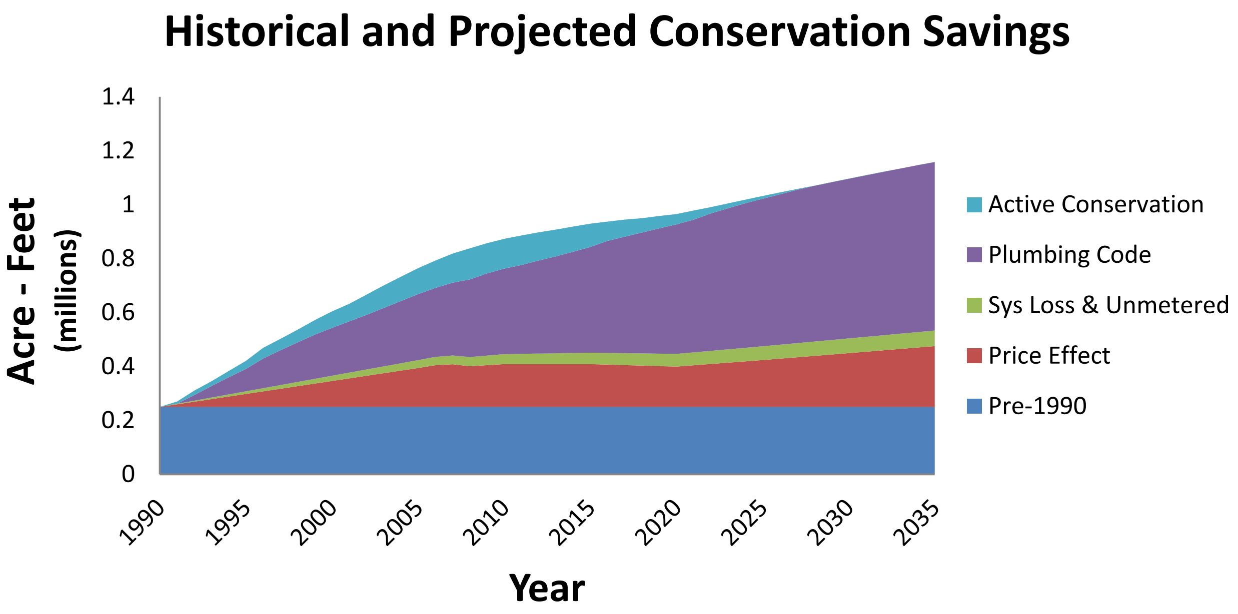


Figure 9.A-7. Historical and Projected Conservation Savings

9.A.2.2.2.6 Resulting Demand Forecasts

Accounting for conservation efforts and assuming normal economic conditions, total water demand across all agencies is projected to grow 20% over the forecast period, from 5.1 MAF in 2012 to 6.2 MAF in 2050. During this period, single-family demand is projected to increase by 26%, multifamily demand by 20%, and commercial demand by 19%. Agricultural use is projected to decline by 15%. The projected rate of growth for total demand is estimated to be larger than in the past, with a rate of 28,000 acre-feet per year compared to a rate of under 20,000 acre-feet per year from 1990 to 2010 (Figure 9.A-8).

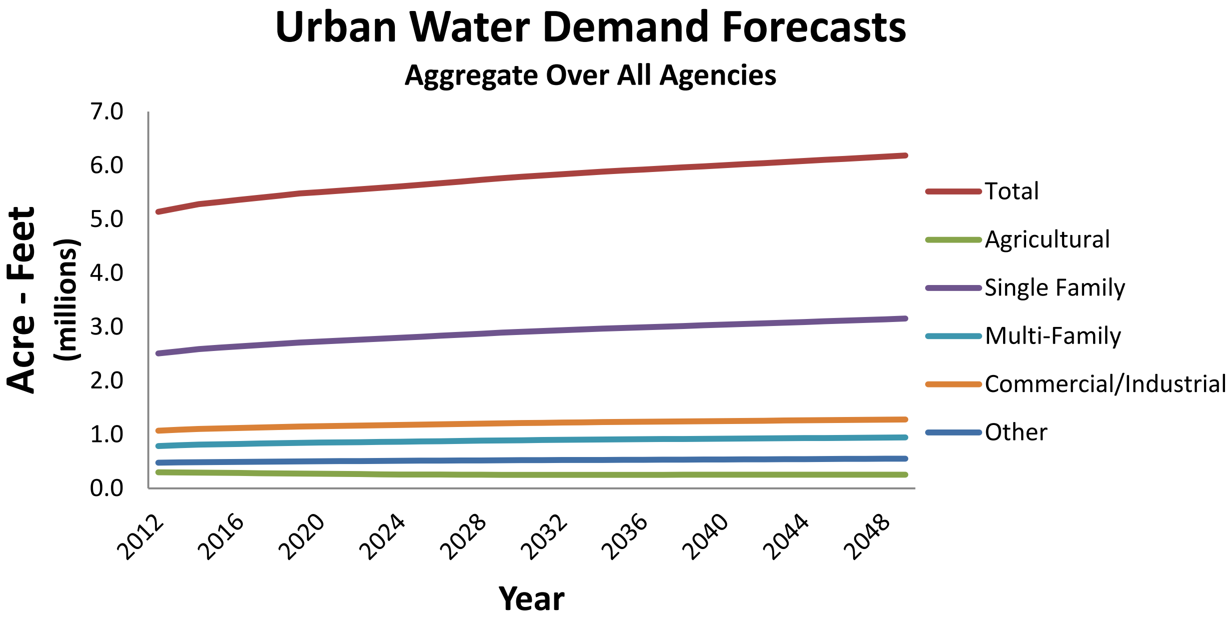


Figure 9.A-8. Urban Water Demand Forecasts

While aggregate demand is projected to increase over the planning horizon, the per capita water demand is anticipated to drop to under 180 gallons per capita per day. Historically, per capita demand dropped from over 200 gallons per capita per day in the later 1980s to under 170 gallons per capita per day in the early 1990s due to the combined effects of the drought, recession and conservation effort. Since the late 1990s, the average per capita use has increased to over 190 gallons per capita per day because of gradual employment recovery and rapid population growth in the hotter and drier regions. The predicted decline over the projection horizon is primarily attributed to conservation savings.

Projections of average water use over time estimate a slight increase for average single-family use in contrast to a decline in average use for the multifamily and commercial/industrial/institutional sectors. Unmetered use is expected to remain stable. The growth in average single-family use is attributed to expected growth in household income. These projections include conservation savings, but do not account for the impacts of New Urbanist developments, which could reduce future single-family use for these areas.

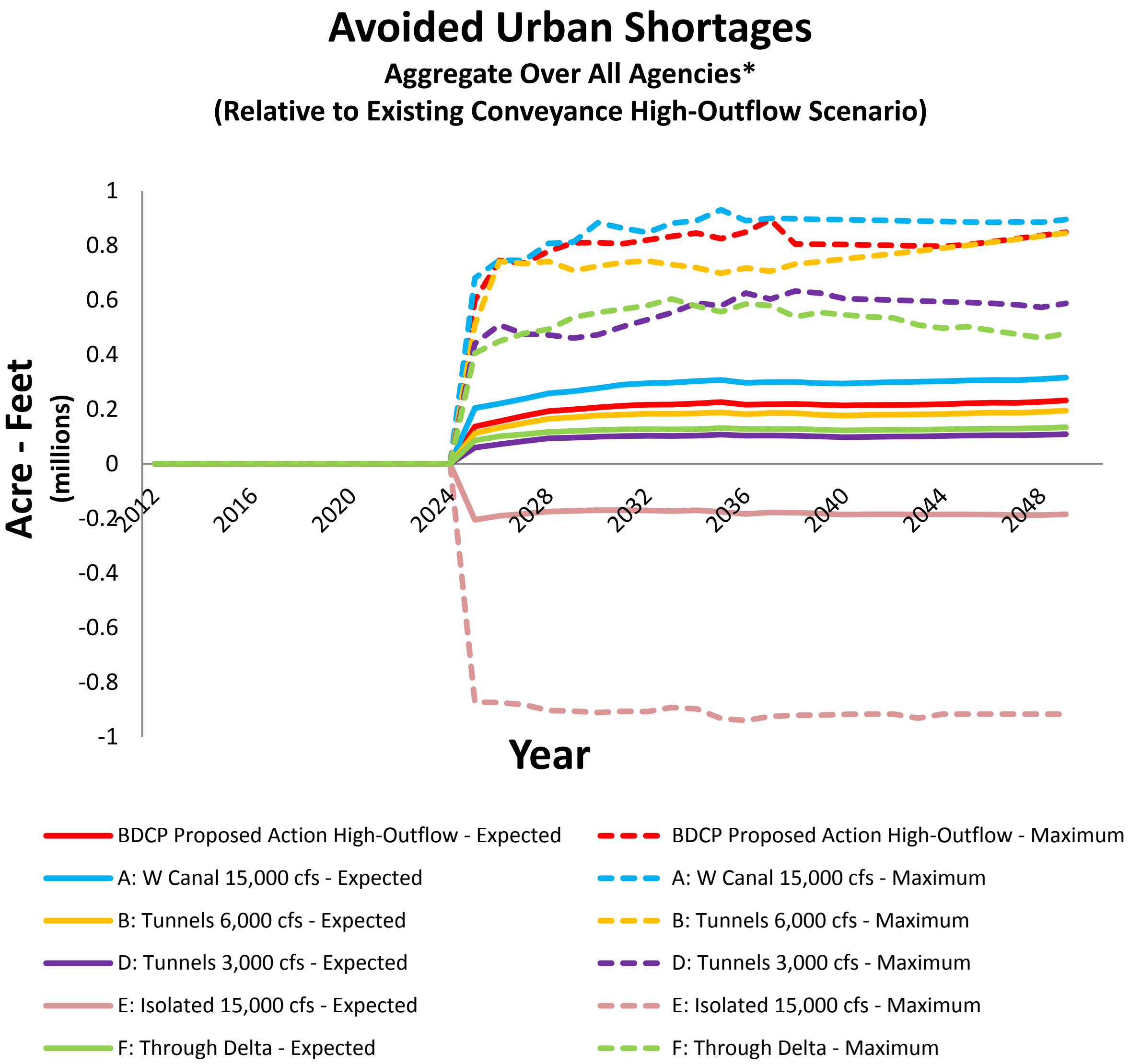
9.A.2.2.3 Forecasting Shortages for the BDCP Proposed Action and Take Alternatives

Shortages are forecasted for each year in each agency in the model under the comparative Existing Conveyance High-Outflow and Low-Outflow Scenarios, and the BDCP Proposed Action and the take alternatives. Further, shortages are calculated under the 83 different hydrologic conditions as already discussed. Shortage is defined as a condition of excess demand, or a disparity between demand and available supply. Shortages are calculated separately for several sectors, including single-family residential, multifamily residential, commercial and industrial, groundwater replenishment, and other demands. All shortages are evaluated using the SDBSIM.

Consistent with the assumption that any supply infrastructure from the BDCP will not become available until 2025, there is no variation in shortages across scenarios before the inception of each take alternative. Beyond 2025, the results demonstrate that there is considerable variation in incremental shortages across take alternatives and existing conveyance scenarios. Shortages under the Existing Conveyance High-Outflow Scenario are projected to be on average 0.5 MAF in 2025 and grow to 0.8 MAF in year 2050. Based on the SDBSIM output, the BDCP Proposed Action High-Outflow Scenario and eight of the nine take alternatives would yield smaller net shortages than the Existing Conveyance High-Outflow Scenario. Take Alternative E is projected to produce larger shortages compared to the Existing Conveyance High-Outflow Scenario, as expected, based on the exceedance probabilities shown in Figure 9.A-1. Although most of the take alternatives would result in decreased shortages, there would still be a significant shortage under the BDCP Proposed Action High-Outflow Scenario and all take alternatives. Such shortages in year 2050 would range from 0.5 MAF under Take Alternative A to 1.0 MAF under Take Alternative E.

