Hydrologic Analysis Technical Memorandum

Nevada Irrigation District

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1 Introduction

Nevada Irrigation District (NID) is an independent public agency that is governed by a five-member elected Board of Directors and employs approximately 200 full- and part-time employees. The District supplies water to nearly 25,000 homes, farms, and businesses in portions of Nevada, Placer and Yuba counties in the foothills of Northern California's Sierra Nevada. Water is collected from mountain watersheds and stored in a system of reservoirs. As water flows to its customers in the foothills, it is used to generate clean, hydroelectric energy in excess of 354 gigawatts per year, to maintain environmental flows, and to provide public recreation opportunities. NID supplies both treated drinking water and crop irrigation water. Approximately 90 percent of NID's annual demand is made up of raw water/agricultural demand during the irrigation season.

NID's water supply system is a "store and release" system, in that reservoirs store snow melt and seasonal rains for release during the typically dry irrigation seasons. Based on the timing of seasonal precipitation events, NID's water supply management is dependent on a combination of springtime snowmelt and winter period rains to fill its storage reservoirs. While there is some natural runoff during the summer months, much of this water is required to meet necessary environmental flows in the rivers; therefore, the irrigation season demand is met primarily with withdrawals from storage reservoirs. Careful management and operation of storage reservoirs is essential to capture the maximum amount of runoff, minimize spillage from reservoirs, and ensure there is sufficient volume available in reservoirs to accommodate runoff during the spring snow melt and storm events.

1.1 Raw Water Master Plan Update

A key planning document for NID is its Raw Water Master Plan (RWMP), originally developed in 1985. The primary purpose of the RWMP is to assess the adequacy of the existing water storage and conveyance system to accommodate current and future water demand. Since 1985, the RWMP has been updated in two phases. The phase I update was completed in 2005 (Kleinschmidt et al. 2005), and the phase II update was completed in 2011 (Kleinschmidt Associates 2011). The RWMP provides information to NID's Board of Directors to make decisions about how NID will operate within the RWMP planning horizon.

NID's water supply comes from four main sources: natural runoff (including snowmelt) from the contributing watershed areas, reservoir carryover storage, contract water purchases, and recycled water. Events such as drought and climate change create imminent challenges for NID in maintaining a sustainable water supply system. According to NID's RWMP (Kleinschmidt Associates 2011), the margin between average watershed runoff volume and NID customer demand is diminishing. Increased future demands within NID's service area will result in increased demand on water storage and greater drawdown of NID's reservoirs, especially during summer months when there is little natural runoff.

The 2011 RWMP was based on projected 2032 water management practices. The following updates are needed to reflect current standards and anticipated operations:

- Expand the planning horizon to 50 years, to be consistent with other regional planning studies (Sustainable Groundwater Management Act and the 2018 California Water Plan Update)[1].
- Update customer demand projections to reflect the new planning horizon.
- Consider hydrologic impacts from climate change, which is expected to change the volume and timing of watershed runoff relative to existing conditions.
- Include new Federal Energy Regulatory Commission (FERC) license conditions, which will generally increase flow in rivers downstream of NID reservoirs for environmental benefit, resulting in less available water to meet NID customer demand.
- Include new long-term water purchase agreement with Pacific Gas and Electric (PG&E).
- Expand the extreme drought water supply analysis from 3 years to 5 years, per Executive Order SB-37-16(8).

1.2 Projections of Climate Change Impacts on Watershed Runoff

The State of California recently published its Fourth Climate Change Assessment (Thorne 2018) to proactively address the current and future impacts of climate change and to make California more climate-resilient. California anticipates conditions under climate change to include:

- Warmer temperatures;
- Rising sea levels;
- Declining snowpack;
- More intense precipitation events;
- More droughts; and
- More area burned by wildfire.

In recent years, California has experienced increased temperatures, more frequent heat waves, and highly variable precipitation including a severe drought from 2012 through 2017.

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[1] There is not a strict rule on planning horizons, although Integrated Regional Water Management Plans and Urban Water Management need "at least" 20 years. The Sustainable Groundwater Management Act (SGMA) stipulates that the planning and implementation horizon is a **50-year time period** over which (groundwater sustainability) plans and measures will be implemented in a basin to ensure that the basin is operated within its sustainable yield. Other related plans have followed suit, such as the 2018 California Water Plan Update. The new 2020 guidelines for UWMPs may require a 50-year planning horizon.

Climate in California is exceptionally variable, ranging from extremely wet in some years to extremely dry in others. While total precipitation is not expected to change substantially on average, future climate projections all tend towards more extreme conditions, meaning wetter wet years and drier dry years (Thorne 2018). With a warmer climate, more precipitation will fall as rain rather than snow (Thorne 2018). By 2050, average water supply from snowpack is projected to decline by one-third. If greenhouse gas emissions are not reduced, average water supply from snowpack is projected to decline by two-thirds by 2100 (Thorne 2018).

In the Sierra Nevada, where NID's water supply network is located, air temperatures are projected to increase on average by 6 to 10°F by the year 2100, resulting in an increase in the rain to snow transitional elevation by 1,500 to 3,000 ft during winter snow storms (Dettinger et al 2018). Snowpack is projected to be eliminated below about 6,000 feet, and snowmelt runoff will occur earlier than it has historically (Dettinger et al 2018).

Climate change will impact NID's water supply. NID's Mountain Division storage reservoirs rely heavily on snowmelt runoff capture in the spring for use throughout the summer and fall dry season to meet customer demands and to maintain reservoir carryover storage to protect against future drought. The loss of snowpack in watersheds in the northern Sierra Nevada region of California will result in increased winter runoff, and reductions in spring runoff (Dettinger et al 2018). Changes to timing in watershed runoff to reservoirs north of the American River basin are expected to decrease end-of-year reservoir carryover storage as a result of reservoirs filling earlier (Dettinger et al 2018). A decline in carryover storage will limit the capability of NID to maintain water deliveries in dry years, and particularly during multi-year droughts. Severe droughts are projected to increase under climate change (Thorne 2018).

1.3 Study Goals and Objectives

The goal of this study is to assemble hydrologic data sets representative of historic and projected climate change conditions for the year 2070 to support the RWMP update. These data sets will cover a range of projected likely outcomes based on various scenarios of greenhouse gas emissions reductions. Hydrologic data sets will be used to develop a supply analysis to quantify how much of the projected runoff is available for water supply. Projected demands in 2070 are currently under development and will be presented in a separate technical memorandum. NID will use information from the water supply analysis and demand analysis technical memorandums to determine if projected supply will be able to meet projected demands in support of its RWMP update.

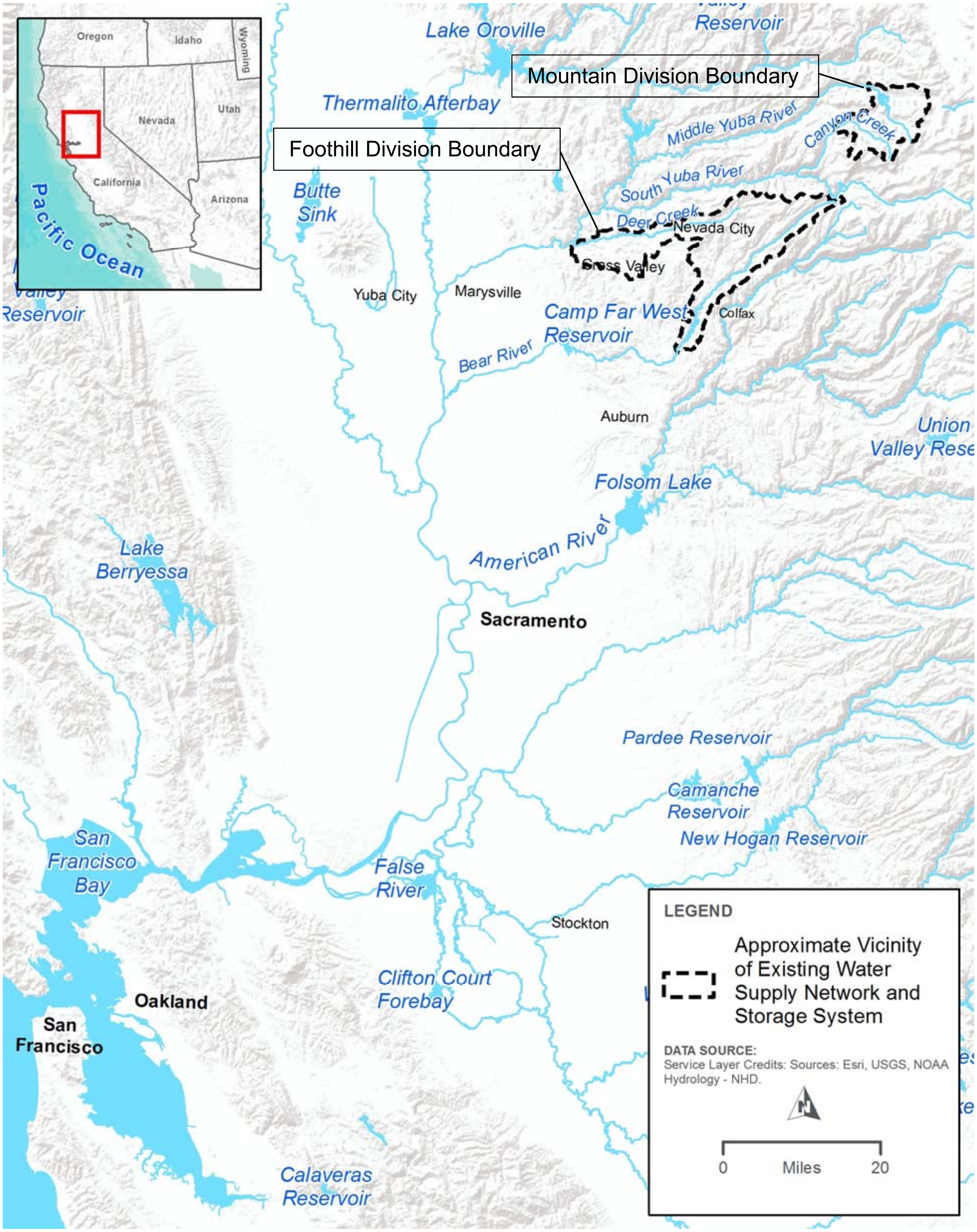
If projected water supply is not able to meet projected demand, it is necessary to analyze various reasonable, practical, and feasible demand-side and supply-side alternatives to bridge the gap between supply and demand. A system operations model approach will be used to evaluate potential alternatives to assess the relative benefit of each to create a resilient and sustainable water system for NID and its customers. An existing reservoir operations model has been expanded to include additional raw water delivery points within NID's service area. Unimpaired hydrology, fundamental input to the reservoir operations model, will utilize the projected 2070 unimpaired hydrology data sets described in this report.

This study builds upon existing unimpaired hydrology data and modeling tools developed for the joint FERC relicensing of NID's Yuba-Bear Hydroelectric Project (FERC Project Number 2266) and PG&E's Drum-Spaulding Hydroelectric Project (FERC Project Number 2310). These data and tools were accepted by FERC and other state and federal agencies to adequately represent conditions within the two hydroelectric project areas and were used to evaluate impacts to water resources as a result of potential operations and facilities modifications during the relicensing process.

2 NID's Water Supply Network

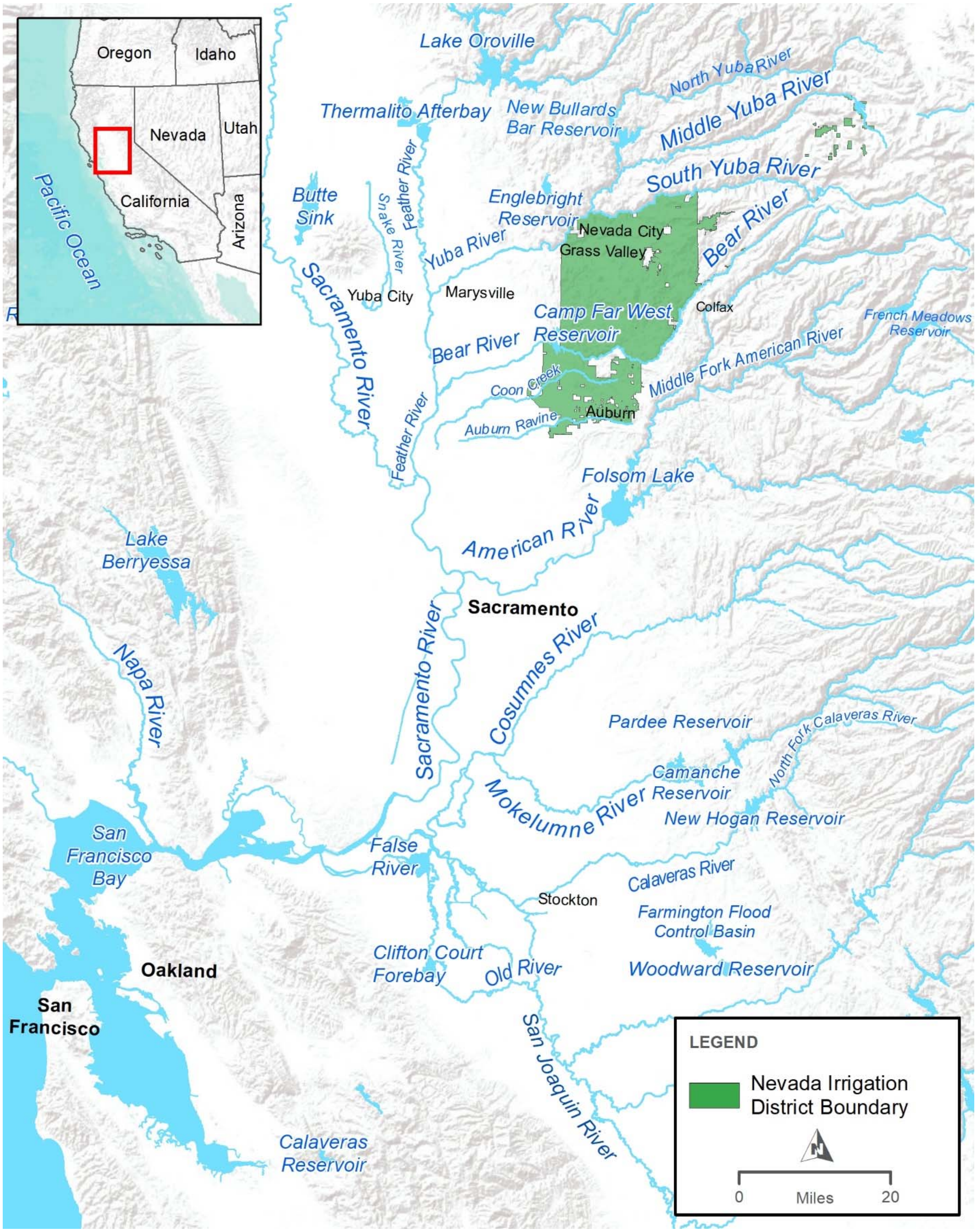
NID currently has a water supply network and storage facilities located in four major watersheds: 1) the Middle Yuba River; 2) tributaries of the South Yuba River; 3) Deer Creek; and 4) the Bear River. All four of these watersheds ultimately flow into the Feather River, and are part of the Sacramento River basin, which drains into the Sacramento-San Joaquin Delta, and then into San Francisco Bay. Figure 2-1 illustrates the general regional location of NID's existing water supply network and storage system.

