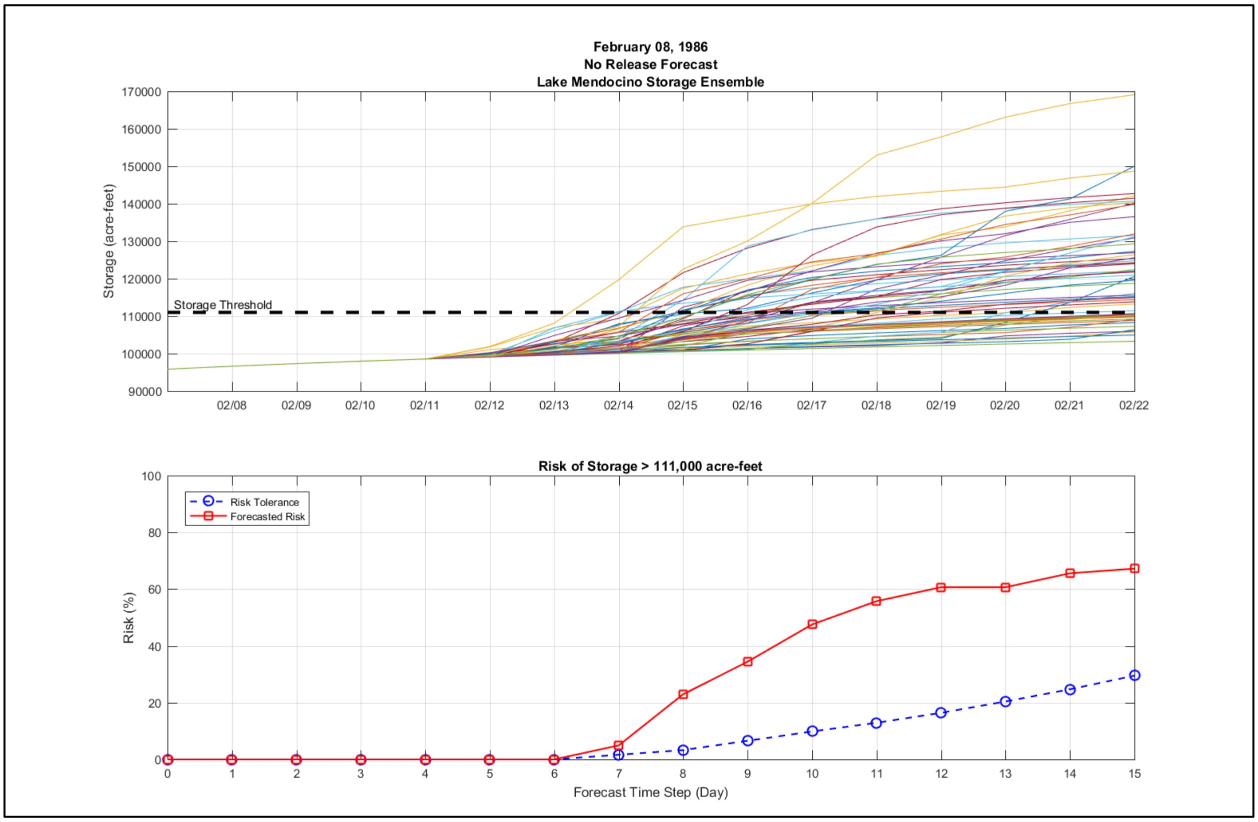
Forecast Informed Reservoir Operations
Lake Mendocino Demonstration Project
Evaluation of Ensemble Forecast Operations



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Prepared by:

Chris Delaney
John Mendoza
Sonoma County Water Agency
404 Aviation Boulevard
Santa Rosa, CA 9540

SONOMA COUNTY WATER AGENCY

Suggested Reference

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1 Introduction

1.1 Purpose and Scope

This report describes the technical analysis completed by the Sonoma County Water Agency (Water Agency) to support the Preliminary Viability Assessment (PVA) of the Forecast Informed Reservoir Operations (FIRO) demonstration project of Lake Mendocino located in Mendocino County, California. FIRO is a water management strategy that uses data from watershed monitoring programs and improved weather and hydrologic forecasting to help water managers selectively retain or release water from reservoirs in a flexible manner that more accurately reflects natural variability of meteorology and hydrology (FIRO Steering Committee, 2015).

A work plan was developed by the FIRO Steering Committee in July 2015 to develop a framework for evaluating whether FIRO is a viable strategy to improve water supply reliability while not reducing the existing flood protection capacity of Lake Mendocino. The FIRO Steering committee formed in 2014 and consists of representatives from the U.S. Army Corps of Engineers (USACE), Sonoma County Water Agency (Water Agency), SCRIPPS Institution of Oceanography (SCRIPPS), the National Oceanic and Atmospheric Administration (NOAA), U.S. Geologic Survey (USGS), U.S. Bureau of Reclamation and the California Department of Water Resources. The study described in this report supports the technical findings of the FIRO PVA.

Lake Mendocino is a dual use reservoir, which is owned and operated for flood control by the USACE and is operated by the Water Agency for water supply. Due to recent changes in the operations of an upstream hydroelectric facility, the Potter Valley Project (PVP), this reservoir has suffered from water supply reliability issues since 2007. Recent studies completed by the Water Agency have found that the water supply reliability of Lake Mendocino is expected to continue to decline with the current growth projections for the areas that rely on Lake Mendocino for their water supply and the potential changes to the regions hydrology expected with climate change. The Water Agency believes that FIRO is a potential alternative to improve the current water supply reliability of Lake Mendocino.

To complete the analysis described in this report, the Water Agency developed a numerical model to simulate Lake Mendocino storage levels, inflows, releases and flow conditions in the Russian River to approximately 65 miles downstream of Lake Mendocino to the USGS Russian River at Healdsburg stream flow gaging station (Healdsburg Gage). This model simulates the operations and constraints of both flood control operations and water supply operations. Model scenarios were developed to simulate existing operations of Lake Mendocino and three FIRO alternatives. The FIRO alternatives analyzed in this study incorporate the risk based flood control operations (Ensemble Forecast Operations) decision support system developed by the Water Agency that utilizes the 61 member ensemble flow forecasts from the NOAA California Nevada River Forecast Center (CNRFC).

Because this study focuses on operations of Lake Mendocino and conditions in the URR, the background information provided in this report will emphasize the region from the Potter Valley Project to the Dry Creek confluence with the Russian River.