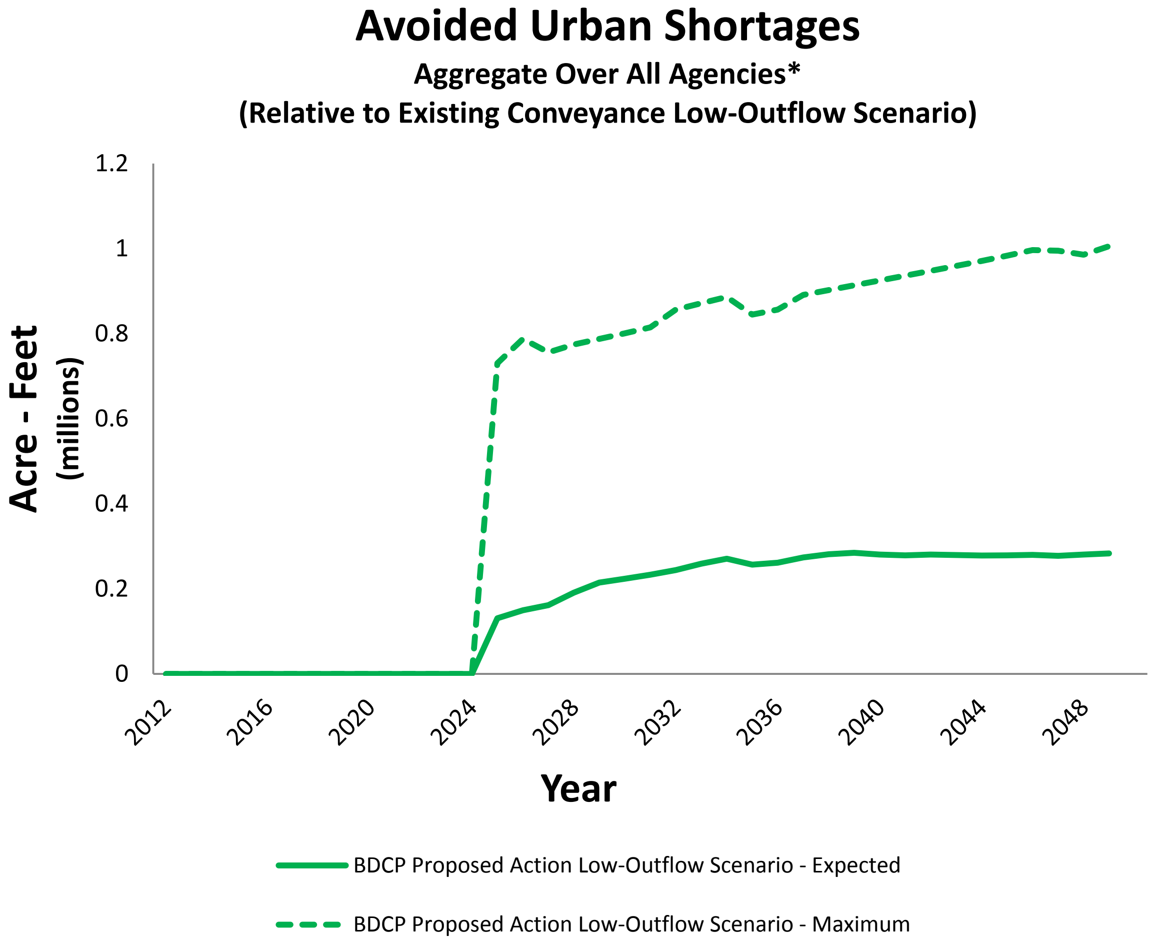
Similarly to the take alternatives, although the BDCP Proposed Action Low-Outflow Scenario would mitigate shortages, as compared to the Existing Conveyance Low-Outflow Scenario, there would still be shortages forecasted to be on average 0.3 MAF in 2025 and up to 0.5 MAF in year 2050. Meanwhile, the BDCP Proposed Action Low-Outflow Scenario is projected to have a shortage of 0.2 MAF in year 2025 that would grows to a little over 0.3 MAF by 2050.

The main goals of this analysis are to measure and value the urban water shortages forecasted to occur under the Existing Conveyance High-Outflow Scenario that would be avoided under each take alternative. Thus, the differences in shortages between the Existing Conveyance High-Outflow Scenario and the take alternatives are considered, rather than the absolute shortage that would result from each take alternative. Similarly, avoided shortages are measured by comparing shortages under the Existing Conveyance Low-Outflow Scenario to shortages under the BDCP Proposed Action Low-Outflow Scenario. Figure 9.A-9 depicts the urban water shortage avoided under the take alternatives relative to the Existing Conveyance High-Outflow Scenario. Figure 9.A-10 demonstrates the urban water shortage avoided under the BDCP Proposed Action Low-Outflow Scenario relative to the Existing Conveyance Low-Outflow Scenario. Both the average over 83 trials (Expected) and largest potential (Maximum) avoided shortages are shown for each forecasted year. Because Take Alternative E would yield a higher shortage than the Existing Conveyance High-Outflow Scenario, the avoided shortage would be negative and should be thought of as an added shortage. Take Alternative C is projected to have the same avoided shortages as Take Alternative A. Take Alternatives G and H are projected to have the same avoided shortages as the BDCP Proposed Action High-Outflow Scenario. Take Alternative I avoided shortages would fall somewhere between those of Take Alternative D and the BDCP Proposed Action High-Outflow Scenario.



Note: Shortages in this graph do not include estimates for Santa Clara Valley Water District.

Figure 9.A-9. Avoided Urban Shortages of Take Alternatives Relative to the Existing Conveyance High-Outflow Scenario



Note: Shortages in this graph do not include estimates for Santa Clara Valley Water District.

Figure 9.A-10. Avoided Urban Shortages of BDCP Proposed Action Low-Outflow Scenario Relative to Existing Conveyance Low-Outflow Scenario

While the expected avoided shortage under the BDCP Proposed Action High-Outflow Scenario relative to the Existing Conveyance High-Outflow Scenario is, on average, more than 0.2 MAF over the forecasted years (2025 to 2050), the maximum avoided shortage averaged over the same period is almost 4 times as large. The Low Outflow Scenario shows similar results. The expected avoided shortage under the BDCP Proposed Action Low-Outflow Scenario relative to the Existing Conveyance Low-Outflow Scenario averages a little under 0.3 MAF over the forecasted years, and the maximum avoided shortage averages at 0.9 MAF.

To properly interpret the results of this analysis, it is important to understand that the economic value of one large shortage can be much greater than that of many small shortages adding up to the same quantity. This result is a consequence of the decreasing marginal value of water, which implies that each additional unit of water is worth less than the last. An obvious corollary is that the first unit of water cut from supply is less valuable than the second unit of water cut from supply. In other words, the first units of water are easiest for consumers to conserve because they can decrease consumption for nonvital activities such as landscape watering. However, as the shortage grows it becomes increasingly difficult to curtail water consumption as consumers are faced with cutting back on more important water uses such as bathing. This increased difficulty leads to a rapid increase in the value of water causing welfare loss to grow exponentially as shortages escalate. As a consequence, there is significant value in mitigating the possibility of a large shortage from occurring.

9.A.2.3 Valuing Urban Water Supply Reliability

The loss framework used in the SDBSIM considers the economic impacts related to a water supply interruption, and emphasizes how water shortages will likely affect ratepayers. The welfare losses during a shortage are determined by the size of the shortage, the forecasted demand, the price elasticity of demand, and the utility's pricing structure, and the source of supply unreliability. The analysis also considers the role of additional investment in water supply alternatives as a way to deal with excess demand in the event of a reduction in SWP deliveries.

An important feature of the SDBSIM is that the model acknowledges that water utilities recover capital costs through volumetric prices such that the rates are set above marginal cost. Concurrently, it recognizes capital costs are sunk costs; thus, only avoided marginal costs are considered in the loss calculation. Not accounting for these two facts would miss a significant part of the welfare loss. Further, it is important to remember that water utilities are public entities so that the impacts of shortages on utilities translate into impacts on ratepayers. In other words, all the welfare loss resulting from a shortage falls on the consumer.

Water shortages following a supply disruption have the potential to adversely affect economic outcomes among several types of water users, including agricultural, residential, industrial, commercial, and government water users. The SDBSIM considers a drought response framework in which water supply reductions are distributed among the users according to their unit value of water (Section 9.A. 2.3.1, *Theory*). Losses are measured by computing consumer willingness to pay to avoid water service interruptions in each sector. For instance, in the residential sector, the willingness of a household to pay to avoid an interruption in water service of a given magnitude is the total amount of money the household would pay to restore water deliveries to the desired baseline level of use.

Residential water use can be classified into several broad categories, each with a different priority of use, and the willingness to pay for water by residential customer depends on the intended use of each unit of water. The willingness to pay for water used for drinking and basic sanitation is larger than the willingness to pay for water used for bathing and laundry, which in turn is larger than the willingness to pay for water used for washing cars, for filling swimming pools, and for outdoor irrigation. When faced with a water service disruption of a given magnitude, residential consumers have the choice of which types of water uses to curtail, and the framework for measuring residential losses incorporates the idea that residents respond to a water service disruption by eliminating less valuable water units before eliminating more valuable water units, for instance, by reducing water used for landscaping irrigation prior to reducing drinking water consumption.

In the event of a service disruption, consumer willingness to pay to avoid a water service interruption rises with the magnitude of the supply shortage, as consumers are forced to cut more deeply into high-priority uses of water when faced with larger shortage levels. Consumer willingness to pay to avoid a water shortage sums the willingness to pay for each unit of water from the baseline level to the disrupted level.

The economic loss calculation places special significance on prevailing water rates in a region prior to a period of supply disruption. Urban water consumers are faced with a given set of water rates that are chosen by their local purveyor, and, given these rates, consumers are generally free to purchase their desired quantities of water. At lower water rates, consumers make landscaping choices that devote a greater quantity of water to outdoor irrigation uses than they would facing higher water rates, so that the potential for water conservation in the face of a shortage is greater (and the economic losses are accordingly smaller) in regions with initially lower water rates. This is because consumers purchase a quantity of water that equates consumer willingness to pay for the last unit of water consumption to the water price established by the local rate structure.

Water rates combined with observed consumption levels at the prevailing rates provide information about the value of water to households at a single point on the demand curve. Because the SDBSIM addresses the economic losses resulting from reducing water consumption below baseline levels, it is necessary to characterize the demand curve at consumption levels that are reduced below baseline levels. The economic loss calculation therefore requires making inferences on consumer willingness to pay for water units at successively higher levels of water rationing, as households are forced to dispense with increasingly high-value uses of water. To characterize these values, the SDBSIM relies on regional water consumption data to estimate demand schedules across households in geographic regions served by individual water purveyors using an econometric model that is capable of explaining water consumption as a function of variables such as rates, income, urban density, and climate conditions. By comparing agencies over time, and from one place to another, the econometric model traces out more complete demand information than could be gained by looking at a single agency at a single moment in time. As described in subsequent sections, the results of the statistical analysis are robust and significant at conventional levels used for hypothesis testing. The results are also consistent with other, similar studies in the academic literature.

9.A.2.3.1 Willingness-to-Pay Calculations

The SDBSIM adopts the approach of Brozovic et al. (2007) in deriving an equation for the estimation of consumer willingness to pay to avoid water service disruptions. This approach is used for each of the sectors observed with sector-specific variables. The theory behind the welfare loss calculation for the residential sector is described below as an example of the method. The theory is similarly applied to the agricultural and the commercial and industrial sectors.

Residential water demand elasticities are estimated for each of *n* regions under a specification of constant elasticity of demand given by:

$$P_i = A_i Q_i^{\frac{1}{\varepsilon_i}}, \; i = 1,2,3,\ldots,n, \qquad (1)$$

where ε_i is the elasticity of water demand in region *i* and A_i is a parameter that scales the magnitude of demand to the price in each region.

Let P_i^* and Q_i^* respectively denote the retail water price and quantity of water consumed by residential households in region *i* under baseline conditions (prior to water rationing). For a given water shortage with an available level of water given by $Q_i(r_i) < Q_i^*$, it is helpful to define the relationship between these quantities in terms of the percentage of water that is rationed in region *i*, r_i, as:

$$Q_i(r_i) = (1 - r_i)Q_i^*. \tag{2}$$

Making use of equations (1) and (2), consumer willingness to pay to avoid a supply disruption of magnitude $r_i \cdot Q_i^*$ in region *i* can be calculated as follows:

$$W_i(r_i) = \int_{Q_i(r_i)}^{Q_i^*} P_i(Q)dQ_i = \int_{Q_i(r_i)}^{Q_i^*} A_i Q_i^{\frac{1}{\varepsilon_i}} dQ_i = \frac{\varepsilon_i}{1+\varepsilon_i} P_i^* Q_i^* [1 - (1 - r_i)^{\frac{1+\varepsilon_i}{\varepsilon_i}}] \tag{3}$$

Consumer willingness to pay to avoid a supply disruption in equation (3) can be calculated for each region by constructing an aggregate demand curve to represent the residential water segment (equation (1)). For regions in which residential customers pay volumetric water rates, P_i^* is the volumetric rate in region *i*, Q_i^* is the total quantity of water delivered to residences at that price in region *i* prior to a supply disruption, and ε_i is the elasticity of water demand for region *i*, which can be estimated from observations of rates and quantities in the region over time along with covariates such as income and weather conditions.