Figure 2-1. Area of NID's existing water supply network and storage system in relation to San Francisco Bay, California, and tributary watersheds.



Facilities located in the Middle Yuba and South Yuba river watersheds belong to NID's Mountain Division. These facilities include Jackson Meadows Reservoir, Bowman Lake, French Lake, Faucherie Lake, Sawmill Lake, Jackson Lake, and Milton Diversion Impoundment. Facilities located in the Deer Creek and Bear River watersheds belong to NID's Foothill Division. These facilities include Rollins Reservoir, Scotts Flat Reservoir, and Lake Combie. Watershed runoff is collected in Mountain Division reservoirs and then is diverted through the Bowman-Spaulding Canal to PG&E's Lake Spaulding. From Lake Spaulding, water is routed to the Foothills Division down either the South Yuba Canal to the Deer Creek watershed, where water is then supplied to NID customers in the Nevada City-Grass Valley area, or down the Drum Canal along the Bear River, where the water is used to generate power before supplying NID customers in southern Nevada County and Placer County. NID's service area is shown in Figure 2-2. Mountain Division and Foothill Division facilities are described in more detail in Appendix A.

Figure 2-2. Map of NID's service area.



3 Unimpaired Hydrology Data Sets

Unimpaired flow is defined as the hydrologic response of watershed basins with no influence (i.e., regulation) of stream flow by man-made structures such as dams or diversions. Quantification of unimpaired flow is important because it is used to estimate watershed runoff. Watershed runoff is the largest contributor to NID's water supply (Kleinschmidt Associates 2011). Climate change is projected to change the quantity and timing of runoff in mountain division watersheds that contribute to NID's water supply. Comparisons between historical and 2070 projections of unimpaired hydrology developed for this study will help quantify how climate change is going to impact NID's watershed runoff and reservoir carryover storage within the planning horizon of the RWMP. Unimpaired hydrology will be used in the RWMP:

1. To quantify the volume of runoff available to NID, relative to historical conditions, based on water rights;
2. To assess NID's ability to meet projected customer demand (separate technical memorandum; and
3. As input to an operations model (described in Section 6) to quantify the cumulative effects of projected changes in the watershed (e.g., hydrologic changes, increased demand, increased environmental flow requirements).

Watersheds that contribute runoff to NID's water supply are either ungaged (flow is not measured by a stream gage) or highly regulated, or both. Because it is not possible to directly measure runoff in these watersheds it is necessary to synthesize unimpaired hydrology to quantify how much water is available to NID, both historically and under projected climate change conditions. Unimpaired hydrology data sets were developed for Water Years[2] 1976 through 2011. The lower bound of 1976 was chosen based on availability of stream gage data. The upper bound of 2011 is based on the available period of record of projected hydrologic data provided by the California Water Commission (CWC 2016) for climate change assessments.

This section of the report describes the existing unimpaired hydrology data set developed in 2008 during FERC relicensing, updates that have been made to this data set post-FERC relicensing, and the methodology used to transform the historical unimpaired hydrology data set to represent projected conditions in 50 years (2070) as a result of three climate change scenarios.

3.1 Historical Unimpaired Hydrology

Historical unimpaired hydrology data sets were developed for Water Years 1976 through 2008 for a total of 59 sub-basins in portions of the Middle Yuba, South Yuba, and Bear rivers (NID 2012) as part of joint FERC relicensing of NID's Yuba-Bear Hydroelectric Project and PG&E's Drum-Spaulding Project. Appendix B details the gage-proration methodology used to develop these data. Unimpaired hydrology data were used as the basis of numerous environmental assessment studies and as input to a reservoir

[2] Water years are defined as October 1 of the previous year through September 30 of the year documented.

operations model (described in Section 6) to simulate joint operating conditions of the two hydroelectric projects. The reservoir operations model was validated using the unimpaired hydrology for three different hydrologic years, wet, normal and dry, and a continuous period of ten Water Years representative of recent historical operations. Validation results showed very good correlation of modeled versus historic regulated hydrology with respect to the timing, magnitude and duration of flows, demonstrating that the unimpaired hydrology closely simulates actual historic discharge volumes (Devine Tarbell & Associates 2008).

Historical synthetic unimpaired hydrology data were developed using a gage proration method (Mann et al 2004) to estimate flows for each sub-basin. Gage proration assumes that runoff is proportional to the drainage area and average annual precipitation depth. Flows were calculated for the sub-basin of interest by scaling the hydrograph of a nearby gaged, unimpaired reference basin with similar elevation and physiography using the following equation:

$$Q_{target} = \left(\frac{A_{target}}{A_{reference}}\right)\left(\frac{P_{target}}{P_{reference}}\right)Q_{reference}$$

Where: Q_{target} is the flow (cubic feet per second) for the sub-basin of interest
$Q_{reference}$ is the flow (cubic feet per second) for the reference basin
A_{target} is the drainage area (square miles) for the sub-basin of interest
$A_{reference}$ is the drainage area (square miles) for the reference basin
P_{target} is the mean annual precipitation (inches) for the sub-basin of interest
$P_{reference}$ is the mean annual precipitation (inches) for the reference basin

USGS Gage South Yuba River at Cisco (USGS 11421000) was used as the reference gage for sub-basins above 5,000 feet in elevation and Pilot Creek above Stumpy Meadows Reservoir (USGS 11431800) was used for lower elevation sub-basins.

The original FERC unimpaired hydrology data set ended in Water Year 2008 and did not cover all areas of the watershed where NID stores water, diverts water, or has water rights, as it only addressed sub-basins within the FERC project boundary. As part of this study, daily average unimpaired hydrology data have been redeveloped for the Bear River lower basin and sub-basins were added for Deer Creek, Coon Creek, and Auburn Ravine. As a result, the total number of sub-basins included in the historical unimpaired hydrology dataset has increased from 59 to 68. The period of record has also been extended to include Water Years 2009 through 2011.

The additional watersheds include areas that are lower in elevation than sub-basins in the existing FERC unimpaired hydrology data set. For example, sub-basins in Auburn Ravine range in elevation from approximately 200 ft to 1,700 ft. Pilot Creek, the original reference gage for low-elevation sub-basins, is representative of mid-elevation watersheds (4,250 feet to 6,250 feet), but is not applicable to lower elevation watersheds because of differences in quantity and timing of snowmelt runoff contributions. Therefore, four additional reference gages were compiled to better represent the extended elevation ranges. A combined gage proration technique was used to incorporate available data for Water Years 1976 through 2011. The method subdivided sub-basin areas into elevation bands and prorated area-weighted gage data associated with each elevation range. For consistency, unimpaired hydrology was redeveloped for all Bear River sub-basins in the FERC relicensing dataset using the updated methodology. Unimpaired hydrology for all other sub-basins from the original FERC relicensing dataset were extended to 2011 using the same methodology as used for the FERC relicensing, as described in Appendix B. Historical unimpaired hydrology for all 68 sub-basins is provided in Appendix E.

3.2 Projected 2070 Unimpaired Hydrology

Hydrologic projections for future conditions representative of year 2070 were developed using simulated historical and projected runoff from the Variable Infiltration Capacity (VIC) model (Liang et al. 1994) to translate gage-proration historical unimpaired hydrology (described in Section 5.1) into projected unimpaired hydrology. The analysis employed daily historical and 2070 future conditions VIC model runoff predictions for water years 1976 through 2011 provided by the California Water Commission (CWC 2016).

The VIC model is a gridded hydrologic model that simulates land-surface-atmosphere exchanges of moisture and energy at each model grid cell. The CWC provided VIC model data for the state of California on a grid spatial resolution of approximately 14 square miles. Recommendations and guidance for using the climatological input and model results were provided for Water Storage Investment Program (WISP) grant applicants (CWC 2016) and for other water supply climate studies, such as the Sustainable Groundwater Management Program overseen by the California Department of Water Resources (DWR 2018). Data are provided for three climate change scenarios:

- Median climate change conditions, based on 20 global climate models (GCMs) and representative concentration pathway (RCP) combinations[3];
- Drier/extreme-warming (DEW) conditions, representing a pessimistic trajectory of greenhouse gas emissions throughout this century[4]; and
- Wetter/moderate-warming (WMW) conditions, representing an optimistic trajectory of greenhouse gas emissions throughout this century[5].

CWC developed meteorology for the three climate projections by applying perturbations to the historical precipitation and temperature time series, a method known as “climate period analysis” (CWC 2016, DWR 2018). The modeled future inter-annual variability is based on the reference period from which change is being measured, so all differences between the future and historical simulations are a result of the climate change signal alone (DWR 2018). Therefore, each future scenario exhibits a similar temporal pattern and the relative distribution of water year types remains the same as the historical record. This methodology does not account for potential changes in inter-annual variability, such as prolonged drought sequences, although the frequency of dry years is expected to increase along with an overall increase in year-to-year variability (Pierce 2018).

[3] The 20 climate model and RCP combinations were composed of 10 general circulation models, each run with two RCPs: one optimistic (RCP 4.5) and one pessimistic (RCP 8.5).

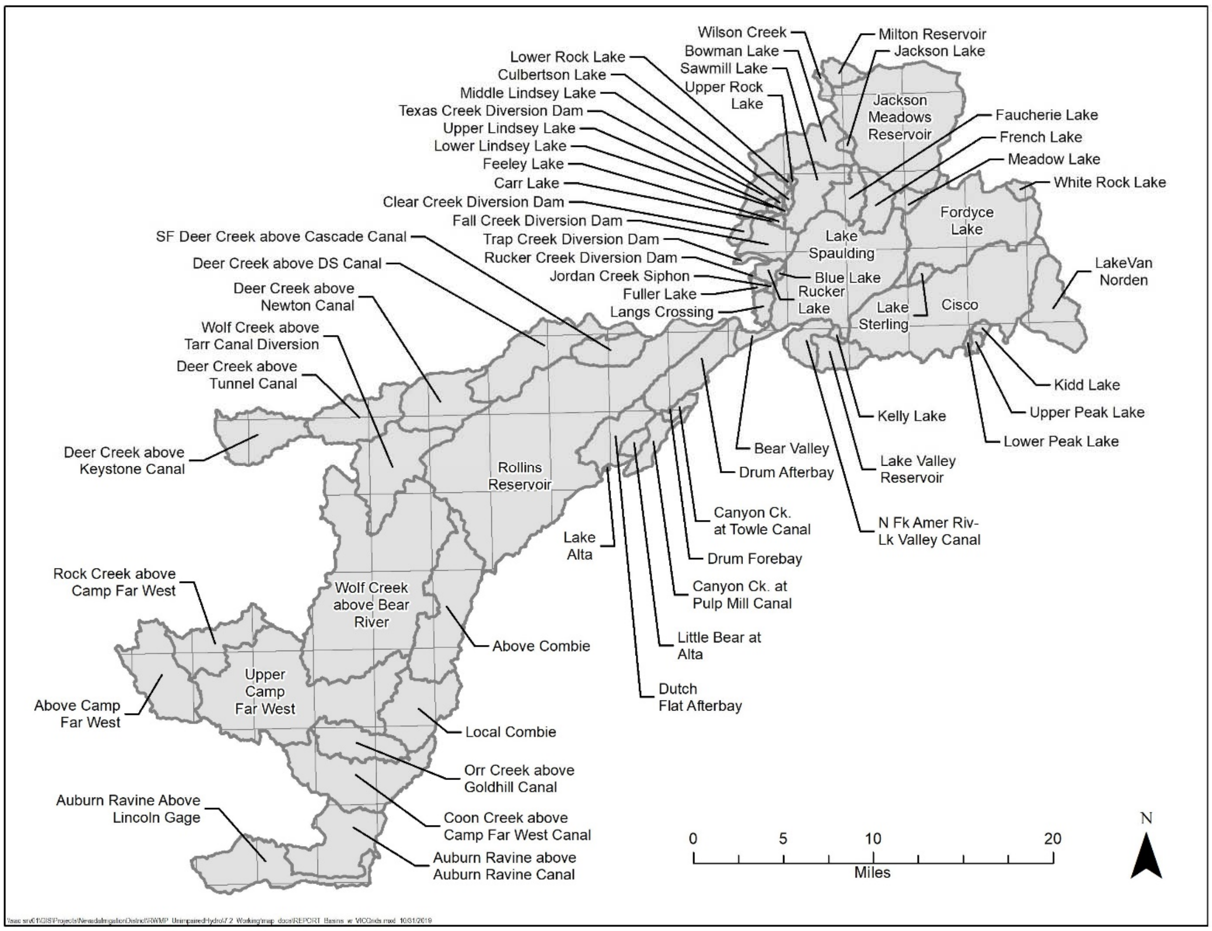
[4] Based on GCM HadGEM2-ES and emission scenario RCP 8.5.

[5] Based on GCM CNRM-CM5 and emission scenario RCP 4.5.

3.2.1 Methods

A geographic information system (GIS) was used to overlay the unimpaired hydrology sub-basin boundaries on the VIC model grid (Figure 3-1). Total VIC model daily runoff (in millimeters) was calculated for each basin as the sum of surface runoff and baseflow from grid cells completely contained within the basin and the values from grid cells weighted by the fractional area intersected by the basin boundary. Daily basin-averaged VIC results were generated for each unimpaired hydrology basin for all three 2070 climate projection scenarios and the historical scenario provided by the CWC.

Figure 3-1. Unimpaired hydrology sub-basins divided by VIC model grid cells.



A comparison of gage-proration historical hydrology to VIC model runoff for water years 1976 to 2011 indicates significant differences in timing and magnitude of flow. Figure 3-2 demonstrates the scattered correlation between VIC model and gage-proration daily runoff in the 41.3 square mile Cisco basin. VIC model flows were calculated by multiplying runoff depth by basin area and converting to cubic feet per second (cfs). Figure 3-3 demonstrates a much tighter correlation on an annual time scale, although VIC model volumes are approximately 28 percent greater. The exceedance diagram in Figure 3-4 further illustrates the significant differences in annual volume. The monthly temporal distribution of flows is shown in Figure 3-5. Both gage-proration flows and VIC model flows peak in May as a result of snowmelt in the higher elevation basin. VIC model flows are slightly higher than gage-proration flows from January through March and slightly lower from April through December.

Figure 3-2. Comparison of gage-proration and VIC model historical mean-daily runoff at Cisco Basin.

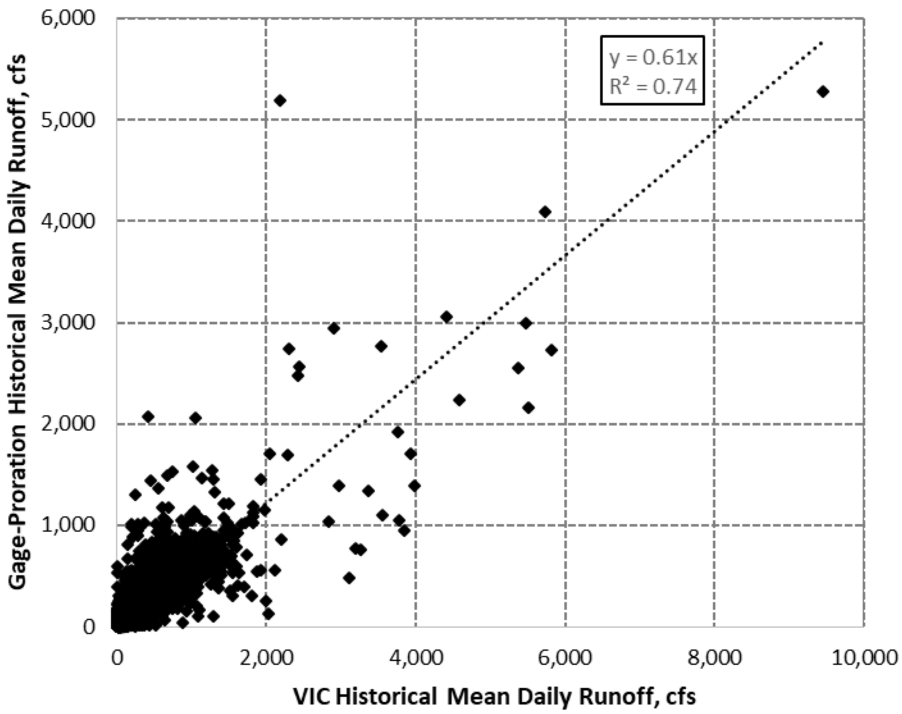


Figure 3-3. Comparison of gage-proration and VIC model historical mean-annual runoff at Cisco Basin.