1.2 Organization of Report

This report is organized as follows:

1. ***Section 2*** provides background information regarding Coyote Valley Dam and Lake Mendocino, which includes water supply operations conducted by the Water Agency and flood control operations conducted by the USACE;
2. ***Section 3*** provides and overview of Ensemble Forecast Operations developed by the Water Agency, a risk based decision support system for determining flood control releases from Lake Mendocino;
3. ***Section 4*** provides a description of the model used to evaluate FIRO alternatives considered in this study;
4. ***Section 5*** presents and describes the results of the FIRO alternatives analyzed in this study;
5. ***Section 6*** provides the findings and conclusions made by this study; and
6. ***Section 7*** provides recommendations for further study

2 Background

2.1 Russian River Watershed

The Russian River drains 1,485 square miles (mi^2) from the Coast Ranges in northern California, flowing 110 miles (mi) from its origination point near the City of Ukiah to the Pacific Ocean near the town of Jenner (USACE 2003, Florsheim and Goodwin 1995) (Figure 2-1). The watershed is 80 mi long and 32 mi across at its widest point, and lies within a narrow valley between the Mendocino Range to the west, with elevations ranging from 1,500 to 3,000 feet, Mayacamas Mountains to the east, with elevations ranging from 3,000 to 4,000 feet, and Sonoma Mountains to the south (Ritter and Brown 1971, USACE 2003). Hills and valleys make up most of the watershed (85 percent), while the remainder lies within alluvial valleys (ENTRIX 2004). The highest points are Mount Saint Helena (4,344 feet) and Cobb Mountain (4,480 feet) (Ritter and Brown 1971, Florsheim and Goodwin 1995). From its source, the Russian River flows through several physiographically distinct sections beginning with an upper section comprised of a series of northwest trending alluvial valleys separated by bedrock constrictions that form the Ukiah, Hopland and Alexander valleys. The valleys occur along fault traces within extensional valleys formed by recent tectonic activity (Florsheim and Goodwin 1995). A middle section begins near the City of Healdsburg where the river turns abruptly west through a sinuous bedrock canyon, then south through an alluvial valley confined by a bedrock constriction near the Wohler Bridge. The lower portion flows west through an alluvial valley within a canyon cutting across the Coast Ranges to the Russian River estuary and the Pacific Ocean.

Vegetation and landcover reflect climate, and past and present land use. The climate is Mediterranean with cool wet, winters and warm, dry summers (Gasith and Resh 1999), but the watershed transitions from a dry interior portion dominated by hardwood forests, oak savannah, chaparral, and grasslands, to a fog-influenced portion near the coast characterized by conifer forest (ENTRIX 2004, Opperman et al. 2005). Early (circa 1800) land uses included cattle and horse ranching, leading to conversion from forest to grassland and general narrowing of the forested riparian corridor (ENTRIX 2004). The California Gold Rush of 1849 hastened the settlement of the watershed and increased demand for wood and agricultural products. Greater need for transportation and shipping routes led to gravel and sand extraction from the Russian River and its floodplains to build railroad corridors and wider, more accommodating roads and highways. Flood control practices further altered the river through channel straightening and levee construction. Current land use is dominated by agriculture (viticulture, orchards), sheep and cattle grazing, suburban and exurban development, and urban centers (Santa Rosa [population 160,000] and Windsor/Healdsburg [population 30,000]) (Opperman et al. 2005) and is guided by general plans approved by incorporated communities and the County of Sonoma.

Several major tributaries (including the East Fork) enter the Russian River between Coyote Valley Dam and the Pacific Ocean (USACE 1982). The East Fork Russian River enters the mainstem at River Mile (RM) 99, with Robinson Creek entering just downstream of Ukiah from the east, Feliz Creek entering from the west near Hopland, and Big Sulphur draining from the east near Cloverdale. Maacama Creek joins the mainstem upstream of Healdsburg. Dry Creek drains much of the western half of the Russian River watershed and enters downstream of Healdsburg. Mark West Creek enters the Russian River from the east at Mirabel Park near Forestville and drains approximately 254 mi^2. The Laguna de Santa Rosa (170 mi^2) empties into Mark West Creek approximately 2.5 miles upstream from its confluence with the Russian River and is a natural overflow basin for the Russian River. After flowing past Mark West Creek, the Russian River turns west and flows past Austin Creek into the Russian River estuary before entering the Pacific Ocean near Jenner.

2.2 Russian River System

The Russian River System (RRS) is a water supply and flood control system that is managed cooperatively by the Water Agency and USACE in the Russian River Watershed. A map of the Russian River watershed is provided in Figure 2-1. There are two major reservoirs that regulate flows in the RRS, Lake Mendocino and Lake Sonoma. Lake Mendocino is located in the upper Russian River Watershed near Ukiah, CA and is impounded by Coyote Valley Dam (CVD), while Lake Sonoma is located lower in the Russian River Watershed west of Cloverdale, CA and is impounded by Warm Springs Dam (WSD). Both reservoirs are owned and operated for flood control by the USACE. As the local non-federal sponsor for Lake Mendocino and Lake Sonoma, the Water Agency operates both reservoirs for water supply operations when water surface elevations are within the conservation pool. The Water Agency makes releases from Lake Mendocino into the Russian River to meet minimum instream flow requirements and downstream water demands for the Upper Russian River reach (URR). The URR is a 63-mile stretch of the Russian River from the confluence of the East Fork and West Forks of the Russian to the confluence of Dry Creek. The Water Agency makes releases from Lake Sonoma, located in the lower watershed, into Dry Creek to meet minimum instream flow requirements and downstream demands for a 14-mile stretch of Dry Creek to the confluence of the Russian River, defined as the Dry Creek reach. Lake Sonoma releases are also used to meet minimum instream flow requirements and demands for the 31-mile stretch of the Russian River from the confluence of Dry Creek to the Pacific Ocean near Jenner, defined as the Lower Russian River reach (LRR). The Water Agency diverts water from the Russian River at its Wohler and Mirabel diversion facilities located near the town of Forestville.

As the non-federal local sponsor for the construction of Lake Mendocino and Lake Sonoma, the Water Agency manages the water supply pool in the two reservoirs. The Water Agency's water rights allow for the direct diversion and rediversion from storage of up to 75,000 acre-feet of water annually from the RRS. The Water Agency is a wholesale water provider to nine cities and special districts, which consist of more than 600,000 residents in portions of Sonoma and Marin counties. The Water Agency makes releases from both Lake Mendocino and Lake Sonoma and operates the RRS accordance with terms of its water rights permits, which sets the minimum instream flow requirements for the different reaches of the system. The Water Agency extracts water from the Russian River at their facilities near Forestville where they divert on average approximately 55,000 acre-feet per year.

The Russian River receives trans-basin diversions from the Eel River through the Potter Valley Project (PVP), a hydroelectric facility owned and operated by the Pacific Gas and Electric Company (PG&E). Water from the PVP is released into the Upper East Branch of the Russian

River. A portion of this water is diverted and used by the Potter Valley Irrigation District under a water supply agreement with PG&E and their own appropriative water rights license.