Consumer willingness to pay to avoid a supply disruption in equation (3) depends on the prevailing retail price charged to consumers in each region under baseline supply conditions, P_i^*. As mentioned before, water conservation in the face of a shortage is more forthcoming at lower water rates than at higher water rates, and consumer willingness to pay to avoid a given magnitude disruption in water supply is accordingly larger in regions with higher baseline water rates.

For regions in which residential customers pay inclining tiered prices for water, the calculation in equation (3) is complicated by the fact that different residences in the region pay different prices for the last unit of water consumed. In an inclining tiered-rate structure, households with a high level of monthly water use pay higher prices for the last unit of water consumed (and higher average prices per unit of water) than households with a lower level of use, which confounds the use of a representative water price for households in equation (3).

Consumer willingness to pay to avoid a supply disruption among households in a region with an inclining tiered rate structure and an arbitrary number of pricing tiers can be calculated as follows. Let h_i denote the number of households in region *i* and let Q_{ij}^* and P_{ij}^* denote the baseline level of water consumption and the equilibrium price paid for the last unit of water consumed by household *j* in region *i*, respectively, where $j = 1, 2, 3, \ldots, h_i$ is an index of households in region *i*. Next, suppose that households in region *i* can be characterized by constant elasticity of demand functions that share a common elasticity of demand of $\varepsilon_i < 0$ so that water demand for household *j* in region *i* is given by:

$$P_{ij} = A_{ij} Q_{ij}^{\frac{1}{\varepsilon_i}}, j = 1,2,3,\ldots,h_i;\ i = 1,2,3,\ldots,n. \tag{4}$$

Household demand for water is larger at lower water rates than at higher water rates, while water prices rise with quantity on the supply side in an inclining tiered structure. This implies that households consuming water on higher pricing tiers have different (i.e., greater) demand for water than households that meet their water needs exclusively on lower tiers. In general there are two ways to handle this issue. First, provided data exist on individual household purchasing behavior, individual demand curves can be estimated for the subset of households aligned on each tier of the rate structure, and then these demand curves can be aggregated to the purveyor level. Second, a representative demand curve can be estimated using aggregate data at the purveyor level using an appropriate price index that incorporates demand information from all pricing tiers. Given the lack of data to implement the first approach, the model uses the second approach, which is described below.

Suppose all households in region *i* respond to a regional supply disruption by proportionately reducing water consumption from the baseline level. For a proportional rationing level of r_{it} across all households in region *i*, each household reduces water consumption to the level $Q_{ij}(r_i) = (1 - r_i)Q_{ij}^*$, so that consumer willingness to pay across all households to avoid a supply disruption of a magnitude $r_i \cdot Q_i^*$ is given by:

$$W_i(r_i) = \sum_{j=1}^{h_i} \frac{\varepsilon_i}{1+\varepsilon_i} P_{ij}^* Q_{ij}^* \left[1 - (1 - r_i)^{\frac{1+\varepsilon_i}{\varepsilon_i}}\right] = \frac{\varepsilon_i}{1+\varepsilon_i} \hat{P}_i^* Q_i^* \left[1 - (1 - r_i)^{\frac{1+\varepsilon_i}{\varepsilon_i}}\right] \qquad (5)$$

where $Q_i^* = \sum_{j=1}^{h_i} Q_{ij}^*$ is the aggregate quantity of water purchased by residential households in the region, and

$$\hat{P}_i^* = \frac{\sum_{j=1}^{h_i} P_{ij}^* Q_{ij}^*}{\sum_{j=1}^{h_i} Q_{ij}^*} \qquad (6)$$

is a price index that represents the weighted average of equilibrium water rate paid by the various households in region *i*.

In the case of volumetric pricing, the price index in equation (6) reduces to the volumetric water rate in region *i*, and the measure of consumer willingness to pay to avoid a supply disruption in equation (5) reduces to the measure in equation (3).

It should be noted that the price index in equation (6) is developed under a drought response scenario of proportional rationing of all rates in an inclining tiered rate structure. In the event that the shortage allocation plan in a given region seeks to protect lifeline customers by rationing water more severely among households on higher tiers than on lower tiers of the rate structure, the relevant price used to calculate economic losses would be larger than the index price in equation (6), and the economic losses commensurately would be greater than the value represented by the regional willingness to pay measure in equation (5). That is, the choice of water rates likely produces an underestimate of the true value of water supply reliability.

The measure of welfare indicated in equation (5) does not account for the avoided costs of service delivery during a shortage. Economic losses that result from water shortage in a given market are mitigated to the extent that delivering a smaller quantity of water reduces the system-wide cost of water service. Because the overall cost of service includes large fixed costs that do not vary with the amount of water delivered through the system (e.g., infrastructure costs, repair and maintenance, administrative expenses), the avoided cost that results from water shortage is relatively small in relation to total cost. The reduction in the cost of water service that occurs in response to a one-unit reduction in water deliveries is the avoided *marginal* cost of service. Examples of components of avoided marginal cost include the energy and chemical costs of treating water units that are no longer delivered, the reduction in conveyance costs, and the decrease in energy and chemical costs of wastewater treatment that arise from a smaller level of water delivery.

The SDBSIM assumes the marginal cost of service delivery is a relatively flat and that it is common across retailers; the delivery cost per unit of water is assumed to be *c*.[7] This is a reasonable working assumption; given the lack of data, one cannot reject the hypothesis that the costs of service delivery are identical. Once accounting for the avoided cost of service delivery, the measure of losses for consumers in retailer *i* of year *t* becomes:

$$W_i(r_i) = \frac{\varepsilon_i}{1+\varepsilon_i}\hat{P}_i^* Q_i^* \left[1-(1-r_i)^{\frac{1+\varepsilon_i}{\varepsilon_i}}\right] - r_i \cdot Q_i^* \cdot c \qquad (7)$$

This framework is used to calculate what consumers would be willing to pay in order to avoid a given supply shortage; that is, the value of water supply reliability. The approach can evaluate losses at the individual retail level; therefore, the aggregate measure of the value of water supply reliability takes into account differences between individual retailers' baseline prices, demand, inherent value of water (elasticity of demand) and the ultimate levels of shortage experienced within a retailer. It can also be used for situations in which shortages may occur in multiple years. This framework is easily applied to any consumer sector by employing sector-specific variables.

9.A.2.4 Econometric Model of Urban Water Demand

An essential factor to determine the value of avoiding a shortage is a measure of how consumers respond to changes in price. To illustrate the importance of such a measure, suppose there is a 50% increase in water rates holding all other water demand factors constant (e.g., weather, technology), and consequently there is almost no reduction in water use. Based on such an observation, it could be inferred that the last units of water consumed before the price change are relatively valuable to consumers; otherwise, there would be a larger reduction in demand. Alternatively, if a 10% increase in rates results in a 50% reduction in demand, then it could be inferred that the units of water consumed before the price change were of relatively low value to consumers. In economics, the standard measure of consumer responsiveness to changes in price is the price elasticity of demand, which summarizes how the willingness to pay to avoid a water service disruption changes with the level of water consumption.

Given its prominent role in valuing water supply reliability, a considerable amount of data has been collected to acquire an accurate estimate of the price elasticity of demand. In fact, the data set constructed is the largest set of residential water price and consumption measures that can be found in California in terms of geographic coverage.[8] These data span over a decade of historical records tracking 119 California water retailers from 1995 to 2010. Although not every retailer is represented in every year, there are approximately 1,200 price-consumption observation points

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[7] Avoided marginal cost of service is assumed to be $250 per acre-foot.

[8] The only comparable study that estimates residential price elasticities in California is by Renwick and Green (2000); they use similar data on residential water use for eight water agencies in the San Francisco Bay Area from 1989 to 1996.

that can be used to estimate the price elasticity of demand. The construction of this data set is outlined in the following section.

The retailer price and consumption data set is linked with demographic variables that likely affect water consumption such as income, household size, and lot size (a measure of need for outdoor water use), as well as annual measures of temperature and rainfall. The model uses year fixed effects to account for shocks common to all retailers within a given year. This allows for a comparison of changes in consumption across years due to price changes without confounding changes in statewide hydrologic conditions; otherwise, it would be impossible to compare consumption changes in a wet year to consumption changes in a dry year. Unique to this study of California residential water, after accounting for changes in consumption due to demographic, weather, and year-to-year fluctuations in demand, the SDBSIM examines the within-retailer relationship between any unaccounted for consumption changes and changes in price. In this way it considers a time series of price and consumption data for each retailer to form an overall estimate of consumer willingness to pay to avoid water shortages. Due to the large sample size and consistent relationship between consumption and price, it is possible to perform statistical tests that demonstrate that the resulting estimate of the price elasticity of demand is statistically significant.

Further, it is possible to examine how consumer willingness to avoid water shortages varies with factors such as income. In the literature on residential electricity demand, evidence from consumer electricity consumption in California shows that higher income households have, on average, a lower price elasticity of demand (Reiss and White 2005). This makes sense because, in higher-income households, money spent on electricity is less likely to cut into other vital expenses such as food, medicine, or transportation. Identical results are found in the residential water sector—lower-income areas are more responsive to changes in price than higher-income areas. As a consequence, higher-income areas are more willing to shoulder the burden of avoiding a shortage than relatively lower-income areas. The relationship identified between the price elasticity of demand and median income in a service area is statistically significant, which allows for confident estimates of retail-specific measures of willingness to pay to avoid water shortages. Assuming that all areas value shortage avoidance identically may result in a severe underestimation of welfare losses during a supply disruption. The SDBSIM produces accurate estimates of aggregate welfare losses that can be disaggregated to the agency or retailer level.

9.A.2.4.1 Construction of the Price–Consumption Data Set

The data set used to estimate the price elasticity of demand consists of single-family residential fiscal year (FY) consumption and prices based on 92 retailers in MWD service areas and 27 retailers in northern California (26 agencies belonging to the Bay Area Water Supply and Conservation Association and San Francisco Retail managed by the San Francisco Public Utilities Commission). For the retailers located in the MWD service area and San Francisco Retail, historical consumption and rate data from FY 1995–96 through FY 2010–11 were collected directly from retailers with the exception of retailers belonging to the Municipal Water District of Orange County (2011) and San Diego County water Authority, for which data were acquired from annual surveys conducted by the wholesale member agencies. For the Bay Area Water Supply and Conservation Agency members, water consumption and water rates were taken from the annual surveys over the period FY 1995–96 through FY 2010–11. The *Public Water System Statistics*, a survey conducted annually by the DWR, is used for retail-level consumption in cases when retailers were not able to provide this data. This data collection tracks single-family residential annual sales, accounts, and water prices at the retailer level from the present going back to 1995.

Sales and account data is used to construct a measure of average monthly household consumption. Average annual single-family household consumption levels for each water agency are calculated by dividing the total single-family residential consumption level for the fiscal year by the number of single-family residential accounts for the given fiscal year. A monthly average consumption level is created by dividing the yearly average by 12. The construction of the price variable is a little more complicated. In addition to price variation across retailers and time, there is variation in the types of price schedules that consumer face. In particular, there exists uniform rate pricing and increasing block tiered pricing. In the former scheme, there is just one uniform rate applied to all water consumed. In the latter, prices depend on how much water has already been consumed in a given month. For example, a retailer using increasing block tiered pricing may charge $1 per 100 cubic feet (ccf) for the first 5 ccf in a month, $1.25 per ccf for 6 through 20 ccf, and $3 per ccf for all subsequent units consumed within a month. In these situations it is not obvious what the choice of marginal price should be.

One approach is to take the average of the tiered prices. The disadvantage of this approach is that most consumers do not consume on the highest tiers, and the result is a price that is not realistically a marginal price for many households. Another approach is to take the marginal price faced by a household with the average monthly household consumption for a given retailer in a given year. The disadvantage of this approach is that different prices may be observed within a retailer across years even though the price structure may not have changed. That is, the price variable is clearly endogenous to consumption because it is an explicit function of it. The SDBSIM takes an approach that sets price equal to the rate on the median tier of the block tiered price structure. Returning to the three-tier example, the median price is $1.25 so this would be the measure of price used in the regression analysis. Using the median tier price as the measure of marginal price has the advantage that the median tier is usually designed to be the tier on which the marginal price of the majority of consumers lies. The marginal price faced by households with average monthly consumption also usually lies on this tier, yet choosing the median price purges the price measure of the described endogeneity problem. There may be other sources of endogeneity that are addressed in the model specification section.