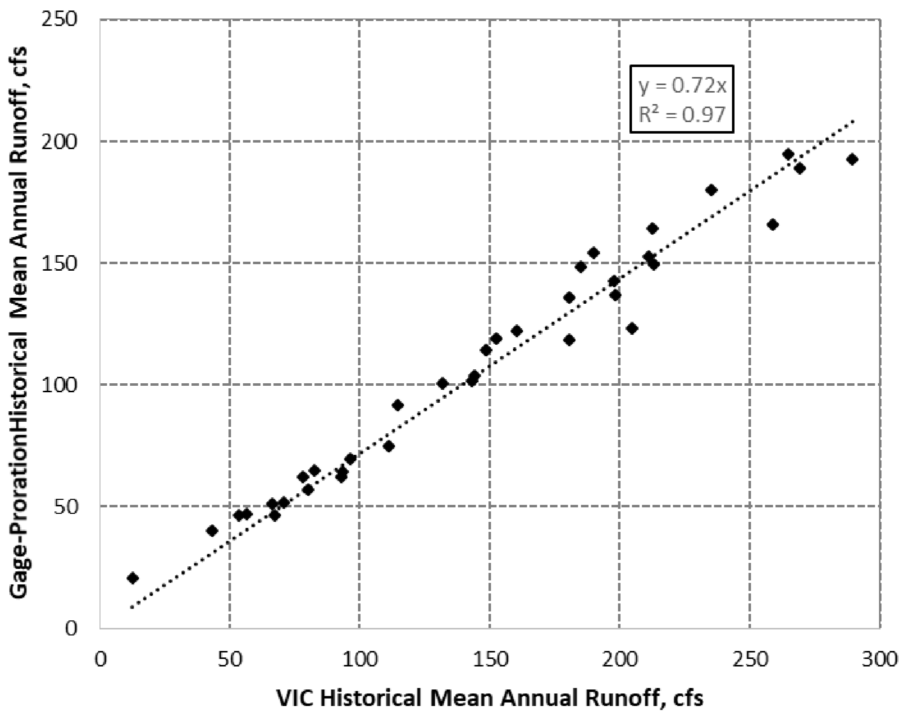


Figure 3-4. Comparison of gage-proration and VIC model historical mean-annual runoff probability of exceedance at Cisco Basin.

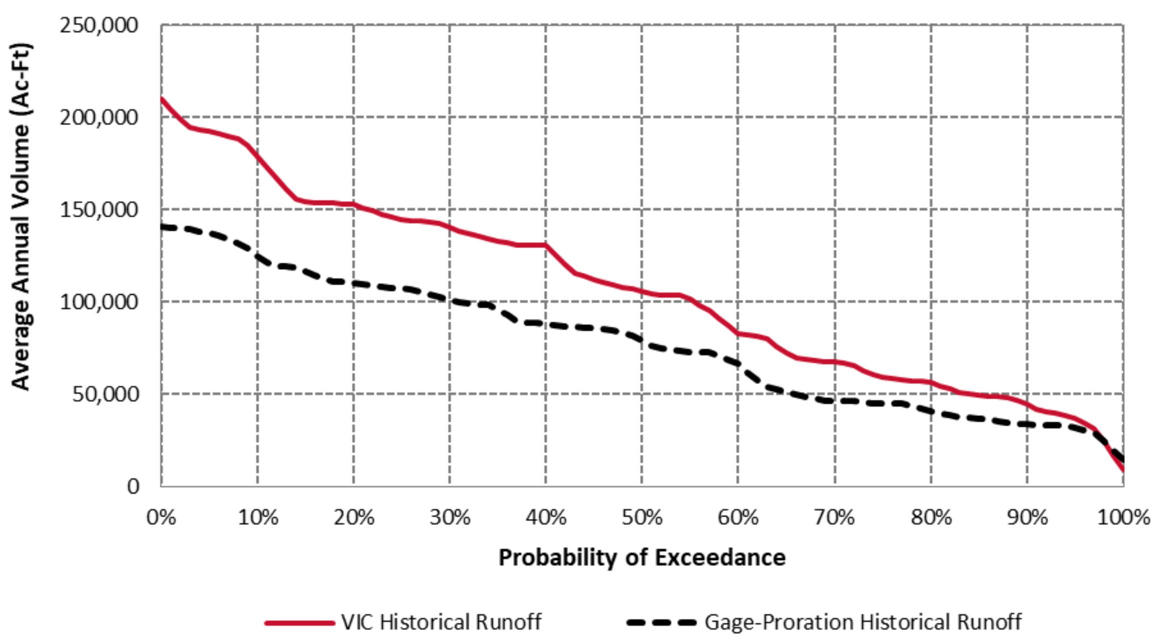
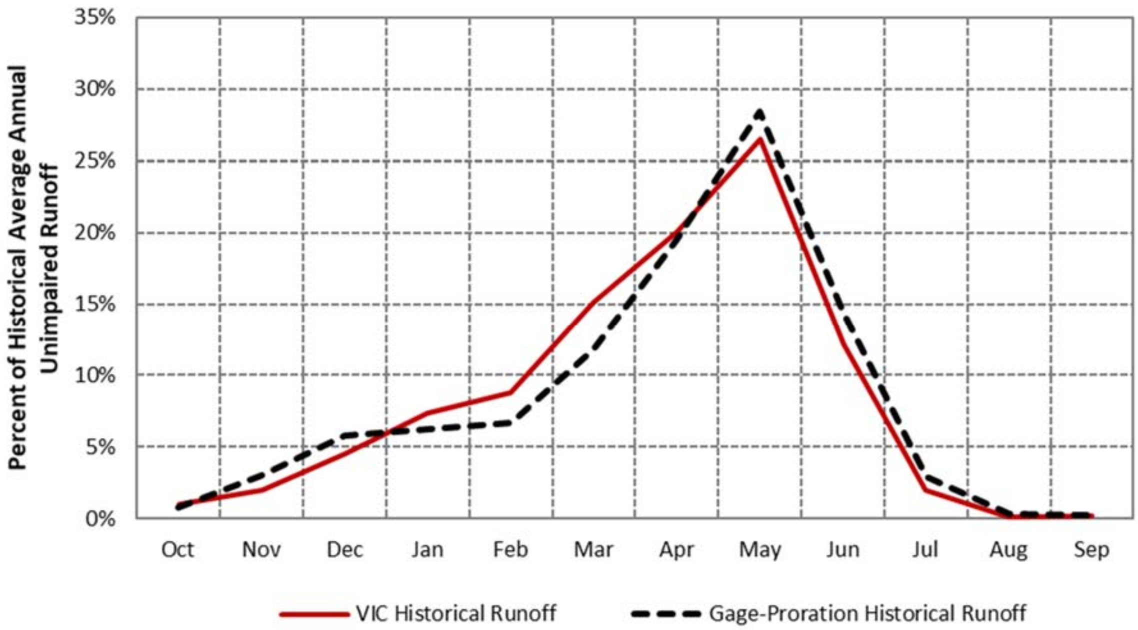


Figure 3-5. Comparison of gage-proration and VIC model historical monthly runoff at Cisco Basin.



Although the VIC Model was recalibrated for 12 large upper watersheds in the Sacramento and San Joaquin River Basins for water years 1970 through 2003 (CWC 2016), model bias can impact results at the smaller scale of the unimpaired hydrology sub-basins. The study sub-basins range in size from less than a square mile to 82 square miles, with an average size of less than 10 square miles. VIC model bias results from multiple factors, including the coarse spatial model resolution, spatial and temporal errors in gridded climate input, complexities of snowmelt simulation, base flow and groundwater interactions, and other model uncertainties. The gage-proration historical hydrology can also be considered a model with its own inherent uncertainties; however, for the purposes of this study it is considered to be the more accurate data set based on successful verification using the FERC relicensing operations model (Devine Tarbell & Associates 2008) and gage–summation (Appendix B). The existing gage-proration hydrology has been used extensively for FERC relicensing and other NID operations studies and is considered to be the historical unimpaired baseline hydrology for this study.

The differences in timing and volume between VIC model historical and future flows are used to develop a transformation of the gage-proration historical hydrology to represent potential future flows. Therefore, a bias correction approach is needed to address the model differences in volume and timing of historical gage-proration and VIC model flows to effectively use the VIC model results for prediction of future flow conditions.

There is no standardized method for bias correction and different approaches can yield significantly different results (Pierce et al. 2015). We chose an approach based on the variable perturbation method used in California's fourth climate change assessment to estimate impacts on the State Water Project (Wang et al. 2018). The method was developed for monthly flows, so required some modification to be applied to daily flows, as described in the following paragraphs.

The variable perturbation method applied by Wang (2018) is similar to the cumulative distribution function transform (CDF-t) bias correction described by Pierce (2015). The VIC model projected results were bias-corrected using CDF-t applied first to daily flows using a month-long time window, and subsequently to annual flows. The CDF-t method assumes that the historical mapping between the model and observed cumulative distribution functions applies to the future period (Pierce et al. 2015). The methodology used to develop future hydrology is described in detail in Appendix C and a summary of the steps is provided below:

1. Evaluate the correlation between daily gage-proration hydrology and VIC model historical runoff depths across all basins. In general the best correlation did not occur between the exact geographically corresponding basins due to various bias errors as described above, with the large VIC model grid scale relative to basin size and lack of calibration at the basin scale likely being significant factors. In addition, the gage-proration method is a function of a small number of reference basins which results in some self-similarity of constructed flows in different basins. The best correlated VIC model results were chosen to be used as the reference hydrology for each basin.
2. Develop linear regressions between each best correlated basin pair and apply to the VIC model historical and projected runoff depths to create the baseline VIC model flows for each unimpaired hydrology sub-basin and each emissions scenario. Because flow volumes differ so significantly between gage-proration flows and VIC model flows when using basin area proration to transform VIC model depths to flows, as shown in Figure 3-2, linear regression was chosen as a reasonable alternative method.
3. Calculate cumulative distribution functions (CDF) of the VIC model historical flows and the VIC model projected flows for each calendar month. Determine the ratio of projected to historical flows for each quantile.
4. Map each gage-proration historical daily flow to the corresponding VIC model historical quantile associated with that flow in the corresponding month. The ratio of VIC model projected flow to VIC model historical flow for that CDF quantile is used as the perturbation ratio for that daily historical flow. A perturbation ratio was determined and applied to each day in the historical record.
5. Calculate CDFs of VIC model historical and projected annual volumes to determine perturbation ratios using the same method as for monthly flows described in Step 3.
6. Map each gage-proration historical annual flow to the corresponding VIC model historical quantile associated with that annual flow to determine the annual perturbation ratios. Apply the annual perturbation ratios to the daily flows calculated in Step 4 for each year in the historical record.
7. Multiply the results of Step 6 by the ratio of the annual volume of gage-proration historical flows to the annual volume of perturbed flows from Step 4 so that the

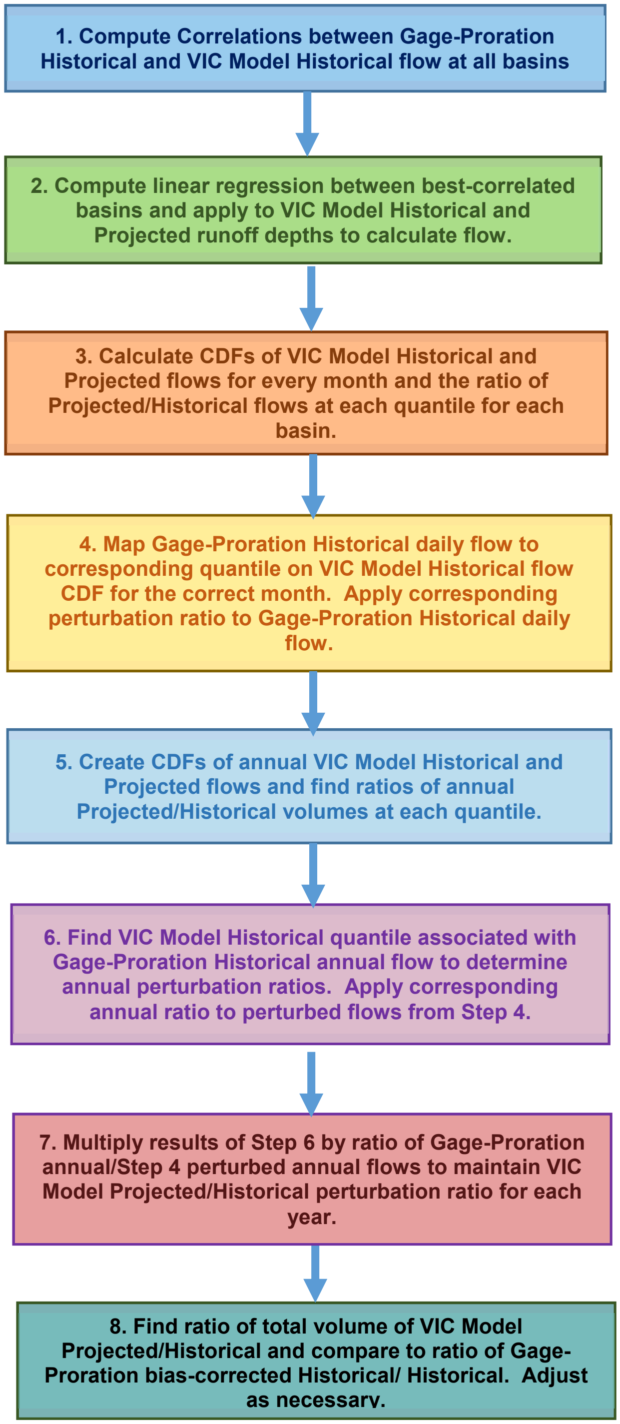
final volume ratio of projected to historical annual flows is equivalent to the VIC model annual ratio at that quantile.

8. A final adjustment was made if needed to correct discrepancies from the total period of record volume ratio of VIC model projected to VIC model historical flows.

A schematic of the transformation steps is given in Figure 3-6.

The transformed gage-proration historical flows are intended to represent potential future hydrology for each emissions scenario. Different methods of developing future flows may result in differences in temporal distributions and magnitudes of individual peak flows on a daily basis. However, general trends demonstrating changes in annual distributions are expected to be similar between methods.

Figure 3-6. Schematic of methodology used to develop projected flows.