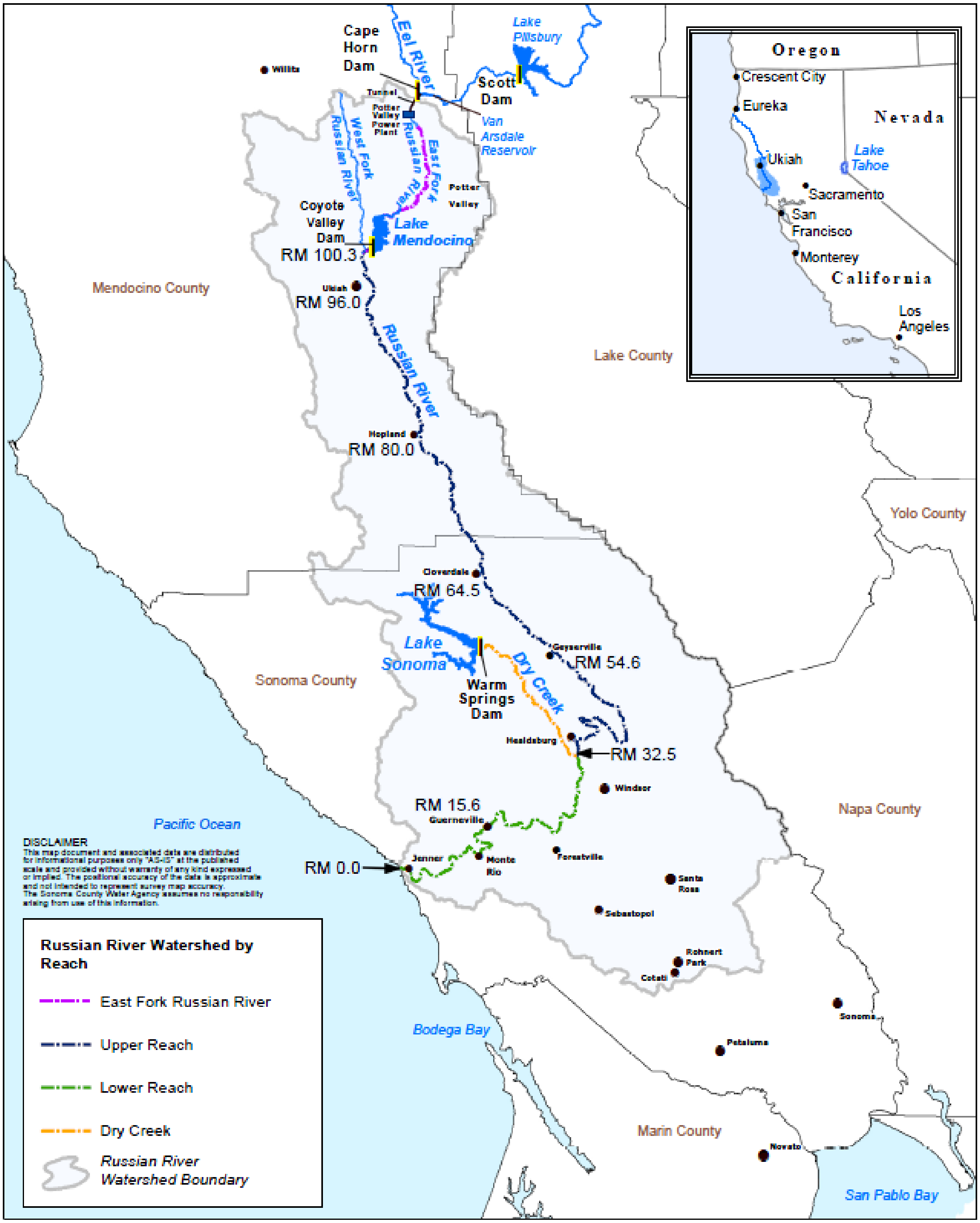


Figure 2-1. Map of the Russian River watershed including the Potter Valley Project.

2.2.1 Climate and Hydrology

Climate in the Russian River watershed is influenced by the watershed's proximity to the Pacific Ocean. As with much of the California coastal area, the year is divided into wet and dry seasons. Winters are cool, and below-freezing temperatures seldom occur, and summers are warm and dry. A significant part of the region is subject to marine influence and fog intrusion. Prevailing winds are from the west and southwest.

Approximately 93 percent of the annual precipitation normally falls during the wet season, October to May, with a large percentage of the rainfall typically occurring during three or four major winter storms. These major storms often come in the form of an Atmospheric River, which is the horizontal transport of large amounts of water vapor through the atmosphere along a narrow corridor. Although brief, Atmospheric Rivers can produce 30-50% of the regions, annual precipitation during a few days (NOAA , n.d.). Flood-producing rainfall is deposited over the basin due, primarily, to orographic action of the mountain barriers combined with frontal rainfall waves and/ or occluded frontal systems (USACE, 1954).

Climatic conditions vary across different portions of the watershed. As shown in Figure 2-2, average annual precipitation is as high as 80 inches in the mountainous coastal region of the watershed, and 20 to 30 inches in the valleys where the majority of the water users are located. Precipitation can also vary significantly from season to season, which can result in a large amount of variability in flows in the Russian River.