In summary, the equilibrium price of water for the typical user in each region was taken to be equal to the price charged ($ per ccf) to a residential customer on the median tier in that year. If the volumetric price ($ per ccf) is uniform across all units consumed, then price is set equal to the uniform rate. The equilibrium quantity consumed is taken as the monthly average consumption level.

The price and consumption data set is linked to retailer-specific measures of median income. Retailer-specific measures of median income were constructed based on the 2000 Census using area and household density-weighted averages across census tracts comprising the relevant retailer. First, the area-weighted number of households, n_{ij}, within each census tract *i* that intersects with a given retail service area *j* were identified. Second, the number of households in intersection ij was used to generate a weighted median income measure for retailer *j*.

In addition to median income, retailer-specific measures of annual precipitation and summer time maximum temperature are also collected. To map weather data, points are georeferenced at the centroid of each water agency. Based on the resulting set of points, local weather data was extracted from rasters provided by the PRISM Climate Group (2013). In cases when retailer boundaries could not be mapped, a proxy zip code was used to generate the weather data for those retailers.

9.A.2.4.2 Model Specification

The initial regression equation is as follows:

$$\ln(q_{it}) = \beta_1 \cdot \ln(p_{it}) + \beta_2 \cdot \ln(p_{it}) \cdot \ln(income_i) + \beta_3 \cdot W_{it} + \mu_i + \tau_t + \varepsilon_{it} \qquad (8)$$

The subscript *i* denotes the retailer (i = 1, … , 119), and the subscript t denotes the year (t = 1995, … , 2010). The dependent variable, $\ln(q_{it})$, is the natural log of average monthly household consumption among single-family residential households. The main right-hand side variables of interest are the natural log of price in retailer *i* of year *t*, $\ln(p_{it})$, and the natural log of price interacted with the natural log of median household income, $\ln(p_{it}) \cdot \ln(income_i)$. The sum of $\beta_1 + \beta_2 \cdot \ln(income_i)$ is the estimated price elasticity for retailer *i*. Notice heterogeneity in the price elasticities is obtained by interacting $\ln(p_{it})$ with the agency-specific measure of $\ln(income_i)$. The regression equation also includes controls for weather with W_{it}, which represents annual precipitation and average summer time max daily temperature in retailer *i* of year *t*. Unobserved factors that may bias the coefficients β_1 and β_2 are controlled for by including both retailer, μ_i, and year, τ_t, fixed effects. The retailer fixed effects represent a significant advantage of this estimation specification because they control for all time-invariant unobservable characteristics that may be correlated with both price and consumption. Any characteristic of a retailer that is very slow to change over time will be controlled for in the analysis.

There may still exist time-varying omitted variables at the retailer-level that bias the coefficients β_1 and β_2. That is, there may exist important unobserved factors that change year to year, and that are correlated with both price and consumption. For example, during a drought there may exist both conservation pricing and intensive conservation campaigns to limit water use. Although the year fixed effects may account for common shocks across all retailers due to drought, there is likely unobserved variation in the intensity of drought and the intensity of conservation campaigns across retail service areas—both may introduce omitted variable bias. The omitted variable, intensity of drought, would likely be positively correlated with water consumption and negatively correlated with conservation pricing—such a correlation structure would bias the estimates of the price elasticities downwards. A second omitted variable, intensity of conservation campaigns, would likely be negatively correlated with water consumption and positively correlated with conservation pricing—such a correlation structure would bias the estimates of the price elasticities upwards. The magnitudes of these biases may be attenuated by the inclusion of the weather variables, strong predictors of drought and conservation campaigns, as retailer-level control variables in the regression. However, if there is residual variation not in these omitted variables, which is not captured by weather yet is correlated with both consumption and price, then the point estimates β_1 and β_2 will be biased. The correlation between such omitted variables and price are broken using instrumental variables estimation. Using this estimation strategy, price with lagged price are first estimated according to the following equation:

$$\ln(p_{it}) = \alpha_1 \cdot \ln\left(p_{i,t-1}\right) + \alpha_2 \cdot \ln\left(p_{i,t-1}\right) \cdot \ln(income_i) + \alpha_3 \cdot W_{it} + \theta_i + \rho_t + \eta_{it} \qquad (9)$$

Using the results of the regression in equation (9), the SDBSIM estimates predicted values of the natural log of p_{it}, $\widetilde{\ln(p_{\iota t})}$, and replace the natural log of price in equation (8) with the predicted values. The final regression equation is as follows: (Wooldridge 2009:506)

$$\ln(q_{it}) = \tilde{\beta}_1 \cdot \widetilde{\ln(p_{\iota t})} + \tilde{\beta}_2 \cdot \widetilde{\ln(p_{\iota t})} \cdot \ln(income_i) + \tilde{\beta}_3 \cdot W_{it} + \tilde{\mu}_i + \tilde{\tau}_t + \tilde{\varepsilon}_{it} \qquad (10)$$

where the specification in equation (10) is identical to equation (8) except for the predicted values of log price.

9.A.2.4.3 Water Demand Estimation Results

Table 9.A-3 presents the estimation results of equation (10). It is notable that the price variables have coefficients significantly different from zero. There is also a positive and significant coefficient on price interacted with income. This funding is evidence that there is statistically significant variation in willingness to pay to avoid a shortage according to income levels.

Table 9.A-3. Single-Family Residential Demand Estimation

Independent Variables	Beta Coefficient	Standard Error	T-Statistic	P-Value	95% Confidence Interval
Price	-0.415	0.079	-5.260	0.000	-0.570 to -0.260
Price* Income	0.108	0.036	3.010	0.003	0.038 to 0.178
Precipitation	-0.012	0.009	-1.300	0.194	-0.030 to 0.006
Temperature	0.192	0.114	1.680	0.093	-0.032 to 0.415
Observations	1,186				
Year Fixed Effect	Yes				
Retailer Fixed Effect	Yes				
Instrumental Variable	Yes				

Agency-specific price elasticities are recovered by simply taking the sum: $\beta_1 + \beta_2 \cdot \ln(income_i)$, using the agency-specific measures of median income. That is, the price elasticity of agency *i* equals the sum: -0.415 + 0.108$\cdot$ $ln(income_i)$. Table 9.A-4 shows estimated price elasticities. These elasticity estimates are consistent with what has been found elsewhere (Espey et al. 1997)

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Table 9.A-4. Estimated Price Elasticities

Agency	Elasticity
Alameda County Flood Control and Water Conservation District; Zone 7	-0.187
Alameda County Water District	-0.197
Anaheim	-0.241
Antelope Valley East Kern	-0.208
Beverly Hills	-0.198
Burbank	-0.244
Calleguas Municipal Water District	-0.198
Castaic Lake Water Agency	-0.198
Central Basin Municipal Water District	-0.257
City of Santa Maria	-0.268
Compton	-0.287
Eastern Municipal Water District	-0.261
Foothill Municipal Water District	-0.202
Fullerton	-0.324
Glendale	-0.251
Inland Empire Utilities Agency	-0.236
Las Virgenes Municipal Water District	-0.173
Long Beach	-0.262
Los Angeles	-0.259
Municipal Water District of Orange County	-0.210
Mojave Water Authority	-0.261
Palmdale	-0.273
Pasadena	-0.241
San Bernardino Valley Municipal Water District	-0.322
San Diego County Water Authority	-0.240
San Fernando	-0.268
San Gorgonio Pass Water Agency	-0.282
San Marino	-0.146
Santa Ana	-0.254
Santa Clara Valley Water District	-0.189
Santa Monica	-0.231
Three Valleys Municipal Water District	-0.226
Torrance	-0.230
Upper San Gabriel Valley Municipal Water District	-0.247
West Basin Municipal Water District	-0.229
Western Municipal Water District of Riverside County	-0.241

Note:
Santa Clara Valley Water District elasticity is a weighted average of all Santa Clara Valley retailer elasticities.

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9.A.2.4.4 Water Supply Alternatives

The preceding sections have described the approach to measuring the cost of mandatory short-term conservation to cope with excess demand (or shortage conditions) caused by reductions in SWP deliveries. Conservation is not the only method of equating supply and demand. It is also necessary to consider the cost of investment in alternative urban water supplies such as recycling and desalination.

The SWP is a foundational water supply for urban agencies in southern California and the Bay Area. Its costs are far below the costs of alternative water supplies typically available in these areas. The cost of the water supply increase resulting from the BDCP Proposed Action is also well below the cost of other water supply alternatives. Under the BDCP Proposed Action High-Outflow and Low-Outflow Scenarios, respectively, the BDCP Proposed Action increases mean SWP deliveries by 1.3 to 1.7 MAF annually relative to the Existing Conveyance High-Outflow and Low-Outflow Scenarios. With a cost of $13.5 billion, the implicit water supply cost of the BDCP ranges from $238 to $321 per acre-foot.[9].

While the BDCP Proposed Action has an implicit water supply cost well below the cost of available alternatives, there is still ample scope for development of these alternatives in the SWP service area. Generally, water supply alternatives such as recycling, stormwater capture, and desalination help agencies cope with the effects of growth, and can serve as a hedge against typical fluctuations in imported water deliveries.

Given the urban water demand growth projected in the SWP service area, implementation of the BDCP alone will not solve all of the region’s water supply challenges. Figure 9.A-11 shows the expected and maximum water shortage remaining after implementation of the BDCP in both the high-outflow and low-outflow scenarios. In the high-outflow case, for example, expected water shortages are expected to grow to 0.4 MAF by 2035 and in critically dry years, shortages would grow to 1.6 MAF. Thus, while the BDCP is an important component of an overall strategy to meet future urban water supply needs, it, alone, does not solve these challenges. In addition to the BDCP, water managers will need to consider additional conservation and investment in urban water supply alternatives beyond those already considered in projecting future shortages.

The preceding sections have demonstrated the cost of coping with reductions in imported water supplies through mandatory short-term water conservation (i.e., rationing). These costs can be accurately measured through application of economic theory and econometric estimation of urban water demand relationships. Short-term water conservation is also feasible and relatively straightforward to implement by customers and water agencies. The economic costs of water supply alternatives are not easily measured, however, because they depend heavily on site-specific factors, pertinent regulations, and demands for water of varying quality. However, by examining the actual cost of past alternative water supply projects, it is possible to portray a range of potential costs that can be compared to the costs of mandatory short-term conservation.