3.2.2 Results

Projected unimpaired hydrology data were developed for all three 2070 climate change scenarios for the 68 unimpaired hydrology sub-basins by applying the methodologies described in Section 5.2.1 and is provided in Appendix E. Hydrologic basins were aggregated into four larger basins to compare projected hydrology to historical gage-proration hydrology. The four locations, Middle Yuba at Milton Diversion Dam, Canyon

Creek at Bowman Dam, Bear River at Rollins Dam, and Deer Creek at Scotts Flat Dam, represent approximately 32 percent of the total area covered by the 68 basins. They were selected as example locations because of their significance within NID's overall water supply network and because they represent a mix of watersheds from the Mountain Division and Foothills Division, demonstrating the variations in climate change impacts from higher- to lower-elevation watersheds.

Middle Yuba at Milton Diversion Dam and Canyon Creek at Bowman Dam represent two higher-elevation watersheds, located in the Middle and South Yuba watersheds, respectively. Middle Yuba at Milton Diversion Dam comprises two sub-basins (Jackson Meadows Reservoir and Milton Reservoir) with a total watershed area of 39.7 square miles. The watershed ranges in elevation from approximately 5,690 feet to over 8,000 feet. Canyon Creek at Bowman Dam comprises five sub-basins (French Lake, Faucherie Lake, Sawmill Lake, Jackson Lake and Bowman Lake) with a total watershed area of 23.7 square miles and an elevation range from 5,390 feet to over 8,000 feet.

Bear River at Rollins Dam, and Deer Creek at Scotts Flat Dam represent two lower-elevation watersheds. Bear River at Rollins Dam comprises five sub-basins (Bear Valley, Drum Afterbay, Dutch Flat Afterbay, Little Bear at Alta, and Rollins Reservoir) with a total watershed area of 103.5 square miles and an elevation range from 1,927 feet to approximately 5,750 feet. Deer Creek at Scotts Flat Dam comprises two sub-basins (SF Deer Creek above Cascade and Deer Creek above DS Canal) with a total area of 22.0 square miles and ranging in elevation from 2,940 feet to approximately 5,000 feet.

Figures 3-7 through 3-10 show monthly percent of historical annual average unimpaired runoff for all three 2070 climate change scenarios along with historical unimpaired flow at these four locations. Monthly comparisons for the full period of record are included in Appendix D.

Figure 3-7. Monthly percent of historical annual average unimpaired runoff (Water Years 1976 through 2011) at Milton Diversion Dam on the Middle Yuba River under historical conditions and under projected 2070 climate change conditions.

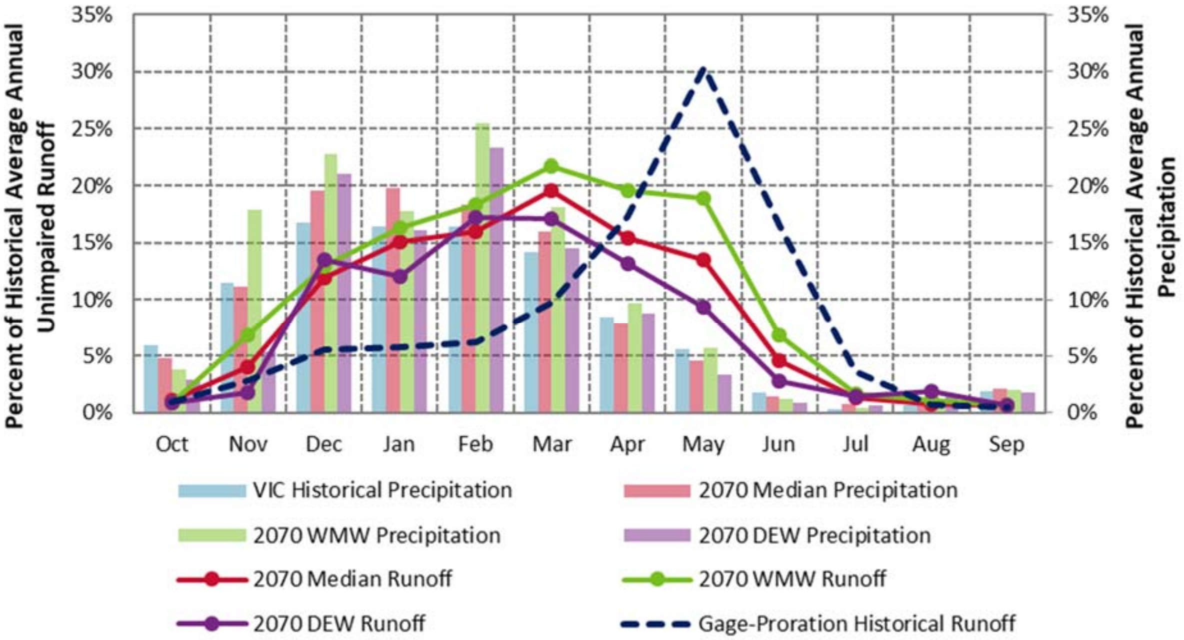


Figure 3-8. Monthly percent of historical annual average unimpaired runoff (Water Years 1976 through 2011) at Bowman Dam on Canyon Creek under historical conditions and under projected 2070 climate change conditions.

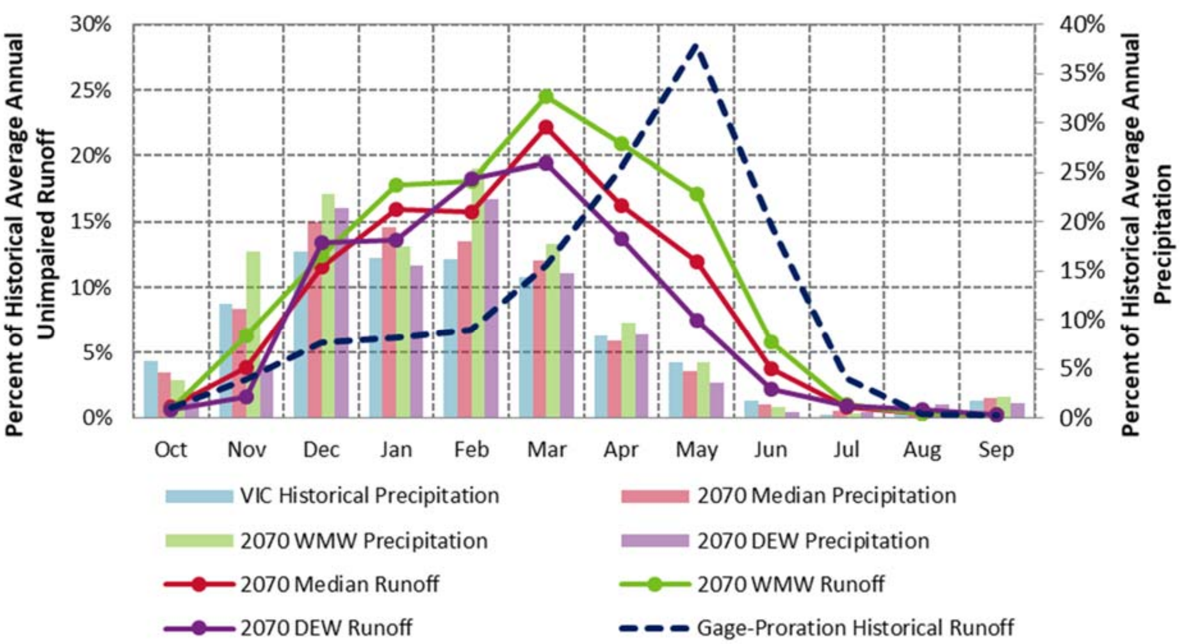


Figure 3-9. Monthly percent of historical annual average unimpaired runoff (Water Years 1976 through 2011) at Rollins Dam on the Bear River under historical conditions and under projected 2070 climate change conditions.

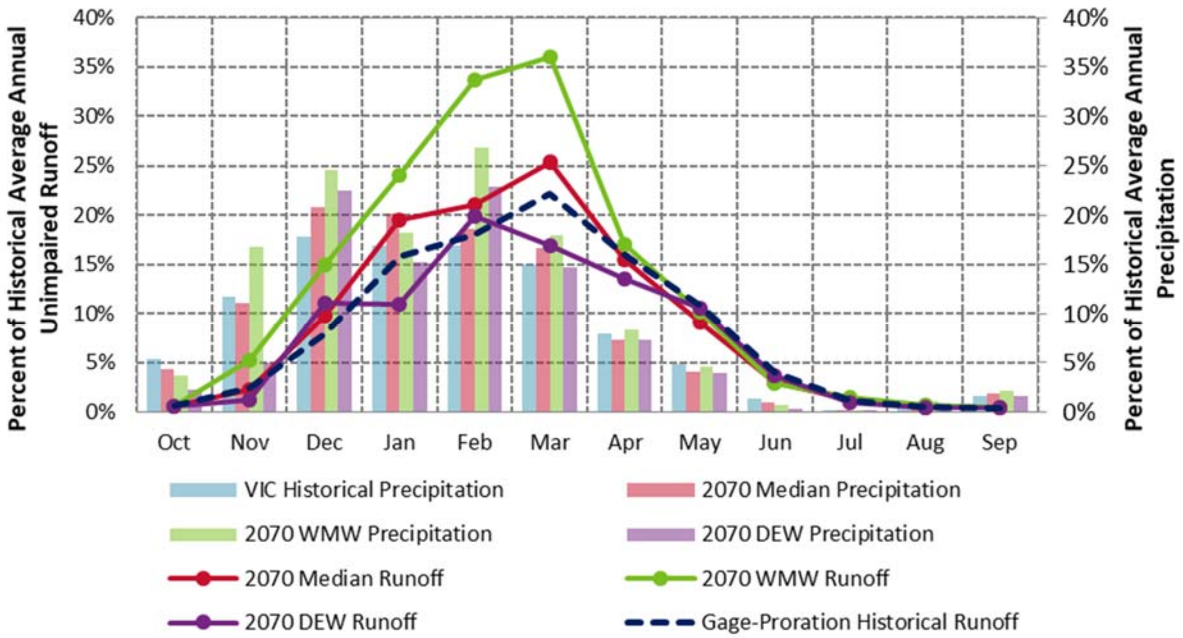
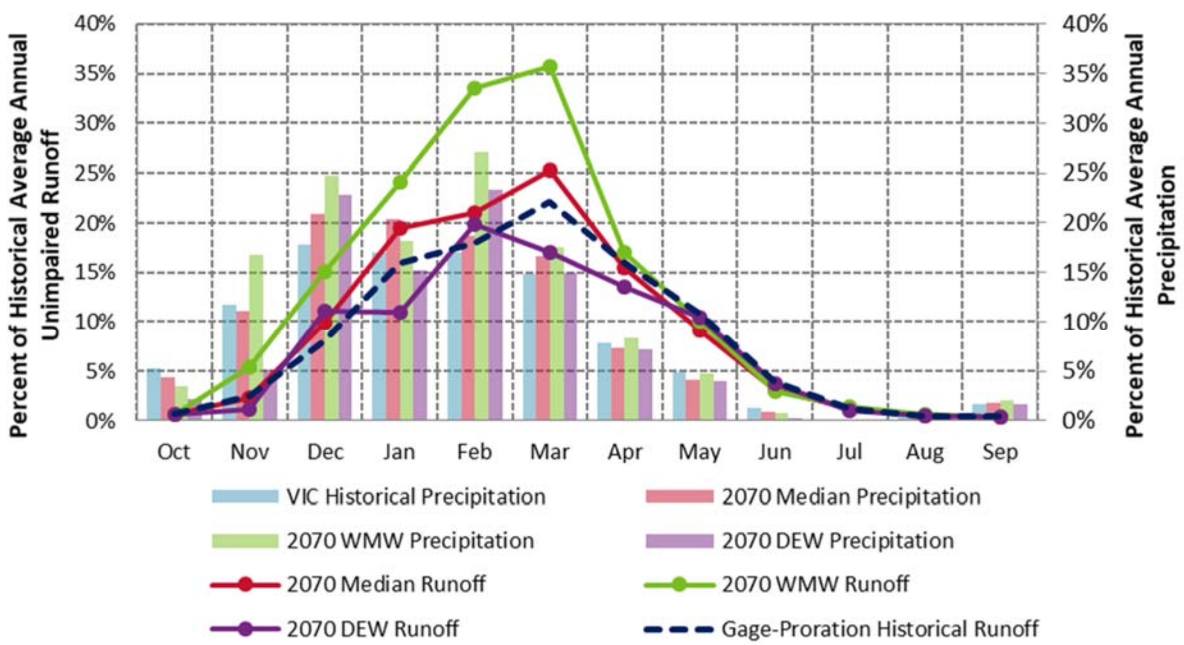


Figure 3-10. Monthly percent of historical annual average unimpaired runoff (Water Years 1976 through 2011) at Scotts Flat Dam on Deer Creek under historical conditions and under projected 2070 climate change conditions.



In the high-elevation watersheds that are historically snowfall dominant during the wet season, the 2070 peak runoff months occur earlier in the Water Year and are more distributed during the rainy season relative to historical conditions as a result of the shift in precipitation from snowfall to rainfall (Figures 3-7 and 3-8). The 2070 scenarios generally exhibit higher percentages of flows from December through March, and lower percentages from May through July. The prominent historical May snowmelt peak is no longer evident at Milton Diversion Dam and is broader and shifted to March at Bowman Dam, which has greater runoff contributions from higher elevation watersheds.

In the low-elevation watersheds that are historically rainfall dominant in the wet season, the shifts in runoff pattern are not as pronounced. This is because the largest contribution to runoff occurs as direct runoff of rainfall during the rainy season and future scenario changes in the snowmelt contribution are small relative to the total annual runoff volume. The Median and colder, wetter WMW scenarios indicate higher flows in December through March and flows slightly less than historical in the drier months (Figures 3-9 and 3-10).

Changes in runoff volume are not directly proportional to changes in precipitation volume between scenarios. Variation of temperature, and rainfall intensity and duration impact hydrologic processes and parameters simulated by the VIC model, such as rainfall losses to interception, detention and groundwater storage, evapotranspiration and sublimation, and changes in infiltration parameters under different degrees of soil saturation. A comparison of VIC model historical and future precipitation and flow indicates that losses are reduced relative to historical for the WMW scenario, with a larger percentage of precipitation transformed to runoff, likely due to more saturated conditions, more intense precipitation, and reduction of snow pack. Losses are higher for the warmer, drier DEW scenario, likely due to drier soils and increases in evapotranspiration.

Table 3-1 summarizes the percent of average annual historical runoff at the four locations. Table 3-2 summarizes annual volumes at each location. The 2070 WMW scenario is approximately 25 percent wetter than historical conditions in the higher elevation example watersheds and nearly 50 percent wetter in the lower elevation watersheds. The 2070 DEW scenario is about 8 to 10 percent drier, and the Median scenario is 6 to 9 percent wetter. The results indicate that there is potential for significantly higher runoff volume during wet years and lower runoff volume during dry years than experienced under historical climate conditions.

Table 3-1. Percent of average annual historical runoff.

Location	Percent of Average Annual Historical Runoff		
	2070 DEW[1]	2070 Median[2]	2070 WMW[3]
Middle Yuba River at Milton Diversion Dam	**92%**	**104%**	**126%**
Canyon Creek at Bowman Dam	**92%**	**104%**	**125%**
Bear River at Rollins Dam	**90%**	**109%**	**148%**
Deer Creek at Scotts Flat Dam	**90%**	**108%**	**147%**

[1] Drier, extreme warming scenario based on GCM HadGEM2-ES and emission scenario RCP 8.5.