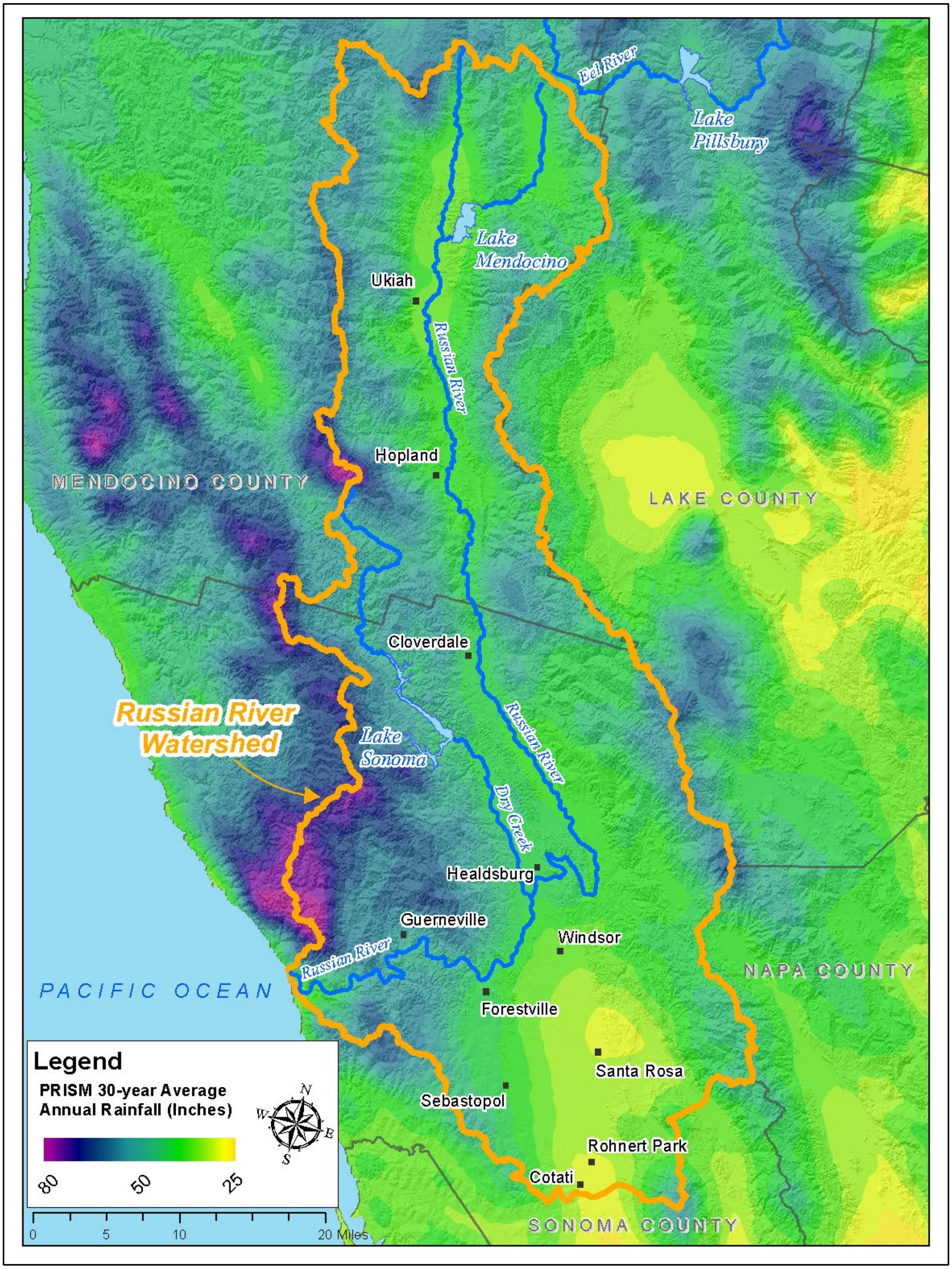


Figure 2-2. 30-year average annual rainfall for the Russian River watershed.

2.2.2 Historical Flooding in the Upper Russian River

Floods in the Russian River watershed are normally of short duration, lasting three to four days, developing within 24 to 48 hours after the beginning of a storm, but rapidly receding within 2 or 3 days (USACE, 1984). Floods occur during the rainy season from November through April and larger storms can inundate the portions of the alluvial valleys (Ukiah, Hopland, and Alexander) adjacent to the river (USACE, 2003). However, storms have occurred in October and May which have caused minor or moderate flooding. Normally floods in the basin are flashy, since the times of concentration on tributaries are short and flows respond rapidly to variations in rainfall (USACE, 1954).

The City of Hopland and surrounding areas are some of the most flood prone regions of the URR. Flood stage at the USGS Gage near Hopland (Hopland Gage) is 21 feet, which corresponds to a flow rate of approximately 15,000 cubic feet per second (cfs). Since the completion of CVD in 1959, the maximum flow rate recorded at the Hopland Gage is 33,700 cfs in December of 1964, and water levels have reached flood stage 16 times (22% of the years). Additionally minor flooding begins occurring in Hopland when stage exceeds the banks of the channel which can cause flooding and closure of the Highway 175 Bridge. According to the CNRFC this occurs at a stage of 15-feet and a flow rate of approximately 8,140 cfs (NOAA, n.d.). Since 1959 flows have exceeded 8,140 cfs 124 times for 62% of the years.

The City of Healdsburg is also prone to flood during extreme rainfall events. Flood stage at the USGS Gage near Healdsburg (Healdsburg Gage) is 53,000 cfs (NOAA, n.d.). Since 1959 the maximum flow rate recorded at the Hopland Gage is 69,300 cfs occurred in January of 1995, and water levels have reached flood stage 4 times (7% of the years).

The USACE considers the 1955 and 1964 floods the two greatest floods of record. The December 1955 flood included a small peak followed by a second larger peak that caused substantial flood damage. The 1964 flood included two smaller peaks before the main flood peak, and caused Coyote Valley Dam to spill for the first time since dam completion. The original Standard Project Flood[1] for Coyote Valley Dam was based upon the January 1943 flood, but USACE later updated this to the December 1955 flood, even though the December 1964 storm produced a higher discharge.

Regulation by Coyote Valley Dam reduced peak flows, increased the lag time between flood peaks entering and exiting Lake Mendocino, and increased the duration of high flow downstream. The median of instantaneous peak flows recorded at the Russian River at Hopland, Cloverdale, and Healdsburg gages decreased after dam closure in 1959, but since the structure only regulates 13 percent of the watershed above Healdsburg, and 7 percent of the total watershed, the decreases are minor (Table 2-1). In 1986, USACE found that the dam reduced flood peaks by 29 percent at Hopland, by 21 percent at Cloverdale, and by 11 percent at Healdsburg (USACE, 2003). The greatest decreases occur upstream, closest to the dam and lessen downstream due to greater contributing area and unregulated tributary inputs. Florsheim

[1] The Standard Project Flood is defined as one that can be expected from the most severe combination of meteorologic and hydrologic conditions characteristic of the region, excluding extremely rare combinations.

and Goodwin (1995) examined the hydrographs upstream and downstream of Coyote Valley Dam for the December 1955 (pre-dam), December 1964 (post-dam), and February 1986 (post-dam) floods. In the case of the December 1955 floods, the analysis compared hydrographs upstream and downstream of the future dam location, and found the timing, magnitude, and duration of flood peaks similar between the two sites. Paired upstream and downstream flood hydrographs for the December 1964, February 1986, and December 2005 storms showed later, lower magnitude, longer duration flood peaks downstream of the dam. Flood peaks arrived 4 to 7 days later, reduced in magnitude by approximately 50 percent below the dam, but the duration of flood flows lengthened by 3 to 4 days (Figure 2-3 shows December 2005 flood).

Table 2-1. Flood flows (cubic feet per second, cfs) on the Upper Russian River before and after Coyote Valley Dam.