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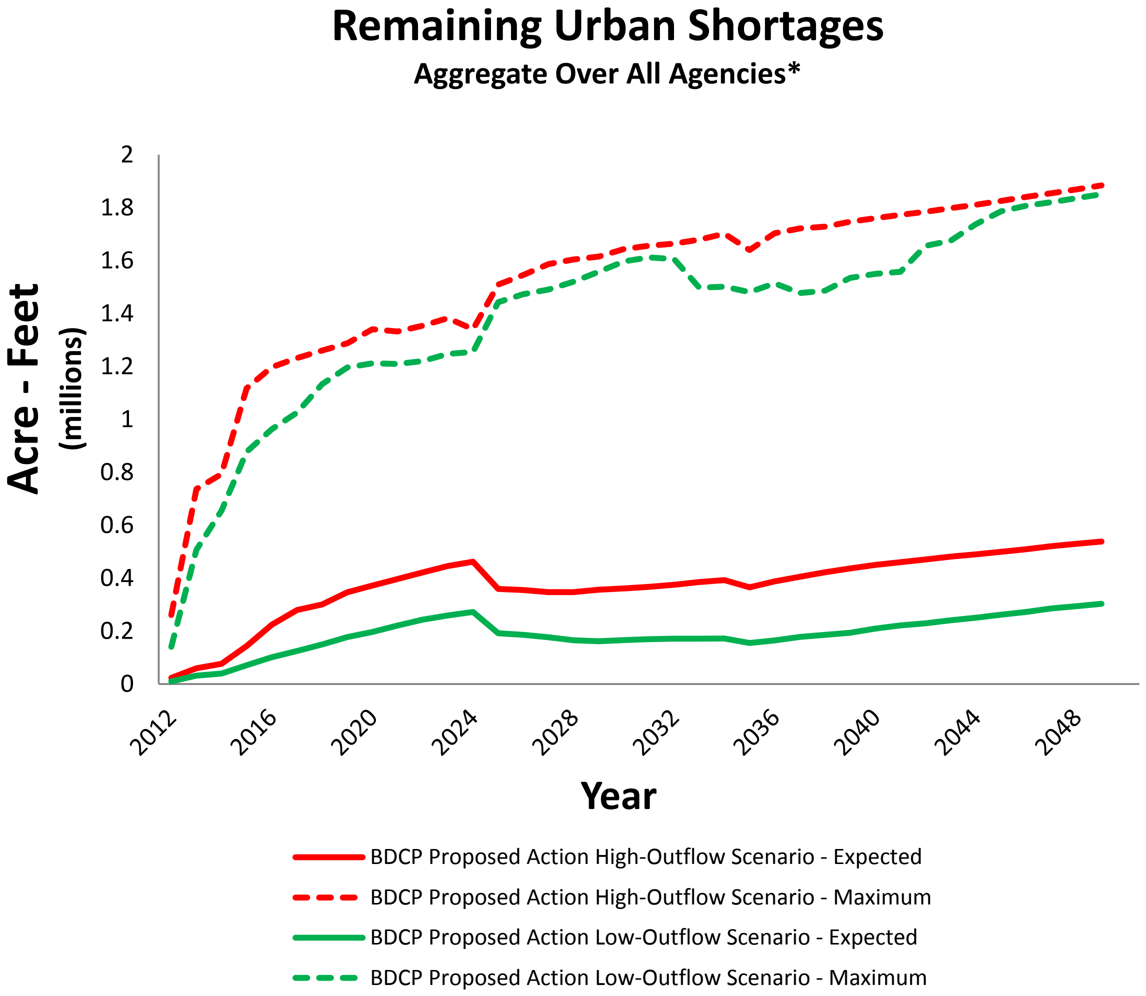
[9] Additional costs for conveyance from the Delta and for some degree of treatment must be added to these figures in order to implicit cost of BDCP to local water supply alternatives. These figures also do not incorporate the effect of the time spent on project construction. An exact comparison of BDCP costs to other alternatives would also require controlling for differences in the time to build the projects.



Note: Shortages in this graph do not include estimates for Santa Clara Valley Water District.

Figure 9.A-11. Remaining Urban Shortages of BDCP Proposed Action High-Outflow and Low-Outflow Scenarios

Table 9.A-5 demonstrates the cost per acre-foot for recycling projects in Southern California. Recycling project costs per acre-foot are calculated using data on total costs and acre-feet yearly. Because there is a lack of information about length of operations, what total costs include, and other project parameters that are needed for an exact calculation, this analysis assumes the cost per acre-foot is equal to the total present value cost per acre-foot yearly at an interest rate of 4.5%, a representative interest rate available to urban water supply agencies.

Table 9.A-5. Cost of Recycling Projects ($/acre-foot)

Project Title	Project Location	Estimated Cost per Acre-Foot
Groundwater Replenishment System [a]	Orange County Water District	$955
Regional Recycle Water Program, Northwest Area Project [b]	Inland Empire Utilities Agency	$1,467
Southeast Water Reliability Project Phase 1 [c]	Central Basin Municipal Water District	$1,672
Widomar Recycle Water System [b]	Elsinore Valley Municipal Water District	$1,312

[a] Orange County Water District groundwater replenishment calculations are before subsidies and have a 5% annual escalation of operating costs from 2009 to 2012 (Groundwater Replenishment Systems 2010)

[b] Bureau of Reclamation 2012

[c] Central Basin Municipal Water District 2012 Southeast Water Reliability Project description

There is no single estimate of the cost of recycled water because its cost is closely tied with the details of the project (California Department of Water Resources 2009: Chapter 11). The cost of recycled projects depends on the location at which the water will be used, or, more precisely, on the distance between the recycling plant and end users. Recycled water generally cannot be transported through existing infrastructure, requiring the installation of “purple pipe” to move the water from the recycling plant to end users. These barriers to implementing recycled water projects are the primary reason that goals for recycled water in the California 2005 water Plan update and the California Water Boards Strategic Plan Update: 2008–2012 were not met.

Table 9.A-5 displays a range of recycled water costs. Unit costs of water produced by these projects range from $1,000 to $1,700 per acre-foot. Other projects outside the study area but still within the State, such as the Eastside recycled water project currently being developed in the City of San Francisco, are projected to have even higher costs. The unit cost of water produced by the Eastside project is expected to be in excess of $4,500 per acre-foot (San Francisco Public Utilities Commission 2011). Taken together, available data indicate that it is difficult to project the costs of recycled water supplies with any accuracy. The data also indicate that recycled water costs can vary widely as a function of project-specific characteristics.

Like recycled water, the costs of desalinated water depend on numerous project details. Permitting, regulatory, and planning considerations, the cost of capital, availability and costs of energy, and proximity to distribution systems are prominent among the challenges to further development of seawater desalination. Costs are also influenced by the type of feed water, as well as the available concentrate disposal options. The largest cost of seawater desalination is electrical energy, which represents 38% of total costs. The remainder of the cost is comprised of 25% capital costs, 16% labor, 11% chemicals, 5% membranes, and 5% maintenance (California Department of Water Resources 2009: Chapter 9). Costs are lowest for desalination of brackish groundwater at $1,000 to $1,500 per acre-foot, followed by seawater desalination at recent costs of $2,000 to $2,300 per acre-foot.

Table 9.A-6. Cost of Desalination Projects ($/acre-foot)

Project Title	Project Location	Estimated Cost per Acre-Foot
Carlsbad Desalination Project[a]	Carlsbad, San Diego County, CA	$2,014–$2,257
Huntington Beach Seawater Desalination Project[b]	Huntington Beach, Orange County, CA	$1,768–$1,812
West Basin Municipal Water District Desalination Project[c]	El Segundo and Redondo Beach, Los Angeles County, CA	$1,273 for brackish $1,700 for seawater
Camp Pendleton Seawater Desalination Project[d]	Camp Pendleton, San Diego County, CA	$1,900–$2,340
Oxnard GREAT Program[e]	Oxnard, Ventura County, CA	$1,680 first phase $1,191 second phase

Notes:

[a] Poseidon Resources, LP and San Diego County Water Authority 2012

[b] Municipal Water District of Orange County and Poseidon Resources, LP 2013. Range includes total costs before any subsidies and includes conveyance costs

[c] University of Arizona Water Resources Center 2011

[d] RBF Consulting 2009; Pacific Institute 2012

[e] Wenner 2012

The costs of recycling and desalination can be compared to the costs of mandatory short-term conservation calculated using the SDBSIM model. Looking across the agencies in the model, in 2035, the present value cost of mandatory short-term conservation needed to address excess demands in the Existing Conveyance High-Outflow Scenario is $1,155 per acre-foot, and is $1,027 per acre-foot in the Existing Conveyance Low-Outflow Scenario. These costs of mandatory short-term conservation are at the low end of the range of water supply alternative costs. Because short-term conservation is a feasible option, and because the costs of alternatives cannot be known with precision for any individual agency, for planning purposes it is appropriate to measure BDCP benefits using mandatory short-term conservation costs. These costs are calculated using the methods described in the previous sections, recognizing that the actual mix of conservation and alternative development will be determined by individual agencies over the coming decades.

To summarize, the analysis of urban water supply benefits of the BDCP is based on an assumed build-out of alternative water supplies. These alternative supplies are used to calculate remaining shortages under the BDCP, the take alternatives, and the Existing Conveyance High-Outflow and Low-Outflow Scenarios. The incremental water supplies produced by the BDCP have an implicit cost far below the cost of available water supply alternatives. However, the shortages remaining after implementation of the BDCP will likely be addressed through a combination of investment in water supply alternatives and water conservation. In this sense, the BDCP is part of a larger statewide water management strategy that will be undertaken in urban areas of California to close the gap between future demands and available water supplies.

9.A.2.5 Estimating Welfare Losses from Reduced SWP Deliveries

Losses are evaluated separately for each forecasted year for each urban agency affected by the BDCP[10] using its own specific economic conditions (baseline price, baseline demand, shortage level, and price elasticity). The forecasted demand and shortages are based on the shortages calculated by SDBSIM taking into account projections of demand growth and development of water supply alternatives.

Shortages are allocated across sectors according to the following scheme: If an urban agency experiences a shortage in a given year then the first shortage allocation goes to the agricultural sector, which may have its supply reduced by up to 30%. Not all urban agencies have an agricultural supply allocation, and if they do, then it typically is a small sector relative to total agency water demand. Hence, the agricultural sector typically absorbs a relatively small share of a shortage. If there still exists a shortage after reducing the agricultural sector's supply then the next units of shortage are assigned to the single-family residential sector. According to conventional practice among water managers, the single-family residential sector is assigned up to a 30% supply reduction before a shortage allocation is made to the commercial and industrial sectors. The rational is that the single-family residential sector has more discretionary water use; for example, outdoor water use. However, in the commercial and industrial sectors a water shortage can result in job cuts and so reductions in these sectors are generally considered to impose a large burden on those least able to afford it. In a few instances, projected shortages are so large that the full 30% supply reduction occurs in each of the agricultural and single-family residential sectors along with a 20% supply reduction in the commercial and industrial sector. In these cases, any additional units of shortage are considered severe and are valued at $3,000 per acre-foot. Under this allocation rule the single-family residential sector ends up receiving the majority of the shortage allocation.

Once an agency-level shortage in a given year has been allocated across the agricultural, single-family residential and commercial and industrial sectors, the welfare loss in each sector is calculated given the loss equation derived earlier. As described above, this expression assumes that the shortfall is made up through short-term water conservation. This assumption is based on the fact that shortage costs are less than the cost of additional development of water supply alternatives.

Agency-specific residential price indices are used for the welfare calculations of shortages to the residential sector. These same prices are used as proxy indices for the welfare calculations of the other sectors. The construction of the price index for each agency is further described in the following section. The price elasticities for the single-family residential sector used in the welfare calculations are those estimated in the previous section; these range from -0.322 to -0.146. For the other sectors, the model uses an elasticity of -0.80 for the agricultural consumers, and an elasticity of -0.10 for the commercial and industrial consumers. These elasticities are consistent with the shortage allocation strategy—shortage assignments are first made to the agricultural sector, which has the lowest value of water, then to the single-family residential sector, and finally to the commercial and industrial sector, which has the highest valuation of water.

Once the losses have been calculated they are then aggregated across agencies to generate a measure of total annual losses. The total annual losses are discounted to the present using a real

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[10] With the exception of Kern County Water Authority.

discount rate. To account for the uncertainty of the timing of shortages this process of loss valuation is conducted for each of 83 unique hydrologic trajectories.

The loss function is dependent on baseline prices for each member agency; therefore, the definition of agency-level water rates will affect the calculated value of water supply reliability. The index price used to characterize the water rate for households in each region is calculated from the rates reported by the individual retailers. For water retailers that charge uniform volumetric rates for water, the index price used for households in the region is the uniform price. For water retailers that implement a tiered rate structure, the price index is taken to be the price on the median tier of the inclining block rate structure.[11] The price index includes volumetric sewer charges and any additional volumetric taxes. The rates are net of any additional surcharges to customers at higher elevation zones, as cost premiums to higher elevation zones are assumed to be offset by the higher costs of pumping to these zones.

In cases of inclining tier rate structures, the relevant rate for the welfare loss calculation depends on how prices are adjusted across tiers to implement a needed conservation level. This analysis assumes that voluntary conservation measures are adopted in proportion to household consumption levels (i.e., that all households respond to a 10% conservation need by cutting back water use by 10%), so that conservation is no more likely to occur among customers on any particular tier of the rate structure. This assumption of proportional adjustment of water use on all rate tiers leads to a conservative measure of index prices in the sense that conservation may be more forthcoming among households on higher pricing tiers and because agencies implementing conservation through price changes may raise water rates to a greater degree on higher rate tiers than on lower rate tiers (or alternatively reduce the quantity of water that qualifies for the lower rates), facilitating a disproportionate level of conservation on higher tiers of the rate structure than on lower tiers of the rate structure.

A number of agencies considered in the analysis provide water at the wholesale level to regional water retailers, for instance, the MWD member agency, Three Valleys Municipal Water District, provides water to multiple regional retailers (e.g., local municipalities and private water companies) within Three Valley's service area. In regions such as these that are served by multiple water retailers, the price index for the wholesale agency are constructed by computing the weighted average of the uniform or median tier rates charged by retailers in the region, weighted by the share of water delivered by each retailer.