[2] Median scenario based on 10 general circulation models, each run with two emission scenarios: one optimistic (RCP 4.5) and one pessimistic (RCP 8.5).

[3] Wetter, moderate warming scenario based on GCM CNRM-CM5 and emission scenario RCP 4.5.

Table 3-2. Annual Flow Volumes for four location under historical conditions and under projected 2070 climate change conditions.

Scenario		Annual Flow Volumes in Acre-Feet			
		Middle Yuba River at Milton Diversion Dam	Canyon Creek at Bowman Dam	Bear River at Rollins Dam	Deer Creek at Scotts Flat Dam
Historical	Average	89,004	91,068	156,830	30,983
	Maximum	192,731	165,289	488,342	102,800
	Minimum	12,557	17,362	8,262	1,747
2070 DEW[1]	Average	81,748	83,976	142,322	31,677
	Maximum	197,825	169,670	416,588	92,156
	Minimum	11,817	16,381	7,633	1,753
2070 Median[2]	Average	92,632	94,258	170,217	37,191
	Maximum	208,767	179,314	535,430	115,882
	Minimum	11,865	16,628	8,176	1,830
2070 WMW[3]	Average	112,013	113,861	231,518	50,457
	Maximum	248,617	212,318	697,622	150,901
	Minimum	15,950	19,873	8,888	1,984

[1] Drier, extreme warming scenario based on GCM HadGEM2-ES and emission scenario RCP 8.5.

[2] Median scenario based on 10 general circulation models, each run with two emission scenarios: one optimistic (RCP 4.5) and one pessimistic (RCP 8.5).

[3] Wetter, moderate warming scenario based on GCM CNRM-CM5 and emission scenario RCP 4.5.

The three 2070 scenarios represent different projections of greenhouse gas emission trajectories (CWC 2016). The WMW and DEW scenarios represent bookend estimates of runoff under optimistic and pessimistic trajectories, respectively. The median scenario represents a moderate trajectory of greenhouse gas emissions. The annual exceedance probabilities demonstrate the bracketing of potential outcomes as shown in Figures 3-11 through 3-14. These figures indicate that the WMW scenario is significantly wetter than historical conditions with differences increasing in higher volume years. The Median scenario has wetter wet years, but generally shows a similar pattern of annual average flow over an exceedance probability of about 40 percent. The DEW scenario shows drier dry years for exceedance probabilities greater than 40 percent, slightly more so for the higher elevation watersheds, and variable higher flows in comparison to historical conditions.

Figure 3-11. Average Annual Runoff Volume Exceedance Probabilities (Water Years 1976 through 2011) at Milton Diversion Dam on the Middle Yuba River under historical conditions and under projected 2070 climate change conditions.

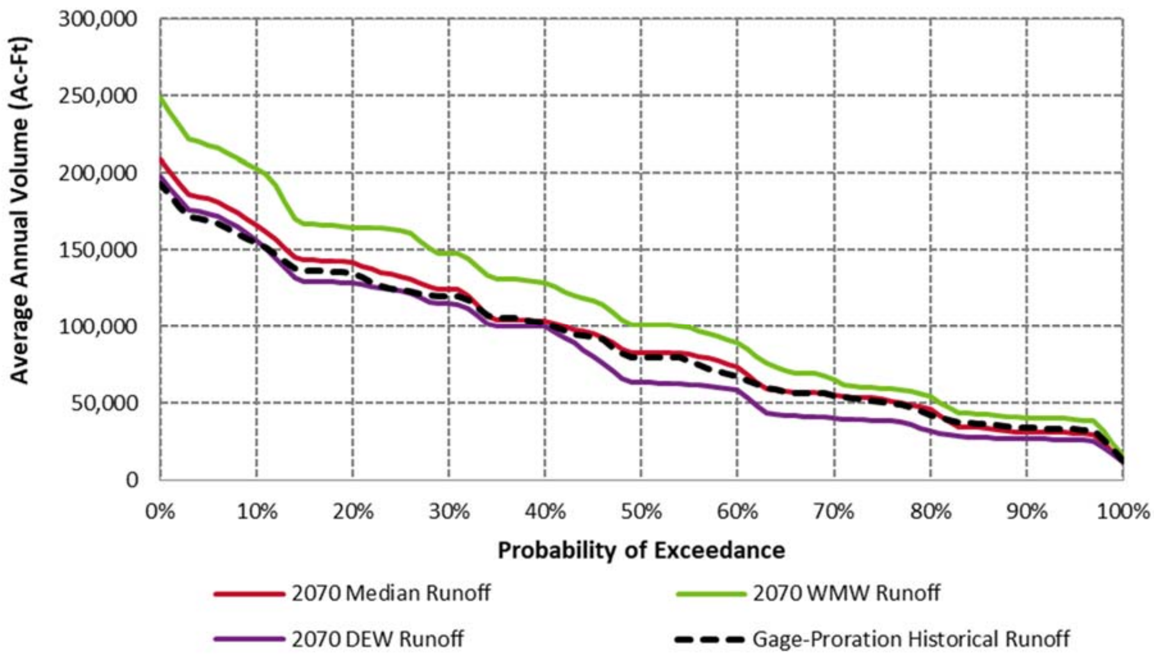


Figure 3-12. Average Annual Runoff Volume Exceedance Probabilities (Water Years 1976 through 2011) at Bowman Dam on Canyon Creek under historical conditions and under projected 2070 climate change conditions.

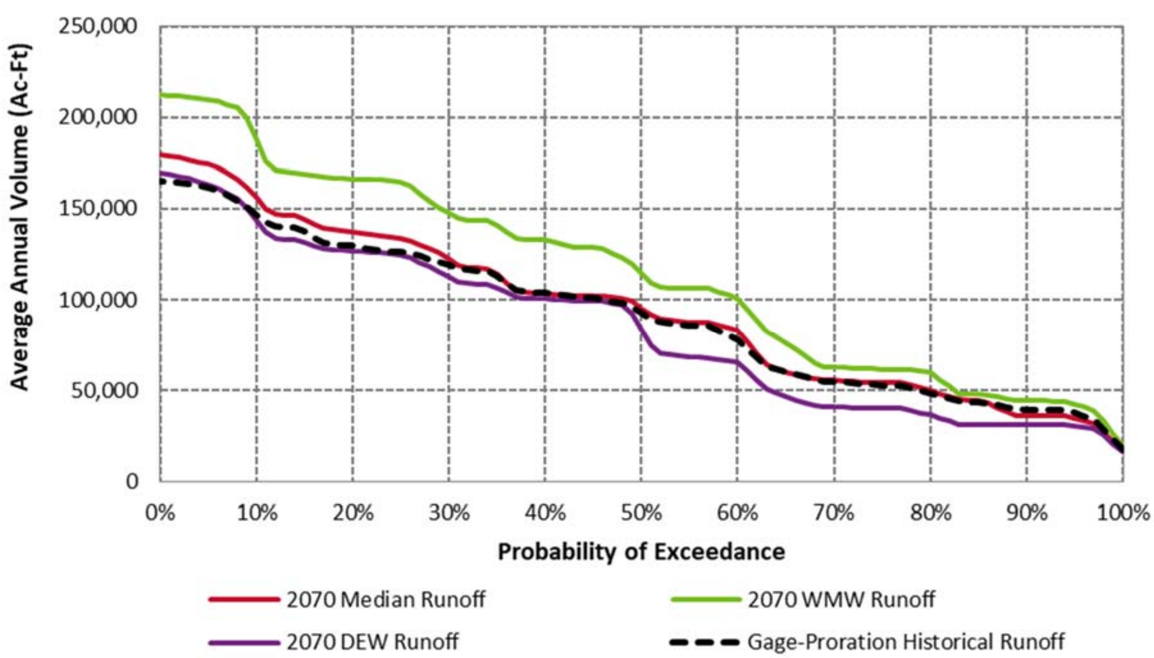


Figure 3-13. Average Annual Runoff Volume Exceedance Probabilities (Water Years 1976 through 2011) at Rollins Dam on the Bear River under historical conditions and under projected 2070 climate change conditions.

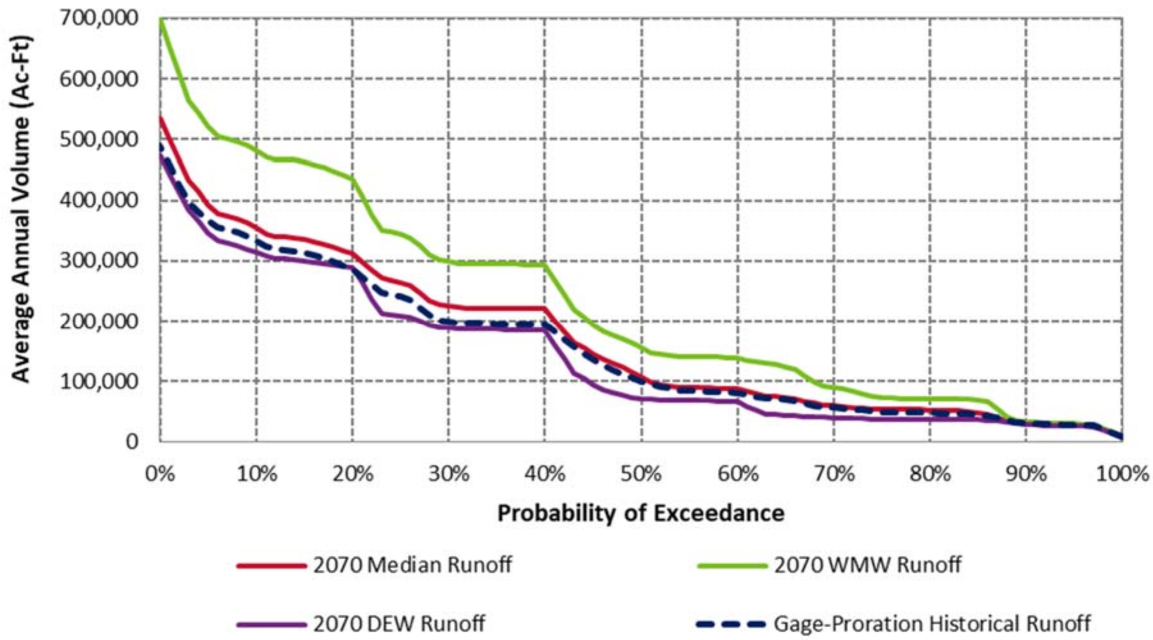
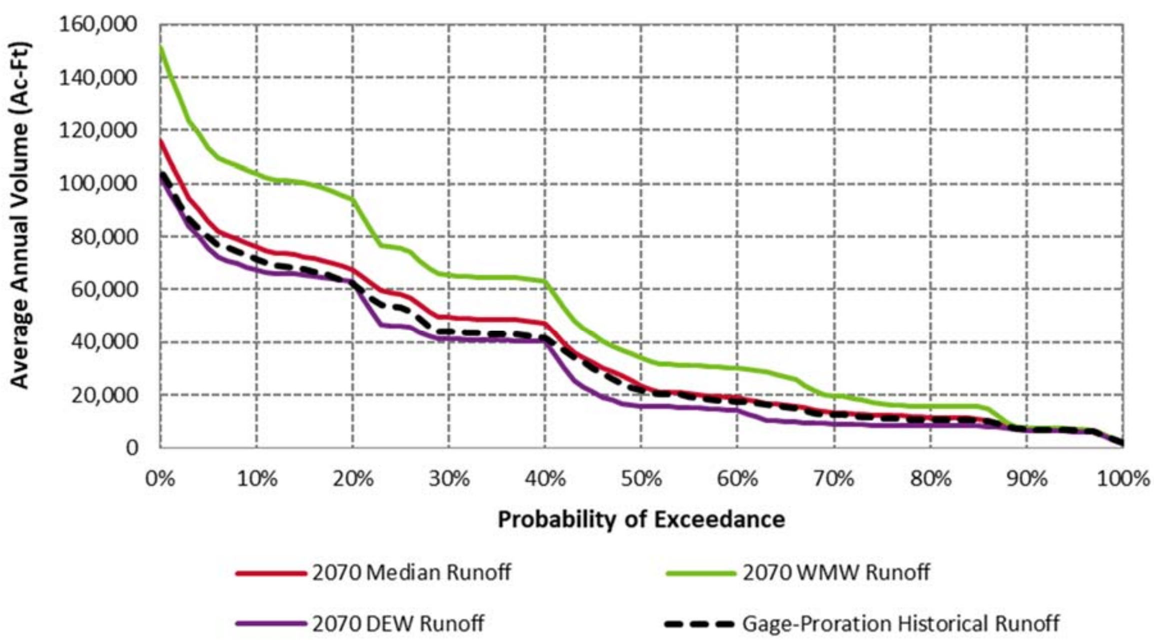


Figure 3-14. Average Annual Runoff Volume Exceedance Probabilities (Water Years 1976 through 2011) at Scotts Flat Dam on Deer Creek under historical conditions and under projected 2070 climate change conditions.

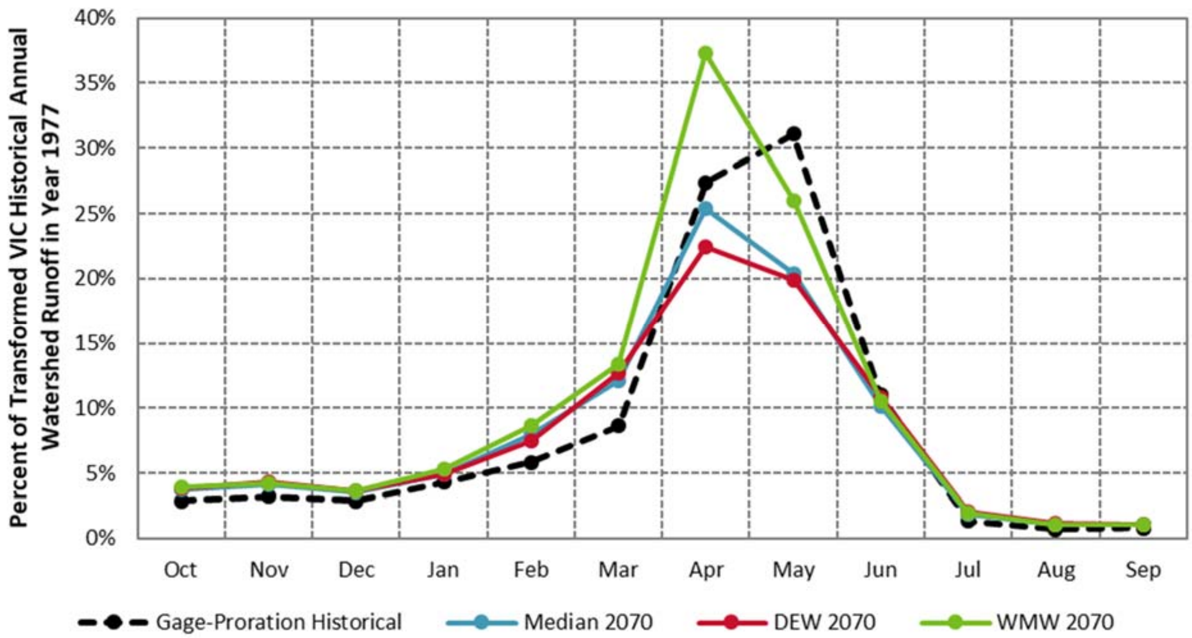


3.3 2070 Drought Projections

The prevalence of droughts in California is expected to increase under climate change (Thorne 2018). The 2070 unimpaired hydrologic data sets (median, DEW, and WMW) provided by the CWC (2016) do not include additional years of drought relative to historical conditions as a result of the climate period analysis method used to estimate the future meteorology driving the VIC model (DWR 2018). The relative distribution of wet, normal and dry years are the same as for the modeled historical period of record because the data sets are perturbations of historical conditions representative of 50 years into the future. Nonetheless, it is possible to draw conclusions on what drought conditions might look like in the future under climate change. While the hydrologic datasets do not include the recent multi-year drought, from 2012 to 2016, there are dry years in the 1976 through 2011 period of record, including 1977, which was considerably drier than any one single year in the recent drought.