Date[1]	**Russian River nr Hopland (cfs) (USGS gage no. 11462500) 1937-present 362 mi^2 drainage area**	**Russian River nr Cloverdale (cfs) (USGS gage no. 11463000) 1951-present 503 mi^2 drainage area**	**Russian River nr Healdsburg (cfs) (USGS gage no. 11464000) 1937-present 793 mi^2 drainage area**
February 1940	34,100	No record	67,000
January 1943	34,000	No record	53,330
January 1954	27,400	33,300	53,700
December 1955	45,000	53,000	65,400
February 1958	32,300	38,100	50,900
Pre dam median	**21,250**	**22,350**	**33,950**
December 1964	41,500	55,200	71,300
January 1974	39700	51,900	64,700
February 1986	35,600	40,700	71,100
January 1995	27,600	39,400	73,000
December 2005	35,600	50,700	58,900
Post-dam median	**14,550**	**18,200**	**32,050**

[1]Before Coyote Valley Dam: pre-1959; Post Coyote Valley Dam: post-1959

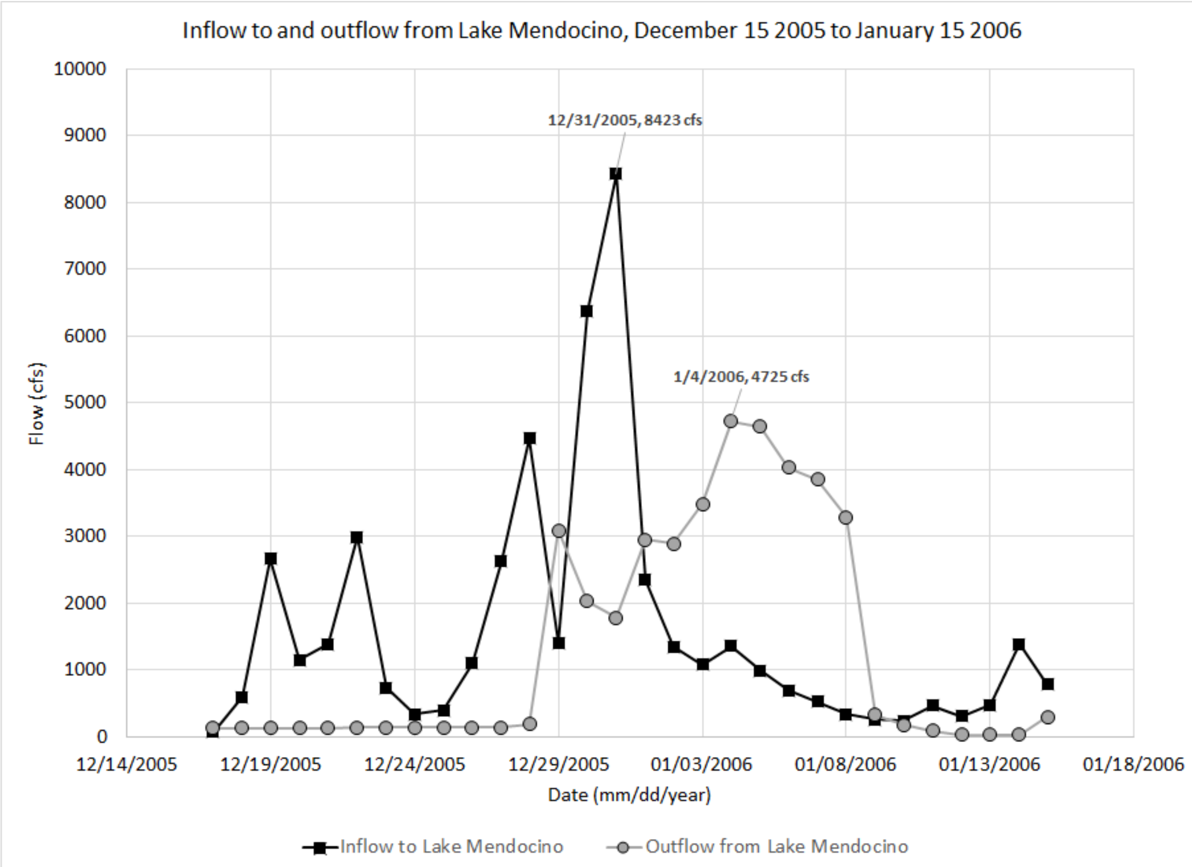


Figure 2-3. Inflow and outflow to Lake Mendocino during December 2005 storm.

2.2.3 Flow Monitoring

Under contract with the Water Agency, the USGS manages and maintains streamflow gages at 29 of locations throughout the Russian River basin. The USACE monitors flow just downstream of the controlled release outlet structures of CVD and Warm Springs Dam. Real time stage and flow data measured at these gages is used to support flood control and water supply operations of Lake Mendocino and Lake Sonoma. Analysis of data recorded from gages along the URR was used to support the development of the model described in this report. A list of USGS and USACE gages along the in the URR is provided in **Table** 2-2 which includes the abbreviated names used to refer to some of these gages throughout this report.

Table 2-2. USGS and USACE gages along the URR with abbreviations used in text and owner ID numbers.

Gage ID	Gage Name	Gage Abbreviation	Owner
11471099	Potter Valley Powerhouse	PVP Powerhouse	USGS
COY	Coyote Valley Dam Gage	Lake Mendocino	USACE
11461000	RR near Ukiah	West Fork Gage	USGS
11461500	RR near Calpella	-	USGS
11462080	RR near Talmage	Talmage Gage	USGS
11462500	RR near Hopland	Hopland Gage	USGS
11463000	RR near Cloverdale	Cloverdale Gage	USGS
11463500	RR at Geyserville	-	USGS
11463682	RR at Jimtown	-	USGS
11463980	RR at Digger Bend near Healdsburg		USGS
11464000	RR near Healdsburg	Healdsburg Gage	USGS

2.3 Potter Valley Project

PG&E's PVP was constructed in 1908 for power generation purposes. Water is collected to storage in Lake Pillsbury, a reservoir created by the Scott Dam on the Eel River. Natural flows of Eel River water and water released from Lake Pillsbury storage are diverted 12 miles downstream from Scott Dam at Cape Horn Dam and then are conveyed through a diversion tunnel and penstocks to the Potter Valley Powerhouse, which is located in the Russian River watershed. A map of the facilities of the PVP is provided in Figure 2-4. Some of the water discharged from the powerhouse is diverted into canals from which the Potter Valley Irrigation District (PVID) receives water under a water supply agreement with PG&E and its own appropriative water rights license. The PVID can divert up to 50 cfs of flows from the PVP for use by their customers. The remaining water discharged from the powerhouse not consumptively used by PVID flows down the East Fork Russian River into Lake Mendocino. The PVP has a maximum flow capacity of approximately 300 cfs and a generation capacity of 9.4 megawatts (MW). PVP diversions and operations are regulated by a license issued to PG&E by the Federal Energy Regulatory Commission (FERC) and serve multiple purposes, including power generation, Potter Valley agricultural irrigation uses, and minimum instream flow releases into the East Fork Russian River.