9.A.3 Benefits of Increased Agricultural Water Supply

Agricultural water supply benefits from implementing the BDCP are estimated using the SWAP model, a regional agricultural production model developed specifically for large-scale analysis of agricultural water supply and cost changes. Developed by the University of California at Davis and DWR, the SWAP model simulates the profit-maximizing decisions of agricultural producers in California subject to resource, technical, and market constraints. The model accounts for SWP and CVP water supplies, other local water supplies, and groundwater. As the availability or cost of these water supplies changes within a SWAP region, the model optimizes production by adjusting the crop

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[11] Median tier rates are taken from retailer-specific 2009 water rate schedules. In cases where water retailers charge seasonal water rates to residential customers the price index is taken from the summer rate schedule. All rates are converted to 2012 dollars.

mix, water sources and quantities used, and other inputs, or even by fallowing land if that is the most cost-effective response. The model assumes a competitive market for farmers such that no single producer can affect or control the price of any commodity, and includes four inputs to production—land, water, labor, and other inputs. The SWAP model includes all SWP and CVP agricultural water contractors in the Central Valley. Agricultural benefits from increased water supply from the Delta include reductions in groundwater pumping and cost, decrease in fallowing, and increases in net returns from crop production.

9.A.3.1 Valuing Agricultural Water Supply Reliability Using SWAP

The SWAP model is an optimization model of California's agricultural economy, developed for use as a policy analysis and planning tool. The model is calibrated using the technique of Positive Mathematical Programming (PMP), which relies on observed data to deduce the marginal impacts of future policy changes on cropping patterns, water use, and economic performance (Howitt 1995b). As a multi-input, multi-output model, SWAP determines the optimal crop mix, water supplies, and other farm inputs necessary to maximize profit subject to heterogeneous agricultural yields, prices, and costs. SWAP's outcomes reflect the impacts of environmental constraints on land and water availability, and can be adapted to reflect any number of additional policy or technological constraints on farm production.

The PMP approach allows for calibration of parameters that exactly match base-year conditions, using observed data on land use, farmer behavior, and other exogenous information. Under the fundamental assumption of profit-maximizing behavior by farmers, the model uses a nonlinear objective function to derive parameters that satisfy first-order conditions for optimization under the base year's observed input and output data. While aggregate data on variables such as crop yield and acreage is often available, it is much more difficult to estimate a crop's marginal production costs. In lieu of relying on these often inaccurate estimates, the PMP technique uses the more reliable aggregate data to infer the marginal costs of production for each crop in a given region.

Aggregate data used in SWAP comes from a variety of sources. Crops are aggregated into 20 categories defined in collaboration with DWR, with a proxy crop identified to represent production costs and returns for each category. Input costs and yields for the proxy crops are derived from the regional cost and return studies from the crop budgets developed by the University of California Cooperative Extension (2011). Base-applied water requirements are derived from DWR estimates (California Department of Water Resources 2010). Commodity prices from the model's base year are obtained from the California County Agricultural Commissioner's reports. County-level data are aggregated to a total of 27 agricultural subregions, based off of DWR detailed analysis units. The SWAP regions aggregate one or more detailed analysis units, which are chosen based on similar microclimate, water availability, and production conditions.

The SWAP model specifically accounts for both surface and groundwater supplies. In total, the SWAP model considers a number of types of surface water: SWP delivery, CVP delivery, and local deliveries or direct diversions. Where applicable, water costs include both the SWP and CVP charge as well as a district's charge. For groundwater, the model includes both the fixed costs of pumping as well as variable costs based on operations and maintenance and energy costs. For more detailed estimation of costs associated with long-run depth to groundwater changes, the SWAP model can be linked to a separate groundwater model.

Using the input data sources described above, the SWAP model solves a PMP calibration function specified as follows for agricultural regions g, crop types i, production inputs j, and water sources w:

$$\underset{xl_{gi,land},watl_{gw}}{\mathrm{Max}} \prod = \sum_{g} \sum_{i} (v_{gi} yld_{gi} - \sum_{j \neq water} \omega_{gij}\, \alpha_{gij}) xl_{gi,land} - \sum_{g} \sum_{w} (watl_{gw} \varpi_{gw})$$

The terms $xl_{gi,land}$ and $watl_{gw}$ signify land and water use. Region-specific crop prices and yield are represented by v_{gi} and yld_{gi}, while ω_{gi} and ϖ_{gi} are input and water costs. α_{gij} are regional Leontief coefficients, depicting the observed level of input use for each crop in each region. Farm production is constrained by the availability of land and water, which are separated in the calibration given that any individual region may be constrained by either one of the two. The land and water constraints are defined as:

$$\sum_{i} xl_{gi} \leq b_{g,land} \; \forall \; g$$

and

$$\sum_{w} watl_{gw} \leq \sum_{w} watcons_{gw} \; \forall \; g$$

where $b_{g,land}$ and $watcons_{gw}$ are land and water availability constraints in each region.

The PMP approach calculates imputed “shadow values” as the constraining inputs, which reflect the true value of an additional unit of land or water in the region. Each additional unit of land or water allows for additional agricultural output, which will depend on the crop produced and the price for that crop in the regional market. The imputed shadow values are thus a function of the revenues from constrained crops, and reveal each region’s willingness to pay for additional units of constrained inputs as a function of their productive opportunities.

In addition to the resource shadow values for land and water, the addition of a calibration constraint forces the program to optimize according to observed base year cropping patterns. As detailed in Howitt (1995b), an arbitrarily small number is included as a perturbation term (ε) to decouple the resource and calibration constraints:

$$x_{gi,land} \leq \tilde{x}_{gi,land} + \varepsilon \; \forall \; g, i \; \varepsilon = 0.0001$$

The more profitable crops in the model will end up limited by the calibration constraints. The less profitable crops are not constrained by the calibration value and therefore determine the shadow values of the constrained input resources, in this case those of land and water. The shadow values on land and water are thus set equal to the marginal net return of a unit increase in those resources, which is a function of revenues from the constrained crops.

The imputed values from PMP calibration are next used to parameterize regional production functions for each crop. The production functions are specified using a constant elasticity of substitution (CES) and have constant returns to scale, as the total value of production is allocated exactly among the different inputs. The use of the CES production function allows for substitution of inputs at a specified substitution elasticities. For example, applied water rates could be partially substituted for by improving irrigation efficiency through capital expenditures on improved irrigation technology. The CES functions are defined as:

$$y_{gi} = \tau_{gi}[\beta_{gi1} x^{\rho_i}{}_{gi11} \beta_{gi2} x^{\rho_i}{}_{gi2} + \cdots + \beta_{gij} x^{\rho_i}{}_{gij}]^{1/\rho_i}$$

where y_{gi} represents output of crop *i* in region g based on the combined inputs *j*.

The relative use of different production factors is depicted by the share parameters β_{gij}. Scale parameters are given by τ_{gi}, and x_{gij} represents production factor usage. If data is available, specific substitution elasticities can be estimated and applied. Alternatively, a fixed value of substitution elasticities can be used for all inputs, assuming a constant elasticity of substitution σ, $\rho_i = \frac{\sigma - 1}{\sigma}$.

Optimal input allocation is determined by the first order condition, which sets the value of marginal product from each input equal to the marginal cash cost plus opportunity cost for that input. Using the shadow values calculated in the PMP calibration step, this value will be equal to the base input price plus the shadow values on the constrained resources. For crops bound by the calibration constraint, the calibration shadow value is additionally added. This process can be generalized for any number of regions and crops. Under the constraint of constant returns to scale, one can algebraically solve for the share values β_{gij}. Because the value of total production *y* is known, substituting in the calculated share values allows for final calculation of the scale parameter τ.

The next step in the SWAP model is estimation of an exponential land cost function, using information on acreage response elasticities and the calibration constraint shadow value. The use of an exponential cost function avoids problems associated with quadratic cost functions that estimate a linear marginal cost for land. Namely, linear estimates can result in negative marginal costs over a range of low land areas, forcing a modeler to adopt unrealistic marginal production costs near the lower bound in order to fit a desired supply elasticity. The use of an exponential cost function, on the other hand, bounds marginal costs above zero and thus avoids this problem.

The total land cost function is defined as:

$$TC_{gi} = \delta_{gi} e^{\gamma_{gi} x_{gi.,land}}$$

where δ is the minimum fixed cost of producing crop *i* in region g, and γ is the response function's elasticity parameter.

These parameters are calculated by regressing the calibration shadow value of land against the observed base level of land use and the elasticity of supply for each crop group.

Agricultural prices in the SWAP model are treated as endogenous by calculating individual demand functions for each crop group. First, a statewide demand function for each crop is calculated using crop demand elasticities estimated by Green et al. (2006). The specified downward-sloping demand curves represent consumers' willingness to pay for each individual crop. All else equal, as production of a given crop increases, its price is expected to decrease. While the statewide price is assumed to be constant across all modeled regions, regional prices are allowed to deviate due to region specific differences in production levels, crop quality, climate, and other factors.

The individual crop demand functions are specified as:

$$p_i = \xi \alpha_i^1 - \alpha_i^2 \left(\sum_g \sum_j y_{gij} \right)$$

where p_i is crop price, α_i^1 and α_i^2 represent the intercept and slope of the demand curve, and ξ allows for a shift in demand due to further exogenous factors. To calculate the statewide California crop price, observed prices are weighted by the relative proportion of statewide production in each region *g.* Subtracting the statewide price from regional observed prices yields the regional marketing cost rmc_{gi}, reflecting differences in prices due to region-specific factors.

At this point, the calibrated functions are aggregated into a nonlinear profit maximization program that considers farm production optimization and considers the previously specified CES production functions, crop- and region-specific exponential land cost functions, and crop demand functions specified above. Accounting for endogenous crop prices, the program maximizes the sum of producer and consumer surplus as follows:

$$\begin{aligned}
\underset{x_{gij},wat_{gw}}{\text{Max}} \; PS + CS = {} & \sum_i \left(\xi \alpha_i^1 \left(\sum_g y_{gi} \right) + \frac{1}{2} a_i^2 \left(\sum_g y_{gi} \right)^2 \right) \\
& + \sum_g \sum_i \left(rm_{gi} \left(\sum_j y_{gi} \right) \right) \\
& - \sum_g \sum_i \left(\delta_{gi} \exp\left(\gamma_{gi} x_{gi,land} \right) \right) \\
& - \sum_g \sum_i \left(\omega_{gi,supply} x_{gi,supply} + \omega_{gi,labor} x_{gi,labor} \right) \\
& - \sum_g \sum_i \left(\varpi_{gw} wat_{gw} \right)
\end{aligned}$$

The program optimizes for each region *g*, crop *i*, and water source *w*. The four production inputs are written out separately, as land cost is estimated by the exponential cost function, and water costs vary by source. The first term in the above equation is equal to the sum of gross revenue plus consumer surplus for each crop in each region. The second term represents region-specific additional revenue from regional crop prices higher than the statewide base price. The third term represents total land costs, the fourth represents total labor and supply costs, and the fifth and final term represents total water costs.

The authors of the SWAP model apply additional constraints to ensure the estimation of realistic outcomes (Howitt et al. 2012). Simple input and water constraints limit model output according to the total input availability in each region. While the CES production function allows for substitution between inputs, the model is further constrained to prevent the model from reducing applied water rates below those normally observed. This ensures that applied water levels under stress irrigation are not unreasonably low.

Further constraints include limiting the amount of perennial crops that can be retired, as farmers would be expected to devote resources in the short run to preserving established perennial stands that have large investment costs. Limiting the amount of perennial retirement assumes that only older stands near retirement would be taken out of production. Additionally, a silage constraint is added to ensure that produced crops continue to meet the regional feed requirements of California dairy herds.

The model is extensible in that any number of additional constraints can be added to more accurately depict agronomic, environmental, or political conditions in an applied setting. However, some constraints may need to be relaxed in order for the model to calibrate properly. A final overall test of calibration for the model examines the difference in input allocation and production outputs between the base data and the modeled outcome, which should be nearly identical.

At this point, if the calibration test is specified the model is ready for use in policy application and sensitivity analysis. Three fundamental assumptions are important to note. First, the model assumes water is interchangeable among all crops in a region. Second, farmers are expected to act in a way that maximizes annual profits, by equating the marginal revenue of water to its marginal cost. Finally, it is assumed that each region adopts a crop mix that will maximize regional profits.