Unimpaired runoff in sub-basins where NID has water rights was summed for each water year in the period of record, Water Years 1976 through 2011, to rank the Water Years from wettest to driest. The driest year in the period of record was consistently Water Year 1977 in all of the 2070 hydrologic data sets, and in the historical data set (Appendix E). Because watershed runoff is the largest contributor to NID's water supply, 1977 is assumed to be the Water Year with the lowest water supply available to NID in the hydrologic period of record (DWR 2016). A comparison of Water Year 1977 runoff under 2070 conditions relative to historical runoff is shown in Figure 3-15. Peak runoff occurred earlier (April) in the 2070 scenarios as compared to historical (May). Dry month base flows (October through December, and July through September) in the 2070 scenarios were similar to historical base flows. Both the Median and DEW 2070 scenarios were approximately 5 percent drier than historical, while the WMW 2070 scenario was 17 percent wetter than historical, as summarized in Table 3-3. WY 1977 was slightly drier relative to the period of record average for both the Median and WMW 2070 scenarios, as compared to historical unimpaired.

Figure 3-15. Monthly percent of average sum of runoff in sub-basins with NID water rights for the driest year in the hydrologic period of record, Water Year 1977, under 2070 conditions relative transformed VIC historical conditions.



3-3. Runoff statistics for WY 1977 under historical conditions and under projected 2070 climate change conditions based on sum of runoff in sub-basins with NID water rights.

Scenario	Percent of Historical Annual WY 1977 Runoff	Percent of Scenario Average Annual Runoff
Gage-Proration Historical	100%	10%
Median 2070[1]	96%	9%
DEW 2070[2]	94%	10%
WMW 2070[3]	117%	9%

[1] Drier, extreme warming scenario based on GCM HadGEM2-ES and emission scenario RCP 8.5.

[2] Median scenario based on 10 general circulation models, each run with two emission scenarios: one optimistic (RCP 4.5) and one pessimistic (RCP 8.5).

[3] Wetter, moderate warming scenario based on GCM CNRM-CM5 and emission scenario RCP 4.5.

4 Reservoir Operations Model

Future increases in water demand within NID's service area, coupled with anticipated periods of drought and ongoing climate change, create imminent challenges for NID in maintaining a sustainable water system for its service area. NID will perform an accounting of water supply and demand for average conditions and for drought conditions within the planning horizon of the RWMP. If the analysis indicates that projected supply will not be able to meet projected demand it may be necessary to analyze various reasonable, practical, and feasible ways (alternatives) to bridge the gap between supply and demand. A reservoir operations model (Ops Model) will be used to evaluate potential alternatives to assess the relative benefit of each to create a resilient and sustainable water system for NID and its customers.

A HEC-ResSim (US Army Corps of Engineers 2013) reservoir operations model (Ops Model) was previously developed in support of the Yuba-Bear/Drum-Spaulding hydroelectric project FERC relicensings (Devine Tarbell & Associates 2008). The Ops Model was accepted by FERC and other state and federal agencies to adequately simulate conditions within the two hydroelectric project areas and was used to evaluate impacts to water resources as a result of potential operations and facilities modifications during the relicensing process.

The Ops Model simulates operating conditions of the two hydroelectric projects, which include a complex network of reservoirs, diversions, canals, and a combined 16 powerhouses. It is a tool that can be used to determine potential sensitivity of the system to changed constraints, including future projections of climate change, customer demand and environmental flow requirements. Unimpaired hydrology is a fundamental input to the Ops Model. The unimpaired hydrology data sets described in Section 5 were developed to be compatible with the Ops Model's physical and temporal input requirements.

4.1 Modifications to the Reservoir Operations Model

Since the end of the FERC relicensing process, several updates have been made to the Ops Model, including an extension of the period of record hydrology, extensions of the watershed simulation area to include more of the Bear River and Deer Creek basins, and 2070 projections of customer demand and climate change. Each of these changes are described below.

4.1.1 Simulation Period of Record

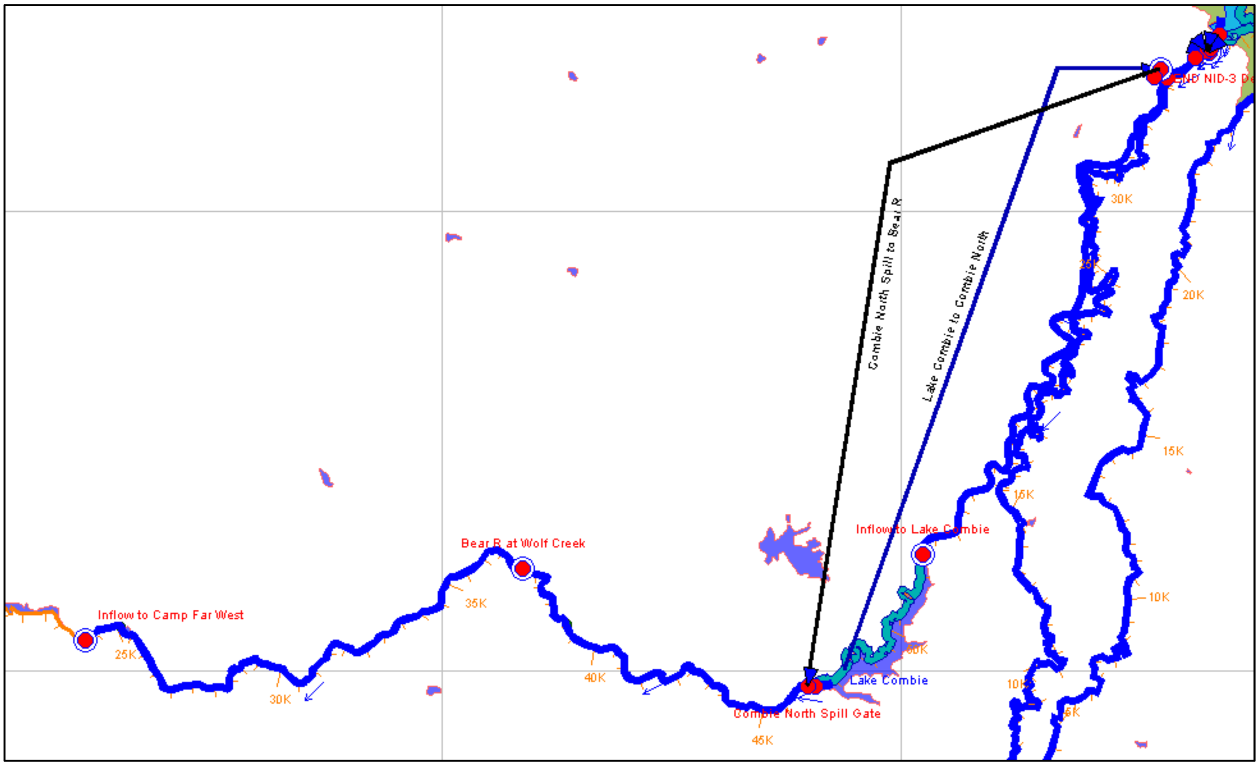
The FERC relicensing simulation period of record included water years 1976 through 2008. The simulation period of record has been extended through 2011, to coincide with the historical unimpaired hydrology period of record extension, described in Section 5.1, and the projected 2070 unimpaired hydrology period of record, described in Section 5.2. In addition to extending the inflow hydrology time series, other input time series were extended in order for the Ops Model to simulate the longer period of record. These include minimum instream flow requirements at multiple locations throughout the watershed, Smartsville Index based Water Year types (FERC 2014) that affect reservoir operations, and aggregated NID and Placer County Water Agency (PCWA) raw water demands.

4.1.2 Bear River Watershed Extension

The Ops Model developed for FERC relicensing simulated the Bear River from the headwaters down to the Bear River Canal Diversion Dam. NID also owns and operates Lake Combie, located approximately 13 river miles downstream of the Bear River Canal Diversion Dam. NID makes releases to Combie Phase I Canal from Lake Combie and maintains a minimum instream flow of 5 cfs in the Bear River below Lake Combie, per California Department of Fish and Wildlife's minimum flow requirement (Water Rights Permit Number 5803). The Ops Model was modified to include additional reaches of the

Bear River from the Bear River Canal Diversion Dam to the inflow to South Sutter Water District's Camp Far West Reservoir, located approximately 19 river miles downstream of Lake Combie (Figure 4-1).

Figure 4-1. Screen-shot of the Ops Model Bear River extension, from the Bear River Canal Diversion Dam to the inflow to Camp Far West Reservoir.



The Ops Model was originally configured to make deliveries to the Combie Phase I Canal (Ops Model demand node NID-3) without explicit simulation of Lake Combie. A representation of Lake Combie was added to the Ops Model, with a storage capacity of approximately 5,555 ac-ft at normal-maximum water-surface elevation. Historically, reservoir storage in Lake Combie is drawn down each fall to allow for collection to storage under NID's Bear River water rights.

The Bear River watershed extension was validated by comparing simulated and historical Lake Combie storage (BR-900) and Bear River flow below Lake Combie (BR-300) for water years 2001 through 2011. Figure 4-2 shows the comparison of Lake Combie storage, and Figure 4-3 shows the comparison of Bear River flow below Lake Combie. Simulated results correlate very well to observed data. The model and calibration analysis are provided in Appendix F.

Figure 4-2. Comparison of historical and simulated Lake Combie Storage, Water Years 2001 through 2011.

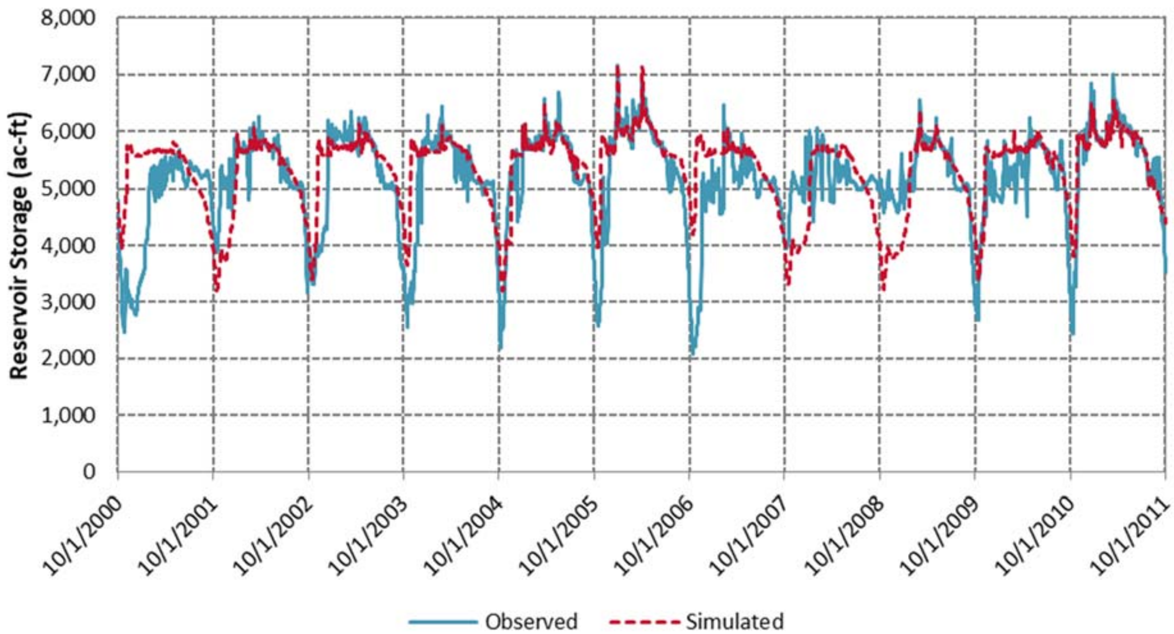
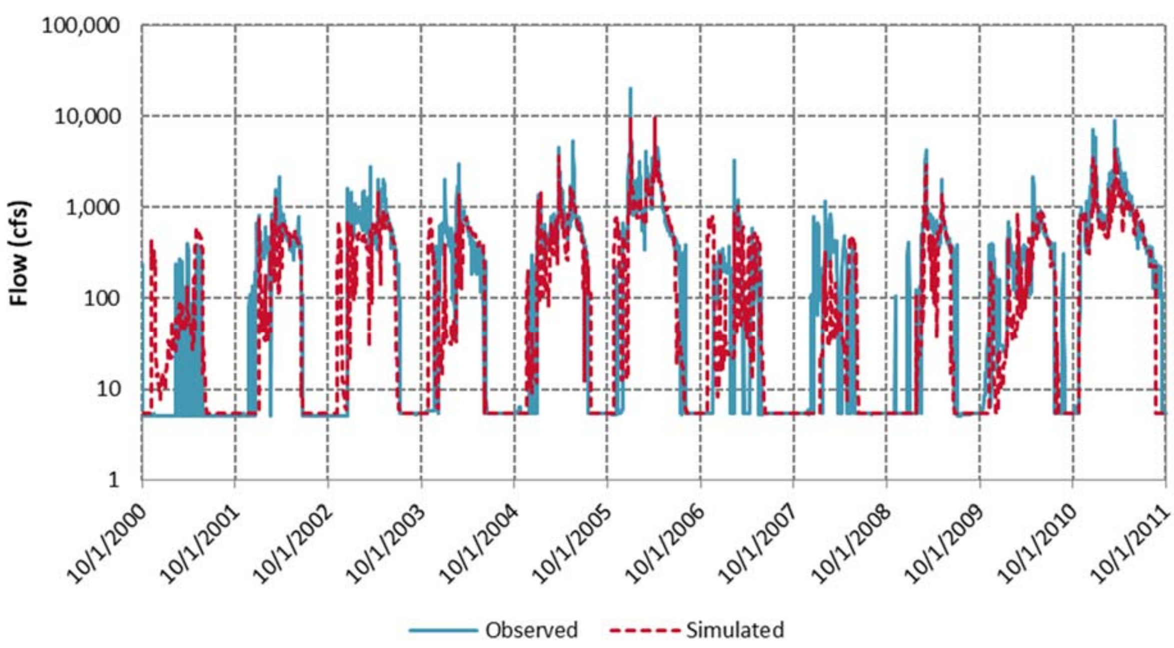


Figure 4-3. Comparison of historical and simulated flow in the Bear River below Lake Combie, Water Years 2001 through 2011.