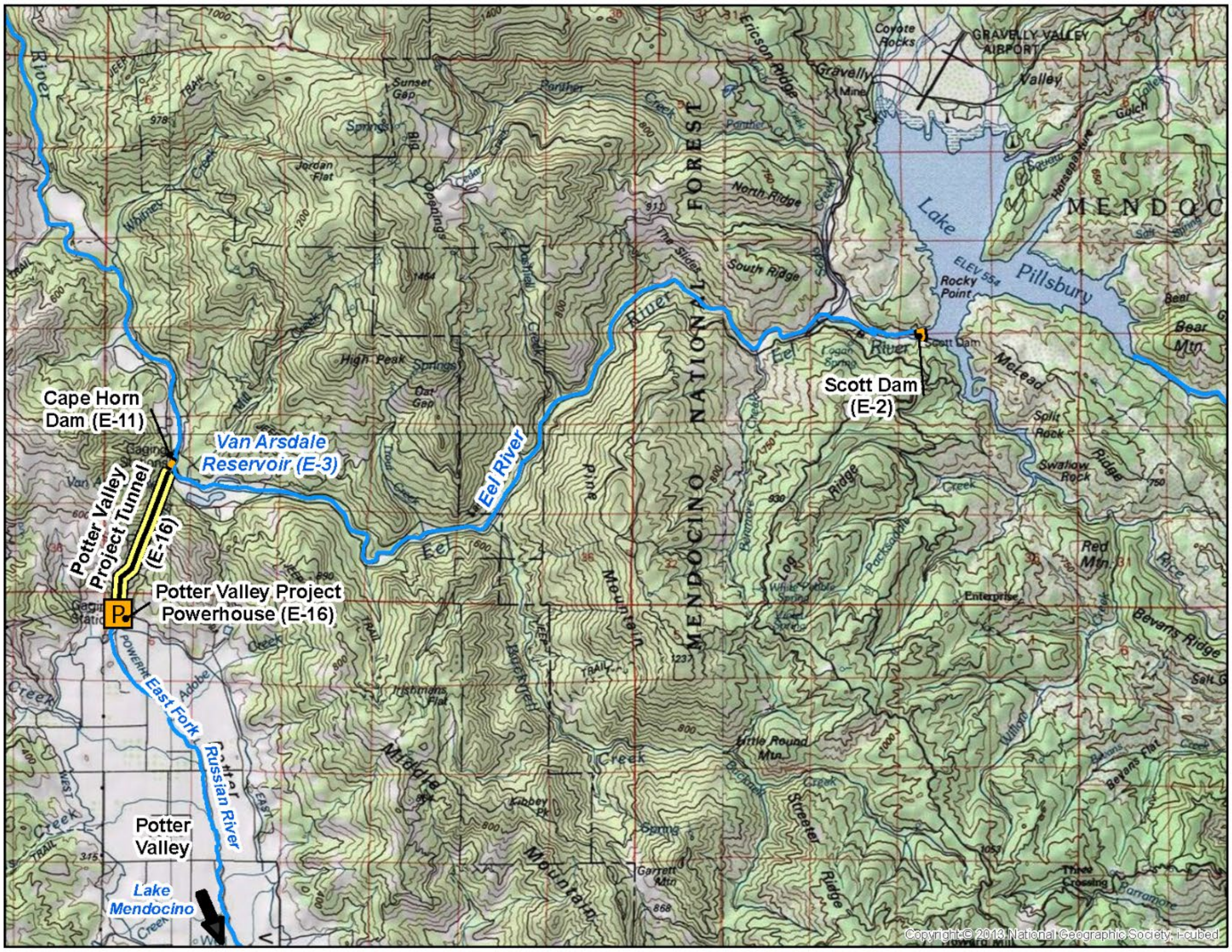


Figure 2-4. Map of the Potter Valley Project

PG&E manages releases from Lake Pillsbury to meet FERC-required minimum release requirements in the Eel River and to provide water for diversions to the PVP powerhouse. PG&E does not manage or coordinate the operation of PVP with the USACE or Water Agency's operations of Lake Mendocino. However, the historical importance of water from the PVP to Lake Mendocino water supplies is demonstrated by the fact that the SWRCB's Decision 1610, which adopted several terms now in the Water Agency's water right permits, established a hydrologic index for the Russian River and Dry Creek minimum instream flow requirements in these permits that is based on cumulative inflows into Lake Pillsbury.

In 2004, FERC amended PG&E's license to improve conditions for salmon species listed as threatened species under the federal Endangered Species Act (ESA). PG&E began operation of the PVP in accordance with its amended FERC license in 2006, and these revised operations substantially reduced the amounts of PVP diversions compared to historical levels. These reductions are illustrated in Figure 2-5, which shows historic average water year inflow into Lake Mendocino and PVP releases shown in blue for two periods: 1) Operations since the construction of CVD and prior to the implementation of the amended FERC license, 1959-2006, and 2) Operations after the implementation of the amended FERC license, 2007-2015. Figure

2-5 shows that Lake Mendocino inflows, represented by the orange bars, for the period 2007 to 2015 have declined from historic inflows, which is largely the result of reduced PVP transfers. Changes in the seasonal timings of PVP diversions have also affected Lake Mendocino water storage reliability. Reduced inflows in the spring have contributed to declining water supply reliability of Lake Mendocino through the summer months (SCWA, 2015). As a result, the Water Agency has had to file several Temporary Urgency Change Petitions (TUCPs) with the California State Water Resources Control Board (State Water Board) to temporarily reduce the minimum instream flow requirements in the Water Agency's water right permits as necessary to preserve water supply storage in Lake Mendocino for downstream beneficial uses.