9.A.4 Benefits Summary: Water Supply Reliability

The SDBSIM and SWAP models asses the economic benefits of increased water supply reliability under the BDCP Proposed Action High-Outflow Scenario and each take alternative relative to the Existing Conveyance High-Outflow Scenario, as well as benefits under BDCP Proposed Action Low-Outflow Scenario relative to the Existing Conveyance Low-Outflow Scenario. These economic gains are expressed in Table 9.A-7 in the form of total expected present value benefits for urban and agricultural water supplies combined. The value of benefits increases over time due to population-driven increases in demand and the higher real energy costs of avoided groundwater pumping.

The SDBSIM calculates the urban welfare benefit of an avoided shortage for each SWP agency under each take alternative for 83 trials of every year forecasted in the CALSIM II. The benefits are then aggregated across all agencies for each forecasted year under each trial. Although the CALSIM II runs only go out to year 2050, benefits are extended 10 years past the 50-year permit term by assuming that the same level of benefits in 2050 occur in every year thereafter out to year 2075. Benefits across all forecasted years for each trial are then discounted back to year 2012 at a 3% real discount rate. Present value benefits for Take Alternative I are estimated based on benefits per acre-foot of Delta deliveries for the BDCP Proposed Action High-Outflow Scenario due to lack of detailed data for Take Alternative I.

The SWAP model produces estimates of average annual benefits in the years 2025 and 2060 for the BDCP Proposed Action High-Outflow Scenario. In order to convert these impacts into present-value terms, average annual benefits for each year that are not directly estimated are interpolated by assuming that benefits change by the same amount year-to-year from 2025 to 2060 and 2060 to 2075. Annual benefits are then discounted over the period 2025 to 2075 back to the present using a real discount rate of 3%. Benefits for the take alternatives are then estimated by multiplying benefits per acre-foot of additional Delta deliveries (relative to the Existing Conveyance High-

Outflow Scenario) that would occur under the BDCP Proposed Action High-Outflow Scenario for CVP and SWP with the additional acre-feet of Delta deliveries (relative to the Existing Conveyance High-Outflow Scenario) to CVP and SWP contractors under each take alternative. The BDCP Proposed Action Low-Outflow Scenario is estimated in the same way, relying on the additional acre-feet of Delta deliveries relative to the Existing Conveyance Low-Outflow Scenario. Note that the SWAP model only captures the valley-wide benefits of agricultural water supply. The benefits of agricultural water supply that fall outside the Central Valley are mostly within the service area of urban water users. Such benefits are captured in the urban supply analysis.

Table 9.A-7. Expected Present Value Benefits of Water Supply Reliability ($ millions)

Take Alternative[a]	Facility Size (cfs)	Deliveries (MAF)	Total Water Supply Benefits[b, c]
BDCP Proposed Action High-Outflow Scenario	9,000	4.705	$15,722
BDCP Proposed Action Low-Outflow Scenario[d]	9,000	5.591	$16,642
A: W Canal 15,000 cfs	15,000	5.009	$21,305
B: Tunnels 6,000 cfs	6,000	4.487	$13,130
C: Tunnels 15,000 cfs	15,000	5.009	$21,305
D: Tunnels: 3,000 cfs	3,000	4.188	$7,799
E: Isolated 15,000 cfs	15,000	3.399	-$11,937
F: Through Delta	N/A	4.172	$9,363
G: Less Tidal Restoration	9,000	4.705	$15,722
H: More Restoration	9,000	4.705	$15,722
I: Fixed Spring Outflow	9,000	4.338	$11,128

Notes:

[a] Construction is assumed to begin in 2015. BDCP operations are assumed to begin in 2025.

[b] All values are in 2012$ (millions) and all values are discounted to present value using 3% real discount rate.

[c] Benefits are calculated out to year 2075.

[d] Benefits for BDCP Proposed Action Low-Outflow Scenario are calculated relative to the Existing Conveyance Low-Outflow Scenario, which assumes Scenario 6 operations, no Fall X2, no north Delta diversions.

cfs = cubic feet per second; MAF = million acre-feet

Table 9.A-7 reveals that expected present value benefits are positive for most of the take alternatives; however, since Take Alternative E would yield higher shortages than the Existing Conveyance High-Outflow Scenario, the present value benefits are accordingly negative. The expected present value benefits from urban water supply are $15.7 billion for the BDCP Proposed Action High-Outflow Scenario and $16.6 billion for the BDCP Proposed Action Low-Outflow Scenario.

It is important to note that because these benefits represent the average over all 83 hydrologic runs, they do not reveal the full picture. Benefits may vary greatly across different hydrologic runs such that there may be much higher present value benefits under certain hydrologic conditions. The variation of benefits over the hydrologic distribution can be seen through an example of SWP urban benefits in one forecasted year, 2035, for the BDCP Proposed Action High-Outflow Scenario under each year of the hydrology. As depicted in Figure 9.A-12, benefits fluctuate greatly in a particular forecasted year depending on the hydrologic conditions.

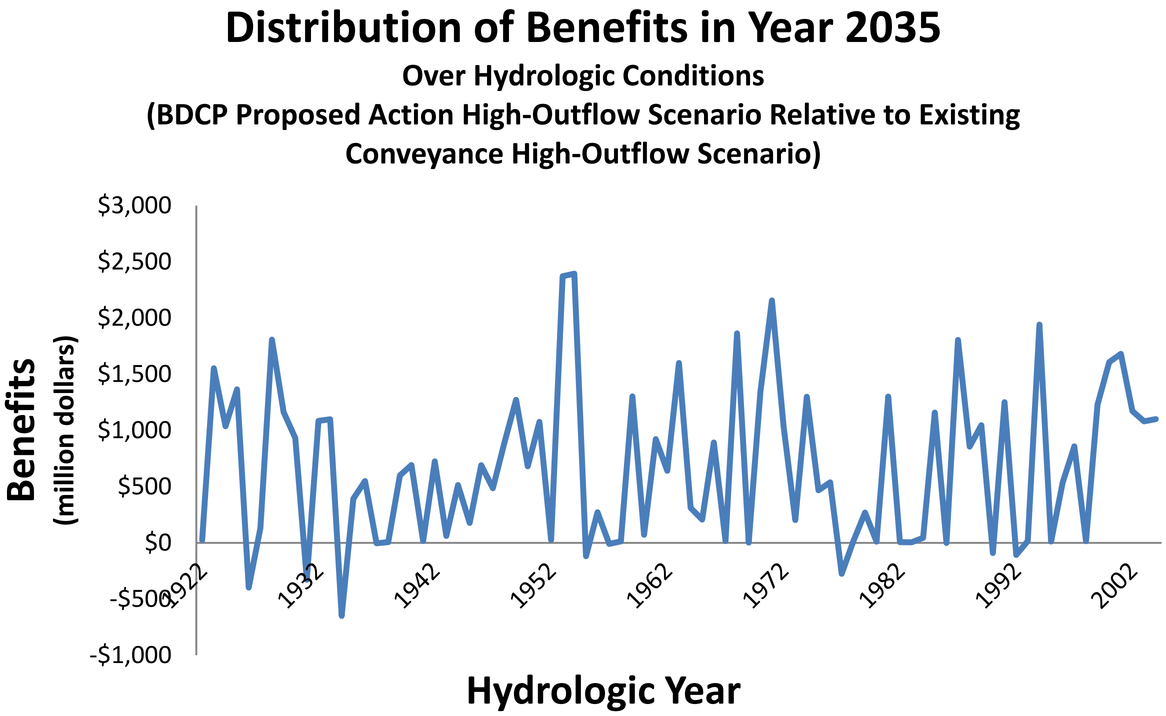

Figure 9.A-12. Distribution of Benefits in Year 2035

The variation in benefits is a result of the fact that while all trials are based on the same historical hydrology, each one has a different starting year. In effect, each trial is a sequential sample drawn from the historical record, with each trial having a unique starting date. The difference in starting years affects the amount of storage in each forecasted year that is coupled with the hydrologic condition assumed under each forecasted year. Benefits are particularly high in cases where critically dry years are coupled with low water supply storage, causing extremely large shortages.

Although the expected present value benefits are telling, it is crucial to assess the distribution of present value benefits across the 83 trials to see what level benefits reach when shortages are largest. Figure 9.A-13 shows the distribution of the present value for the BDCP Proposed Action High-Outflow Scenario across the 83 trials.

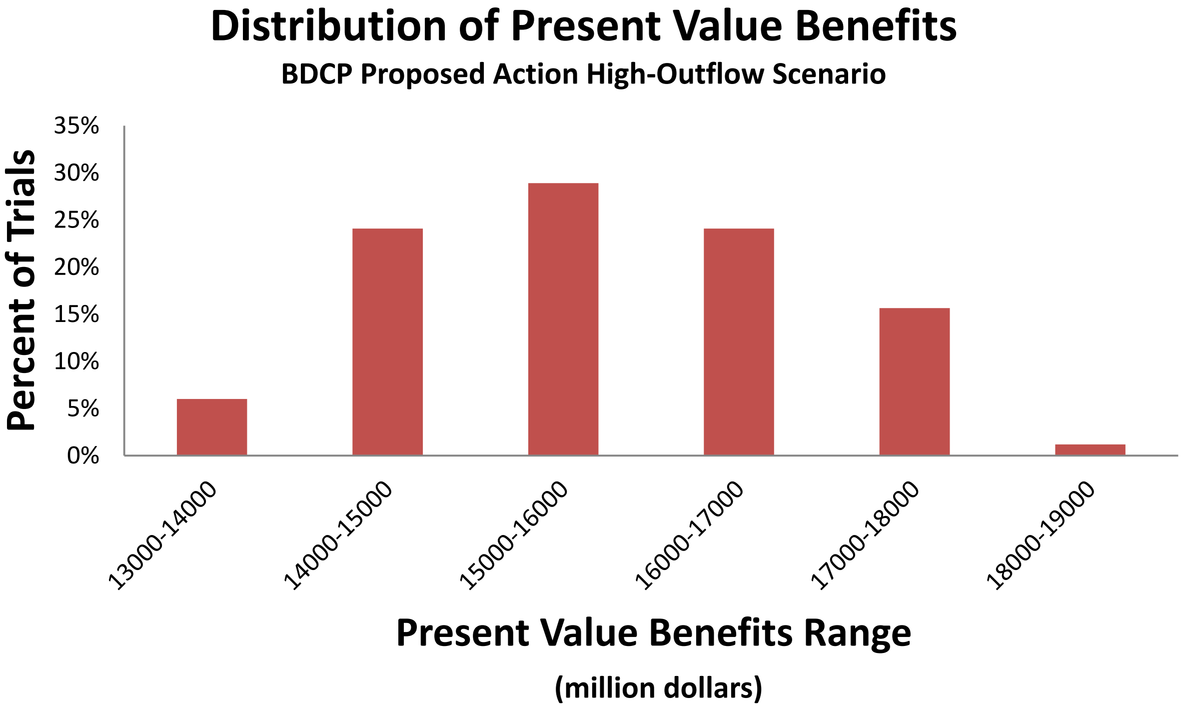

Figure 9.A-13. Distribution of Present Value Benefits for BDCP Proposed Action High-Outflow Scenario

As explained in Section 9.A.2.2.2, *Forecasting Shortages for the Take Alternatives*, it is most important to mitigate the instances of extremely large shortages because they lead to more devastating outcomes than several small shortages summing to the same amount of deficiency. Although the BDCP Proposed Action High-Outflow Scenario would result in an expected present value of $15.7 billion, it would reach over $17.5 billion almost 10% of the time. In other words, if the BDCP Proposed Action High-Outflow Scenario is not implemented, the welfare loss to urban water consumers would range between $13.4 billion and $18.0 billion, with a 10% chance of reaching over $17.5 billion. All the take alternatives, including the BDCP Proposed Action Low-Outflow Scenario, have a distribution of losses revolving around the expected present value displayed in Table 9.A-7.

9.A.5 Benefit Analysis: Water Quality

Implementation of the BDCP will result in water quality benefits through reduced salinity levels. Two separate models are used to estimate the water quality benefits for the urban and agricultural agencies receiving Delta water exports. The Lower Colorado River Basin Water Quality Model (Metropolitan Water District of Southern California and Bureau of Reclamation 1999) estimates salinity-related benefits for the MWD service area. The South Bay Water Quality Model (Bureau of Reclamation 2006) originally developed for the economic evaluation of a proposed expansion of Los Vaqueros Reservoir, estimates salinity-related benefits for the Contra Costa and Santa Clara Water District service areas.