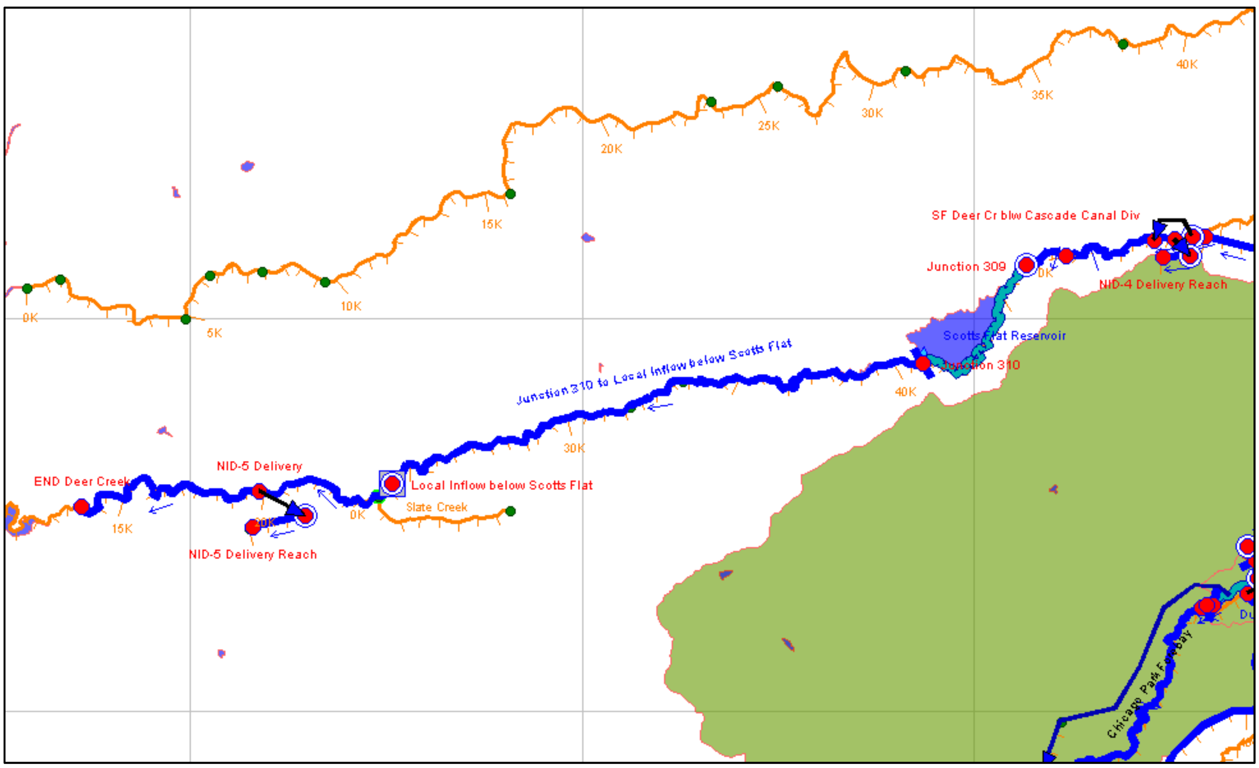
4.1.3 Deer Creek Watershed Extension

The Ops Model developed for FERC relicensing did not explicitly simulate Deer Creek. The model simulated flow through the Deer Creek Powerhouse, which was delivered to a demand node (NID-4) to assess delivery shortages to Deer Creek from NID's Mountain

Division storage via the South Yuba Canal. It did not include local inflow contribution from the Deer Creek watershed or the simulation of Scotts Flat Reservoir. NID owns and operates Scotts Flat Reservoir as a storage reservoir and diverts water from Deer Creek at multiple locations.

The Ops model was modified to simulate Scotts Flat Reservoir, diversions from Deer Creek, and a minimum instream flow below Cascade Canal Diversion (Figure 4-4). Diversions from Deer Creek are represented as two demand nodes, one representing diversions upstream of Scotts Flat Reservoir (demand node NID-4, Cascade Canal) and diversions downstream of Scotts Flat Reservoir (aggregated demand node NID-5, D-S Canal, Newtown Canal, Tunnel Canal, and Keystone Canal). Simulated inflows to Deer Creek include imported water from NID's Mountain Division storage through the South Yuba Canal, local watershed accretion, and wastewater effluent from the Nevada City wastewater treatment plant.

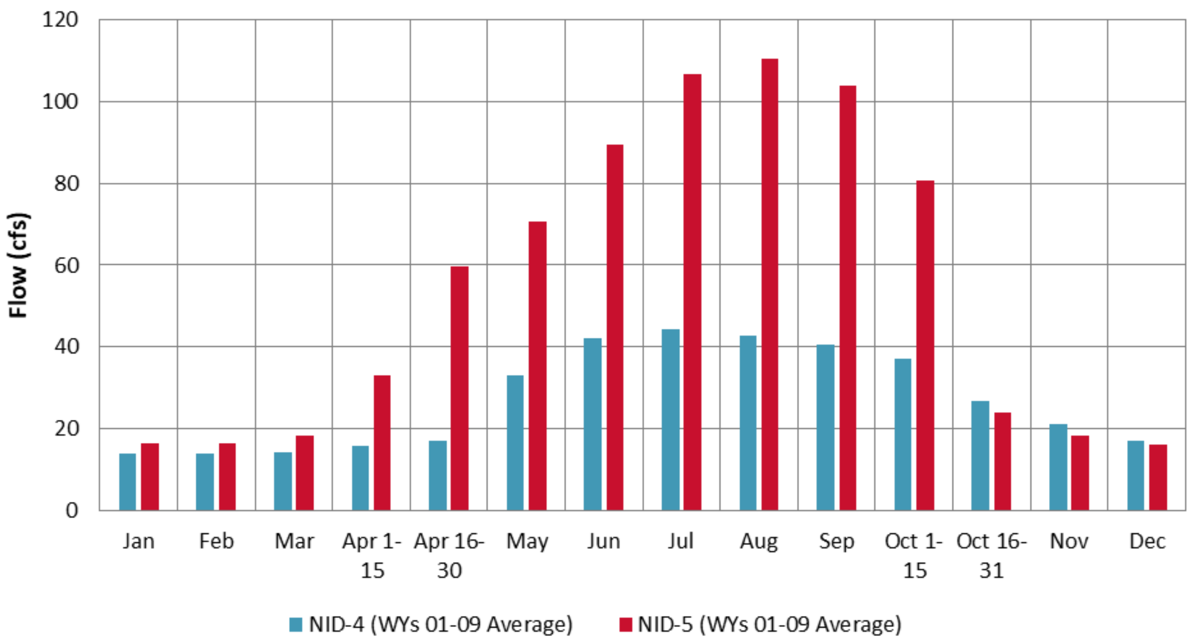
Figure 4-4. Screenshot of the Ops Model Deer Creek extension.



For FERC relicensing, existing water delivery demands in the Ops Model for NID and Placer County Water Agency (PCWA) were based on the average of historical gage data for Water Years 2001 through 2009. For consistency, the same methodology was applied here to develop the revised NID-4 and new NID-5 demand patterns, which were used to validate the model. The irrigation season typically runs from mid-April through mid-October. Therefore, April and October demand patterns were split between the first half of the month and the second half of the month. NID-4 demand pattern (Figure 4-5) is based on historical flow data at the head of the Cascade Canal (DC-102). NID-5 demand pattern (Figure 4-5) is based on the summation of historical D-S Canal, Newtown Canal, Tunnel Canal, and Keystone Canal flow data (DC-145, DC-131, DC-

140, and DC-127). These demand patterns were converted into a daily demand time series for the simulation period of record. The Ops Model removes up to this amount of flow from Deer Creek, if available, after meeting all minimum instream flow requirements. If there is inadequate supply to meet demand, it is accounted for as a delivery deficit, or an unmet demand.

Figure 4-5. Simulated Deer Creek existing water demand at Ops Model node NID-4 (above Scotts Flat Reservoir) and NID-5 (below Scotts Flat Reservoir).



The Deer Creek watershed extension was validated by comparing simulated historical Scotts Flat Reservoir storage (DC-900) and Deer Creek flow below Scotts Flat Reservoir (DC-125) for water years 2001 through 2011. Figure 4-6 shows the comparison of Scotts Flat Reservoir storage, and Figure 4-7 shows the comparison of Deer Creek flow for controlled releases below Scotts Flat Reservoir.

Figure 4-6. Comparison of historical and simulated Scotts Flat Reservoir storage, Water Years 2001 through 2011.

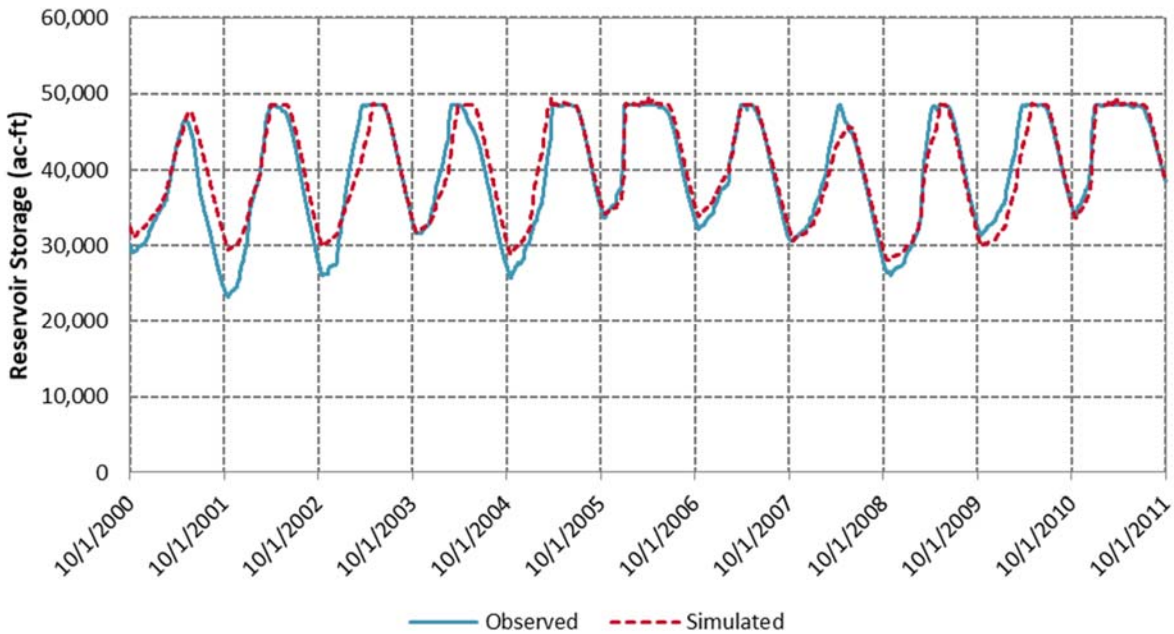
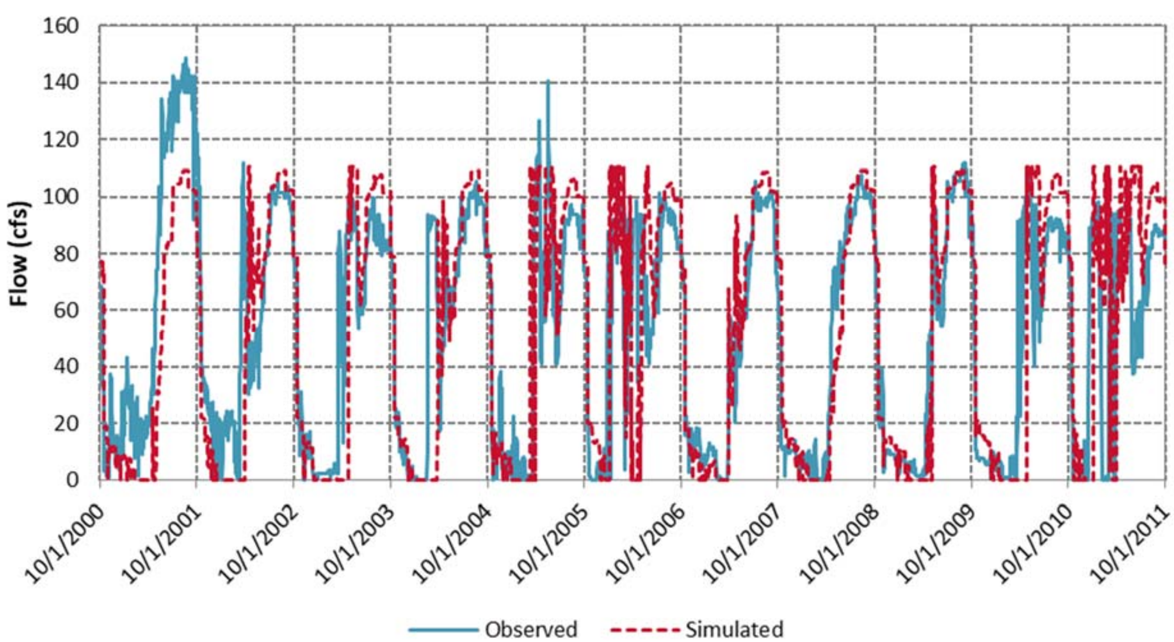


Figure 4-7. Comparison of historical and simulated controlled releases (excludes spill) in Deer Creek below Scotts Flat Reservoir, Water Years 2001 through 2011.



4.1.4 Projected 2070 Conditions

For FERC relicensing, the Ops Model was configured to simulate existing conditions and projected conditions. Projected conditions were representative of historical hydrology and projected 2062 NID and PCWA customer demand. NID's 2062 projected demand was based on extrapolation of 2032 projected demand from the RWMP Phase II update (Kleinschmidt Associates 2011). This projection included NID's soft service areas assuming historical demands. PCWA's 2062 projected demand was based on data received from PCWA. FERC projected conditions did not include hydrologic changes resulting from climate change.

For this study, the Ops Model has been updated to represent projected conditions in 50 years (2070), including climate-changed input hydrology data (described in Section 5.2), and updated projections of NID customer water demand (HDR 2020). PCWA demands were not modified, assuming that 2062 projected demands adequately represent 2070 projected demands. All projected model runs will include anticipated FERC license conditions (FERC 2014). A copy of the Ops Model is provided in Appendix F.

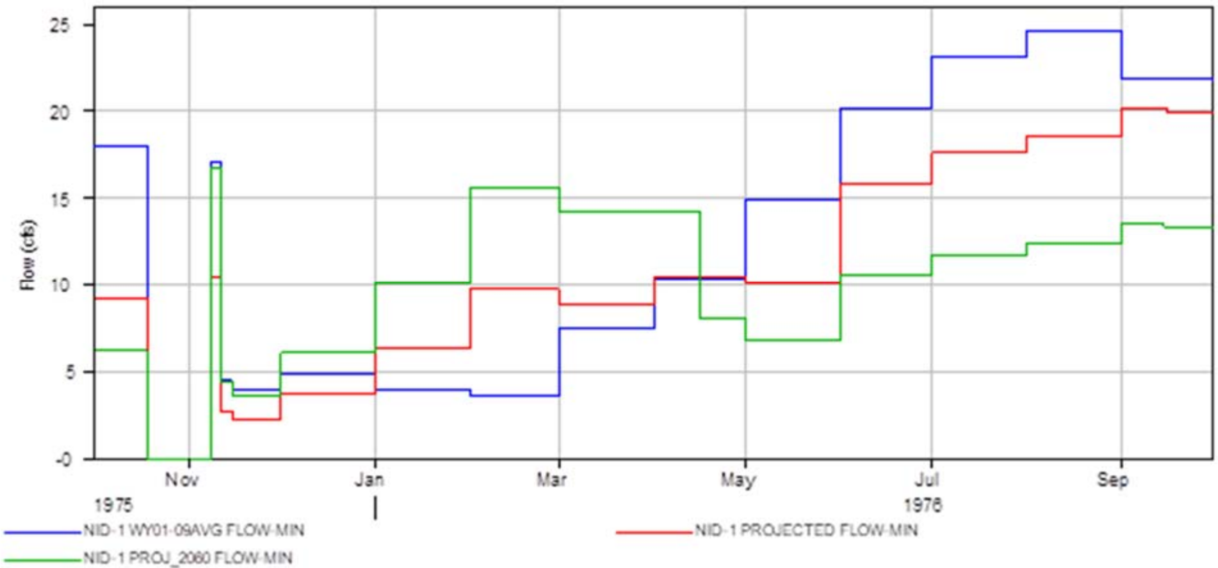
NID water demands in the Ops Model are represented by 5 delivery nodes. Table 4-1 summarizes the areas represented by each node.