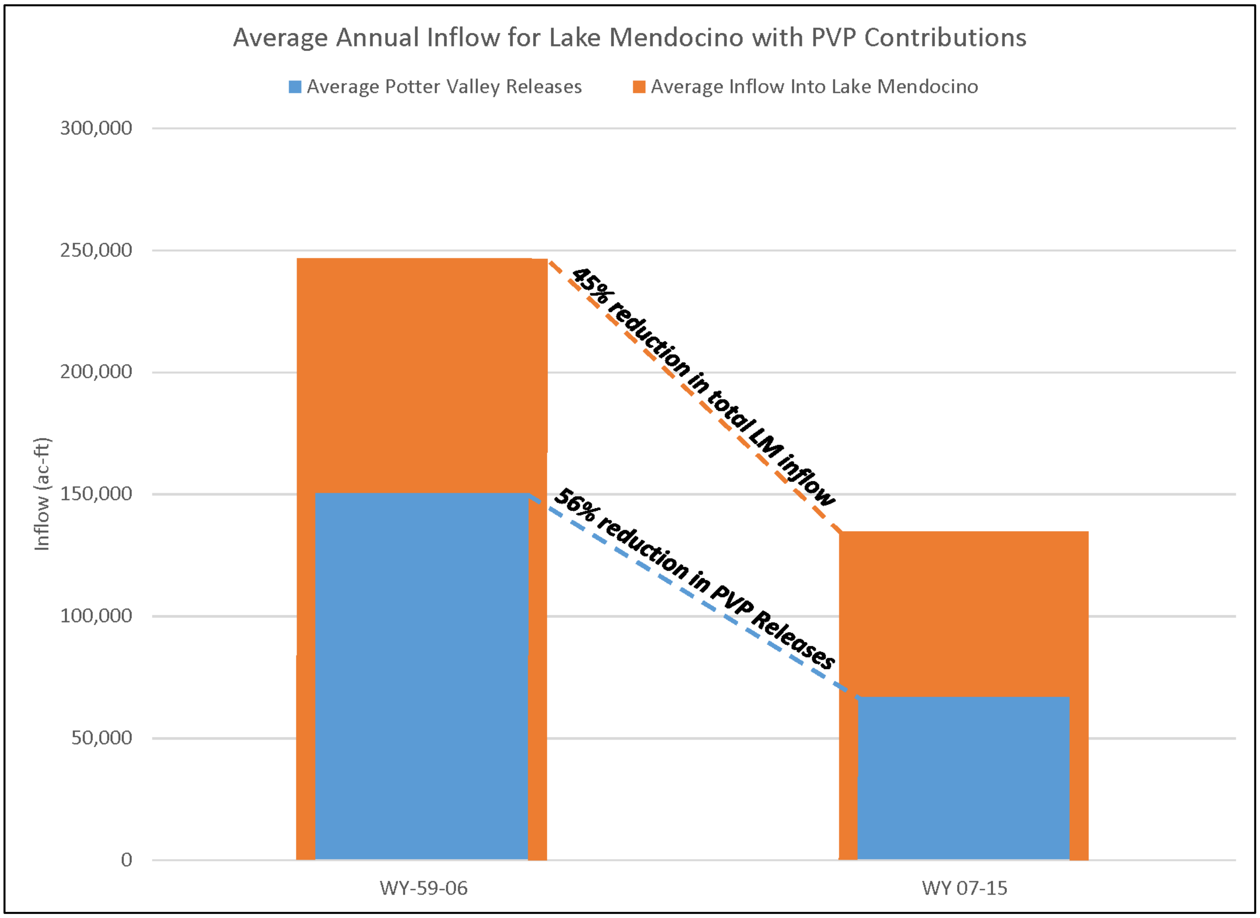


Figure 2-5. Lake Mendocino Average annual inflow for periods both prior to and after the implementation of the PVP FERC license amendment in the fall of 2006.

2.4 Lake Mendocino

Lake Mendocino is located on the East Fork Russian River, about 4 miles northeast of the City of Ukiah in Mendocino County, California (Figure 2-1). Lake Mendocino was created by the construction of the CVD Project, which was authorized by the Flood Control Act of 1950 for the purposes of flood control, water supply, irrigation, recreation and stream flow regulation. Construction was completed by the USACE in January 1959, with the Water Agency participating as the non-federal local sponsor. CVD is an earth embankment dam approximately 160 feet high with a crest length of 3,500 feet.

Lake Mendocino has a total current storage capacity of 116,500 acre-feet, which includes a water supply pool of between 68,400 acre-feet and 111,000 acre-feet, depending on the time of year. Based on reservoir bathymetric surveys (original in 1952 and most recent in 2001) the average sedimentation rate in the reservoir is estimated to be 143 acre-feet per year (AFY). The invert of the controlled outlet is at an elevation of 637 feet above mean sea level (USACE, 2003). This level in the reservoir establishes the top of the inactive pool, which, according to the 1986 Water Control Manual, was estimated to have a capacity of 135 acre-feet. Based on the historic rate of sedimentation, it is expected that the inactive pool has reached its capacity to accumulate sediment.

The outlet works of CVD consists of a single conduit approximately 720 feet long and 11 feet in diameter. There are three pairs of hydraulically operated release gates; 3 of which are service gates and three are emergency gates. Maximum release capacity of the controlled outlet is approximately 7,500 cfs when the water surface elevation is within the Emergency Release Pool (above elevation 773 feet mean sea level). There is a powerhouse at CVD containing 2 turbine/ generator units with rated power generation capacities of 2,500 and 1,000 kilowatts.

The spillway of Lake Mendocino is located in a low saddle about 0.6 miles upstream from the southern abutment of the dam. The spillway structure consists of an 800-foot long approach channel and a 200 foot wide rectangular weir. Since construction of CVD the spillway has only been activated once in December of 1964 when inflows exceeded 14,000 cfs.

The watershed of the reservoir has an area of approximately 105 square miles, which is approximately 7 percent of the total watershed area of the Russian River Basin. Average annual inflow into the reservoir since the construction of CVD is approximately 230,000 AFY, with a peak annual inflow of 443,000 acre-feet in 1983 and a minimum annual inflow of 60,000 acre-feet in 1977. Inflow into the reservoir consists of unimpaired flows from the contributing watershed area and a portion of the water diverted though the PVP from the Eel River.

2.4.1 Lake Mendocino Flood Pool Operations

The USACE determines the schedule and amount of water released from Lake Mendocino during flood control operations. Regulation for flood control and water supply operations are described in Appendix I of the CVD Water Control Manual (WCM), which was originally published by the Corps in April 1959 and revised in August 1986. Exhibit A, the water control diagram, of the WCM manual was most recently revised in September 2003 to incorporate the most recent bathymetric survey information (USACE, 2003).

Storage in the reservoir is controlled by the reservoir guide curve (Existing Guide Curve) defined in the WCM. The Existing Guide Curve sets the maximum threshold for storage of conservation water[2] in the reservoir, which varies during the year. A diagram of the reservoir pools of Lake Mendocino is provided in Figure 2-6. The volume of the conservation pool defined in the WCM is 68,400 acre-feet (elevation 737.5 feet mean sea level [msl]) from November through February. From March 1 to May 10 the defined water supply pool linearly increases to a

[2] Conservation water is water stored in the conservation pool of the reservoir. The conservation pool lies above the dead pool and below flood pool.

storage level of 111,000 acre-feet (elevation 761.8 feet msl). From October 1 to October 30 the water supply pool linearly decreases from 111,000 acre-feet to 68,400 acre-feet. The storage volume of the conservation pool is reduced at the onset of the rainy season to maximize flood space capacity and is then increased in the spring, when the likelihood of large storm events is low, to maximize storage for water supply purposes. The maximum guide curve storage elevation of 761.8 feet msl provides 3-feet of freeboard from the spillway crest (764.8 feet msl) to limit spillway overflow resulting from variations due to wind and wave action, diurnal fluctuations in PVP releases, or possible minor surface runoff (USACE, 1954).