The Lower Colorado River Basin Water Quality Model uses data on demographic characteristics, water deliveries, total dissolved solids (TDS) concentration, and costs for typical water uses by sector for 15 subareas covering the MWD service area. It assesses the average annual economic impacts of SWP and Colorado River salinity changes using mathematical relationships between TDS and important characteristics in each affected category of water use, such as the useful life of appliances, specific crop yields, and costs to industrial and commercial customers. For this analysis, a routine was developed to estimate salinity of urban water supplies delivered to the south coast based on timing of urban deliveries, mixing in San Luis Reservoir and salinity estimates at Edmonston Pumping Plant. The South Bay Water Quality Model uses estimates of relationships between salinity and damages to residential appliances and fixtures to estimate the impacts of changes in salinity. For Contra Costa Water District, water quality estimates are based on diversion volume and water quality at Old River and Rock Slough. For Alameda County District, Zone 7, and Santa Clara Valley Water District, water quality is based on diversion volume and salinity at Banks Pumping Plant. Changes in water quality at the City of Antioch's diversion are used to estimate additional cost of treatment or replacement supply. Annual benefits depend on both the salinity improvement and the total delivered water to which the improvement applies.

Near-term agricultural water quality impacts are also estimated. Salinity, measured as electrical conductivity or parts per million of TDS, is the single best indicator of the effect of changes in water quality on agricultural production. In the short term, an improvement in salinity can spur reduced leaching fraction and irrigation costs, lower soil salinity, improved crop yields, and greater crop selection. In the Delta, in particular, which is composed of areas of shallow, saline groundwater, a reduction in the salinity of applied irrigation water can keep lands productive for longer while reducing the cost of drainage treatment and disposal. The short-term benefit of the BDCP on agricultural water quality is quantified as the value of changes in leaching requirement; that is, the value of reduced irrigation water required to maintain root zone salt balance.

Estimates of the value of changes in leaching requirement are based on accepted methods for calculating leaching fraction for irrigated crops (Ayers and Westcot 1994). This analysis is based on the assumption that growers can reduce the irrigation water applied to maintain root zone salt balance. The reduced salinity of irrigation water results in economic benefits through savings on irrigation water used by growers. For the purposes of this analysis, this saved water is valued at the avoided cost of additional water supply, which is assumed to come from groundwater pumping. The salt leaching benefit from improved water quality is calculated in two parts. For the portion of SWP and CVP water that replaces groundwater pumping, the benefit is calculated relative to the applied groundwater quality. For all other applied water from the take alternatives, the benefit is calculated relative to the water quality of the Existing Conveyance High-Outflow and Low-Outflow Scenarios. The calculations account for the variation in crops across affected delivery areas.

Table 9.A-8 displays water quality impacts in the urban and agricultural sectors combined under the BDCP Proposed Action High-Outflow and Low-Outflow Scenarios and the take alternatives. The analysis described above produces estimates of average annual benefits in the years 2025 and 2060 under the BDCP Proposed Action High-Outflow Scenario relative to the Existing Conveyance High-Outflow Scenario. In order to convert these impacts into present value terms, average annual benefits for each year that is not directly estimated are interpolated by assuming that benefits change by the same amount year-to-year from 2025 to 2060 and 2060 to 2075. Annual benefits are discounted over the period 2025 to 2075 back to the present using a real discount rate of 3%. Benefits are calculated for the BDCP Proposed Action High-Outflow Scenario, Alternative E, and Alternative F by the approach described above. The benefits for most of the remaining take

alternatives are calculated using an interpolation method drawing on data from Chapter 8 of the Public Draft EIS/EIR (Appendix 8.H. *Electrical Conductivity*, Table EC–10). Due to lack of information, BDCP Proposed Action Low-Outflow Scenario and Take Alternative I are assumed to have the same water quality benefits as BDCP Proposed Action High-Outflow Scenario.

Table 9.A-8. Present Value Benefits of Water Quality Improvements ($ millions)

Take Alternative[a]	Facility Size (cfs)	Deliveries (MAF)	Total Water Quality Benefits[b, c]
BDCP Proposed Action High-Outflow Scenario	9,000	4.705	$1,819
BDCP Proposed Action Low-Outflow Scenario[d]	9,000	5.591	$1,819
A: W Canal 15,000 cfs	15,000	5.009	$1,319
B: Tunnels 6,000 cfs	6,000	4.487	$1,002
C: Tunnels 15,000 cfs	15,000	5.009	$1,319
D: Tunnels: 3,000 cfs	3,000	4.188	$1,068
E: Isolated 15,000 cfs	15,000	3.399	$2,576
F: Through Delta	N/A	4.172	$2,759
G: Less Tidal Restoration	9,000	4.705	$1,819
H: More Restoration	9,000	4.705	$1,819
I: Fixed Spring Outflow	9,000	4.338	$1,819

Notes:

[a] Construction is assumed to begin in 2015. BDCP operations are assumed to begin in 2025.

[b] All values are in 2012$ (millions) and all values are discounted to present value using 3% real discount rate.

[c] Benefits are calculated out to year 2075.

[d] Benefits for BDCP Proposed Action Low-Outflow Scenario are calculated relative to the Existing Conveyance Low-Outflow Scenario, which assumes Scenario 6 operations, no Fall X2, no north Delta diversions.

cfs = cubic feet per second; MAF = million acre-feet

Under the BDCP Proposed Action High-Outflow and Low-Outflow Scenarios, water quality benefits associated with salinity would total roughly $1.8 billion in the combined urban and agricultural sectors from 2025 to 2075. These benefits largely stem from the fact that the BDCP Proposed Action High-Outflow and Low-Outflow Scenarios have a higher proportion of north Delta exports versus south Delta exports (49 and 48% from north, respectively) than the Existing Conveyance Scenario (100% from south). As a result the total salinity levels overall are reduced for the BDCP Proposed Action since the north Delta exports have a lower level of salinity than the south. Note that other water quality benefits not directly related to salinity changes, such as any potential treatment cost savings in other constituents in the urban sector, were not considered. In addition, the urban models do not encompass all recipients of SWP or CVP water. Consequently, the estimates presented here represent a partial, though substantial, portion of water quality benefits to urban users. Also, because the long-term value of agricultural water salinity changes is not included in this analysis, the salinity benefits presented here for the agricultural sector should likewise be viewed as a conservative estimate.

9.A.6 Benefit Analysis: Reductions in Seismic Risk

An important benefit of an isolated conveyance facility is that it reduces the vulnerability of the water export system to seismic events in the Delta region. As presently configured, large earthquakes in and around the Delta region will cause numerous levees to fail, with the result that some number of islands will flood. When these islands flood, sea water will be pulled into the Delta, potentially reducing project deliveries for some period of time. During this outage period, no SWP deliveries can be made, resulting in a potential shortage to consumers.

9.A.6.1 Post-Earthquake Water Supplies

While there has been a considerable amount of research on the effects of earthquakes on Delta water supplies, there has been less study of the post-earthquake level of water exports under the take alternatives. This analysis assumes a level of water supply availability in the face of an earthquake that depends on the size of the facility under each take alternative (Neudeck pers. comm.). It is assumed that there would be 1.0 MAF of water supplies available under the Existing Conveyance High-Outflow and Low-Outflow Scenarios in the face of post-earthquake conditions. The BDCP Proposed Action High-Outflow and Low-Outflow Scenarios would mitigate some of the post-earthquake shortages with an assumed 3.8 MAF of water supplies under post-earthquake conditions. As seen in Table 9.A-9, the water supplies under post-earthquake conditions for the different take alternatives range from 1.6 MAF under scenarios with a 3,000-cfs facility to 4.5 MAF for scenarios with a 15,000-cfs facility. Since no-earthquake levels of Delta deliveries for Take Alternative E are lower than the predicted post-earthquake level for a 15,000-cfs facility, post-earthquake supplies for this alternative are assumed to be the same as no-earthquake levels of exports. Although these levels of post-earthquake exports for each scenario are assumed to persist up to 3 years following a major seismic event, this analysis assumes just a one-year drop in exports under each scenario. Total supplies under post-earthquake conditions are split up amongst the urban and agricultural contractors. It is assumed that 25% of total supplies belong to SWP urban, 50% to CVP agriculture and 25% to SWP agriculture (Neudeck pers. comm.).

9.A.6.2 Valuing Reduced Seismic Risk

The economic value of reduced seismic risk is the value that is put on the additional available water in the face of an earthquake under each high-outflow take alternative relative to the Existing Conveyance High-Outflow Scenario and relative to the Existing Conveyance Low-Outflow Scenario for the BDCP Proposed Action Low-Outflow Scenario. A unique marginal value is used for each take alternative. The marginal values for each take alternative for SWP urban are estimated as the shadow price placed on the last acre-foot of available water supply from the SWP urban water reliability analysis (Section 9.A. 2.3.1, *Willingness to Pay Calculations*).[12] The marginal values for each take alternative for CVP and SWP agriculture are taken as the shadow price placed on the last acre-foot of available water supply from the SWAP model. The marginal value is used to value the decrease in water under each scenario from normal (no earthquake) conditions to post-earthquake conditions by assuming the constant marginal value of water for each acre-foot of water cut by the earthquake. The economic value of reduced seismic risk for the take alternatives and the BDCP Proposed Action High-Outflow Scenario are calculated as the difference in this value of shortage due

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[12] SWP urban shadow prices are taken from the urban water supply benefits analysis. Shadow price of water for each scenario is a weighted average over all urban agency shadow prices averaged over the 83 trials.

to an earthquake under the Existing Conveyance High-Outflow Scenario and the value of shortage under each take alternative. Benefits are calculated in the same manner for the BDCP Proposed Action Low-Outflow Scenario relative to the Existing Conveyance Low-Outflow Scenario. The expected value of reduced seismic risk assumes a 2% probability of an earthquake occurring in any forecasted year. Outcomes are discounting over the period 2025 to 2075 back to the present using a real discount rate of 3%. Table 9.A-9 displays the present value benefits of reduced seismic risk.

The present value benefits of reduced seismic risk for the BDCP Proposed Action High-Outflow Scenario and the BDCP Proposed Action Low-Outflow Scenario are projected to be $0.5 billion and $0.4 billion, respectively, for urban and agriculture combined. Total benefits for the take alternatives with facilities range from $0.1 billion under Take Alternative D with a 3,000 cfs facility to $0.7 billion under Take Alternative E with a 15,000 cfs facility. The difference in benefits across take alternatives with the same facility size stem from the marginal value of water under each scenario and the amount of water available under normal conditions for each scenario. Benefits are negative under Take Alternative F, as opposed to zero, even though it is projected to have the same available water supply as the Existing Conveyance High-Outflow Scenario under post-earthquake conditions, because of differences in the marginal value of water and the water supply availability under normal conditions between the two scenarios. Similarly, benefits for Take Alternative A and Take Alternative E are different due to the differences in the marginal value of water and the water supply available under normal conditions.

Table 9.A-9. Present Value Benefits of Reduced Seismic Risk ($ millions)

Take Alternative[a]	Facility Size (cfs)	Deliveries (MAF)	Earthquake Supply (MAF)	Total Seismic Benefits[b, c]
BDCP Proposed Action High-Outflow Scenario	9,000	4.705	3.800	$470
BDCP Proposed Action Low-Outflow Scenario[d]	9,000	5.591	3.800	$364
A: W Canal 15,000 cfs	15,000	5.009	4.500	$563
B: Tunnels 6,000 cfs	6,000	4.487	2.900	$313
C: Tunnels 15,000 cfs	15,000	5.009	4.500	$563
D: Tunnels: 3,000 cfs	3,000	4.188	1.600	$55
E: Isolated 15,000 cfs	15,000	3.399	3.399	$665
F: Through Delta	N/A	4.172	1.000	-$62
G: Less Tidal Restoration	9,000	4.705	3.800	$470
H: More Restoration	9,000	4.705	3.800	$470
I: Fixed Spring Outflow	9,000	4.338	3.800	$470

Notes:

[a] Construction is assumed to begin in 2015. BDCP operations are assumed to begin in 2025.

[b] All values are in 2012$ (millions) and all values are discounted to present value using 3% real discount rate.

[c] Benefits are calculated out to year 2075.

[d] Benefits for BDCP Proposed Action Low-Outflow Scenario are calculated relative to the Existing Conveyance Low-Outflow Scenario, which assumes Scenario 6 operations, no Fall X2, no north Delta diversions.

cfs = cubic feet per second; MAF = million acre-feet

9.A.7 References Cited

9.A.7.1 Literature Cited

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