Table 4-1. Summary of water delivery nodes included in the Ops Model.

Ops Model Node	Diversion Location	NID Gages Represented by Demand Node
NID-1	Rock Creek	YB64+YB86+YB108+YB255
NID-2	Auburn Ravine	YB132+YB259
NID-3	Combie Phase I Canal	BR301
NID-4	Cascade Canal	DC-102
NID-5	Deer Creek downstream of Scotts Flat Reservoir	DDC145+DC131+DC140+DC127

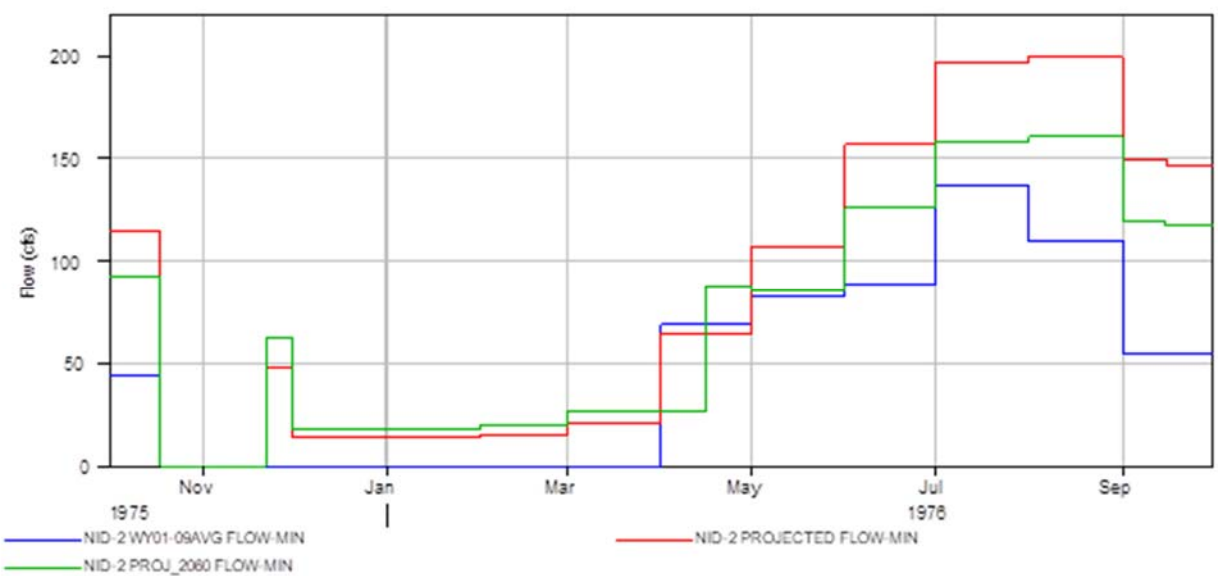
Output from the demand model (HDR 2020) was not an exact match for the NID-1 Ops Model node. Output for Fiddler Green from the 2011 RWMP and from the updated demand model were used to scale irrigation season deliveries developed for FERC relicensing for 2062. Figure 4-8 shows a comparison of NID-1 demand inputs to the Ops Model for historical 2001-2009 average demands, the old 2062 projected demands and the updated 2060 demands.

Figure 4-8. Demand time series for Ops Model node NID-1, historical 2001-2009 average (blue), old 2062 projection (red), new 2060 projection (green).



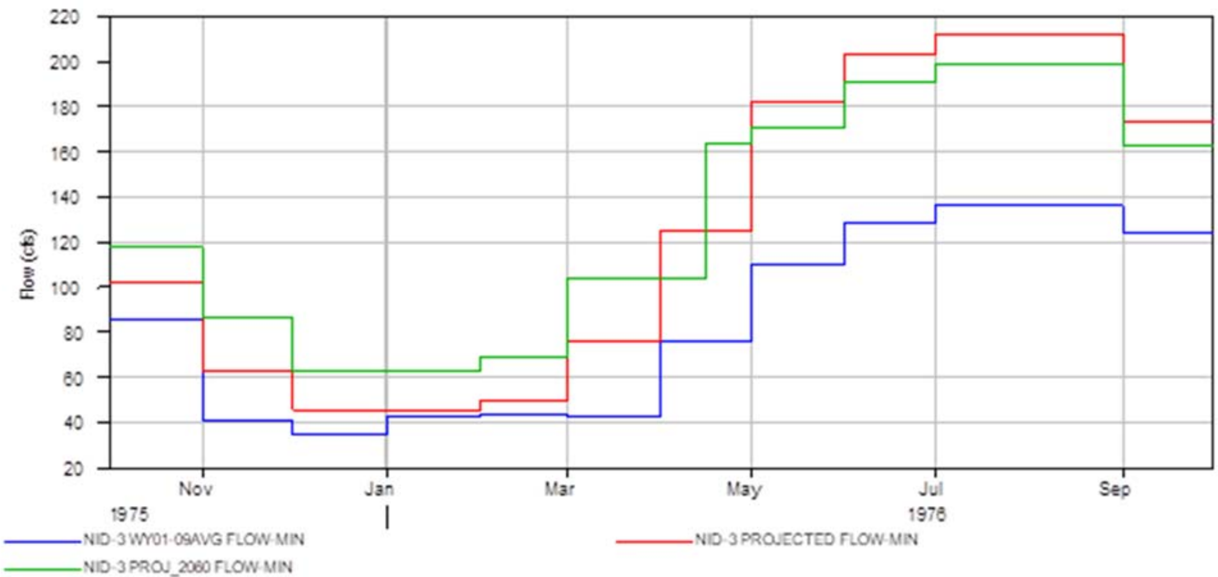
Output from the demand model (HDR 2020) was not an exact match for the NID-2 Ops Model node. Output for Auburn Ravine Natural (Wise P.H. to Hwy 65) from the 2011 RWMP and from the updated demand model were used to scale irrigation season deliveries developed for FERC relicensing for 2062. Figure 4-9 shows a comparison of NID-2 demand inputs to the Ops Model for historical 2001-2009 average demands, the old 2062 projected demands and the updated 2060 demands.

Figure 4-9. Demand time series for Ops Model node NID-2, historical 2001-2009 average (blue), old 2062 projection (red), new 2060 projection (green).



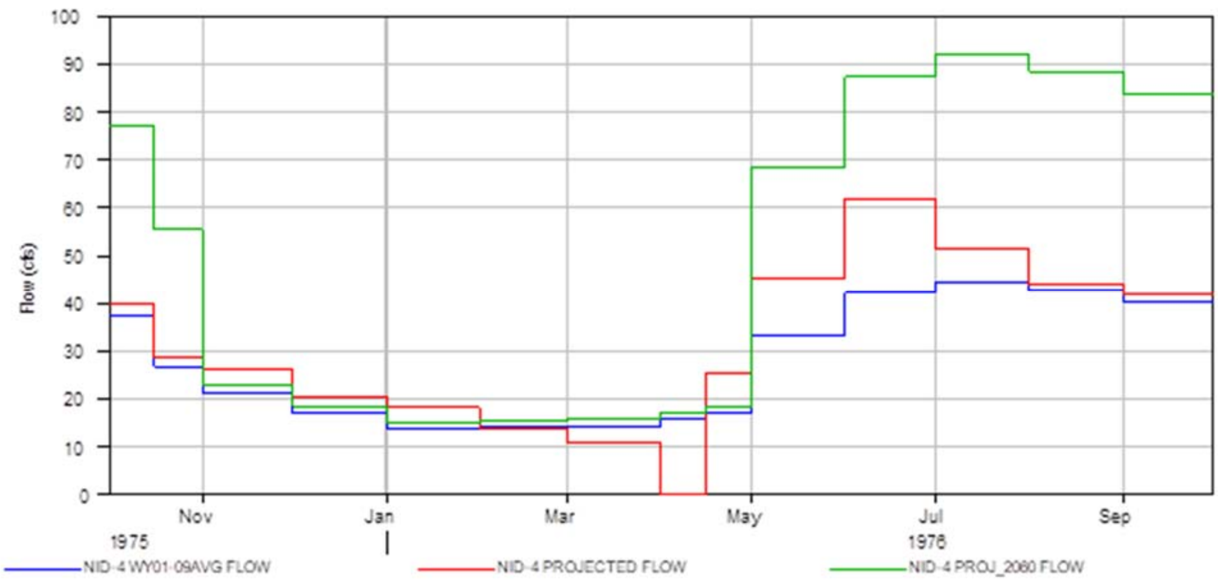
Output from the demand model (HDR 2020) is an exact match for the NID-3 Ops Model node. Output for Combie Phase I (Dam to Bear River Siphon) from the 2011 RWMP and from the updated demand model were used to scale irrigation season deliveries developed for FERC relicensing for 2062. Figure 4-10 shows a comparison of NID-3 demand inputs to the Ops Model for historical 2001-2009 average demands, the old 2062 projected demands and the updated 2060 demands.

Figure 4-10. Demand time series for Ops Model node NID-3, historical 2001-2009 average (blue), old 2062 projection (red), new 2060 projection (green).



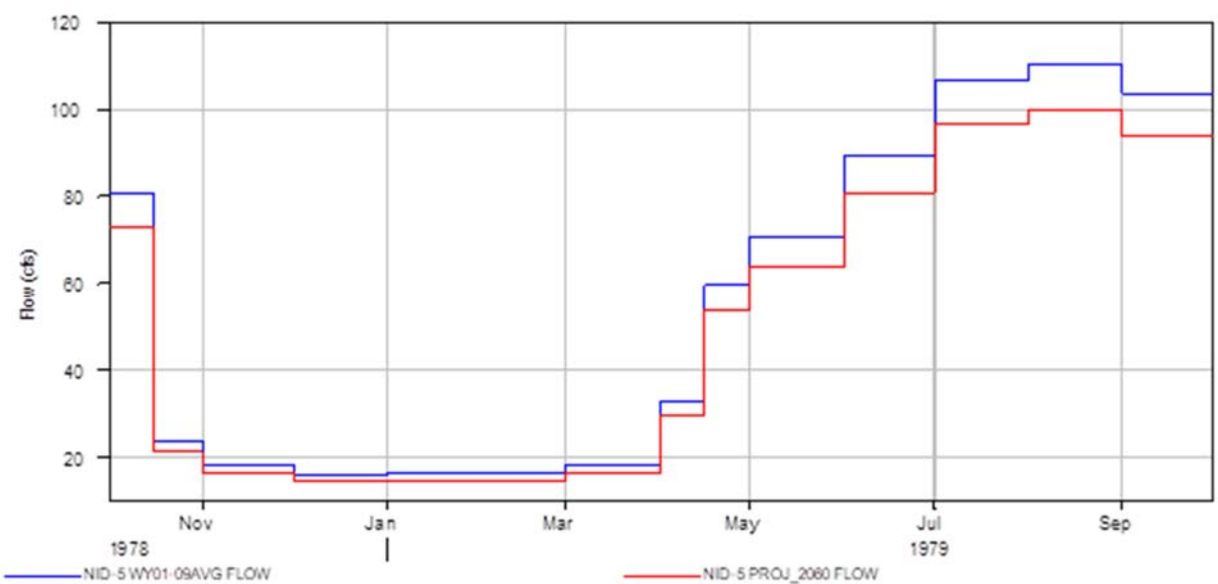
Output from the demand model (HDR 2020) is an exact match for the NID-4 Ops Model node. Historical 2001-2009 diversions were scaled to updated demand model output for Cascade System. Figure 4-11 shows a comparison of NID-4 demand inputs to the Ops Model for historical 2001-2009 average demands, the old 2062 projected demands and the updated 2060 demands.

Figure 4-11. Demand time series for Ops Model node NID-4, historical 2001-2009 average (blue), old 2062 projection (red), new 2060 projection (green).



Output from the demand model (HDR 2020) is an exact match for the NID-5 Ops Model node. Historical 2001-2009 diversions were scaled to updated demand model output for D/S (Deer Creek South Canal to D.S. Ext Pumps) plus Deer Creek Natural. Figure 4-12 shows a comparison of NID-5 demand inputs to the Ops Model for historical 2001-2009 average demands and the updated 2060 demands (NID-5 was not included in the original FERC Relicensing Ops Model).

Figure 4-12. Demand time series for Ops Model node NID-5, historical 2001-2009 average (blue) and new 2060 projection (blue).



5 Conclusion

Environmental and energy policies in California (Senate bills 100 and 350) and worldwide (Paris Agreement) aim to reduce greenhouse gas emissions. How much greenhouse gas emissions are reduced is expected to dictate to what extent climate change will affect our environment. Acknowledging this as a source of uncertainty, three projections of 2070 climate-changed hydrology data were developed representing a median greenhouse gas emissions trajectory, a pessimistic greenhouse gas emissions trajectory, and an optimistic greenhouse gas emissions trajectory.

The projected unimpaired hydrology developed for each scenario was investigated in detail for two higher-elevation and two lower-elevation watersheds. The study indicates that the effects of climate change will significantly impact the timing and volume of watershed runoff, NID's primary source of water supply, especially in NID's Mountain Division watersheds.

The prominent May peak of snowmelt runoff is no longer apparent in the projected hydrology on the Middle Yuba at Milton Diversion Dam and shifted from May to March at Bowman Dam on Canyon Creek. The rainy season runoff distribution shifts to a broader peak from December through May, with significantly lower flows than current conditions from May through July.

The lower watersheds do not exhibit as extreme a shift in the runoff temporal distribution; however, the winter months (December through March) are generally wetter under the Median and WMW projections. The three potential future scenarios investigated demonstrate the uncertainty with respect to impacts on magnitude of changes in runoff volume. The optimistic WMW scenario indicates up to 148 percent of historical runoff volume in lower watersheds and the pessimistic DEW scenario reduces runoff volumes to approximately 90 percent of historical and indicates the potential for drier dry years. The median scenario indicates a slight increase over historical runoff volumes, with wetter wet years. NID is proactively updating its RWMP to assess the possible impacts of climate change and other projected changes within its service area on its ability to maintain a sustainable water system in the future.

The hydrologic projections presented here are intended to be used by NID to assess the adequacy of existing water storage and conveyance systems to provide a reliable water supply throughout the RWMP planning horizon. Projected unimpaired hydrology will be used to assess water supply availability in a subsequent tech memo. Projected unimpaired hydrology will be used:

- To quantify watershed runoff under climate change.
- To quantify carryover storage using the Ops Model with projected demands and anticipated FERC license minimum instream flow requirements.

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Appendix A. Water Supply Network Description

Appendix B. Development of Historical Gage-Proration Unimpaired Hydrology

Appendix C. Development of Future 2070 Unimpaired Hydrology

Appendix D. Comparisons of Projected and Historical Hydrology at Select Locations

Appendix E. Unimpaired Hydrology Raw Data – Historical Gage Proration, 2070 Median, 2070 DEW, 2070 WMW

Appendix F. Reservoir Operations Model