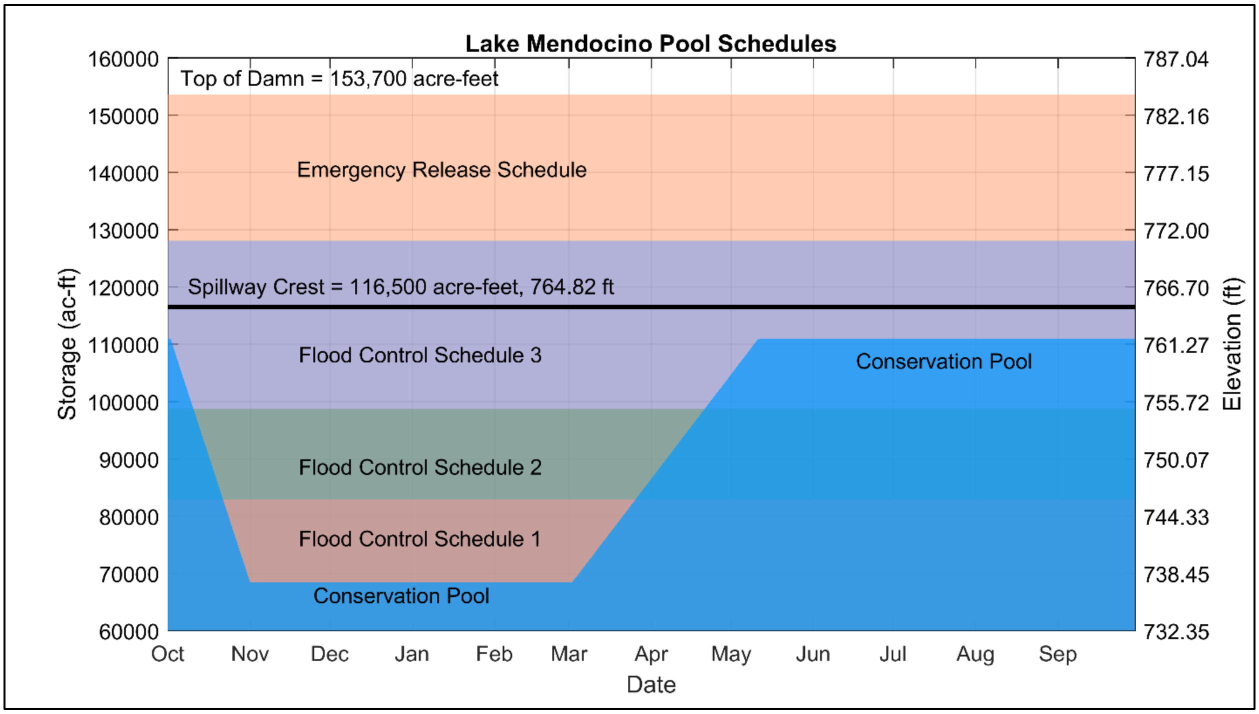


Figure 2-6. Lake Mendocino Pool Schedules defined in the 2004 Water Control Diagram.

The Existing Guide Curve displayed in Figure 2-6 and described above was implemented in the spring of 2007. Prior to 2007 the increase in the conservation pool from 68,400 acre-feet did not begin until April 1 and reached a maximum level of conservation storage of 86,400 acre-feet (elevation 748 feet msl) on April 20. Prior to 2009 the increase in the conservation pool could start on March 1, but the Water Agency had to make a written request to the USACE annually.

The flood control pool is defined by the storage levels above the conservation pool and below the emergency pool. Under typical flood operations, water is temporarily detained in the flood control pool until the threat of flooding downstream has diminished. After the threat of downstream flooding is determined to be gone, water is released from the reservoir to bring storage levels back down to the top of the conservation pool.

Flood releases during flood control operations are guided by 3 release schedules (*Flood Control Schedule 1, 2 and 3*) defined in the WCM and illustrated in Figure 2-6. These flood control schedules define maximum flood control release constraints for different reservoir storage levels.

Flood control releases from Lake Mendocino are also guided by downstream maximum flow criteria defined in the WCM. When flow at the USGS Russian River near Ukiah Gage (West Fork Gage) exceeds 2,500 cfs and is rising, Russian River flows at the USGS Russian River near Hopland Gage (Hopland Gage) are monitored hourly to assess for any needed release reductions. The WCM further requires that controlled flood releases cannot contribute to flows greater than 8,000 cfs at the Hopland Gage. When flows at the Hopland Gage exceed 8,000 cfs due to unimpaired flows downstream of CVD, reservoir releases cannot exceed the minimum release requirement of 25 cfs (USACE, 2003). The flow rate of 8,000 cfs at the Hopland Gage is approximately is level of flow above which the Highway 175 Bridge becomes inaccessible due to flooding as discussed in Section 2.2.2. USACE operators typically apply a 20% buffer or factor of safety to the 8,000 cfs flow limit when Hopland Gage flows are rising (Bond, 2016).

The WCM also defines an emergency release schedule that provides guidance for releases made through the emergency gates of CVD when reservoir water levels are within the emergency pool (128,100 to 153,700 acre-feet storage level). Since construction of the CVD was completed in 1959 an emergency release has never been made.

2.4.2 Deviation to Flood Control Operations

Due to ongoing drought conditions the USACE approved a deviation from the normal water control plan in February 2015 to store up to an additional 5,825 acre-feet, or 5% of total storage at Lake Mendocino. Due to drought conditions storage levels never exceeded the conservation pool in 2015, so the deviation was never exercised for this year. A deviation was again requested by the Mendocino County Russian River Flood Control and Water Conservation Improvement District (RRFC) for the winter of 2015/2016 and resulted in the USACE temporarily retaining inflow into Lake Mendocino for a series of storms in February 2016 above the conservation pool. The additional water stored under this deviation has provided a water supply benefit to the Water Agency and water users in the URR for the remainder of the 2016 water year.

2.4.3 Lake Mendocino Water Supply Operations

The Water Agency is the local, non-federal sponsor for Lake Mendocino and has an agreement with the USACE dating back to 1959 to store and release water from Lake Mendocino to maintain minimum instream flows downstream of CVD and provide flows for reasonable and beneficial uses and purposes. This contract will continue in full force and effect for the life of the project. As the local sponsor, the Water Agency makes water supply releases as necessary to comply with its water rights permits and diversions made by downstream users when Lake Mendocino storage levels are within the conservation pool as shown in Figure 2-6.

Figure 2-7 provides summary of the minimum instream flow requirements that must be met when the Water Agency is controlling releases from Lake Mendocino. Under existing operations the minimum instream flows required by the Water Agency's water right permits are observed from October 16 to April 30. From May 1 to October 15 the Water Agency operates to reduce minimum instream flows specified in a Biological Opinion issued by NMFS in 2008. The Water Agency's water rights permits define a hydrologic index based on cumulative inflow into

Lake Pillsbury beginning on October 1st (beginning of the water year). Thresholds of cumulative Lake Pillsbury inflow are defined for the first of the month from January 1 to June 1 to determine the hydrologic condition. A summary of these thresholds is included in Figure 2-7. There are three hydrologic conditions defined by the Water Agency's water rights permits: "*Normal*," "*Dry*," and "*Critical*". Each of these conditions is used to determine a corresponding schedule of flows for the URR. Compliance with the minimum instream flow requirements is determined from observed flows at the USGS gaging stations that provide real-time information for eight locations along the URR.

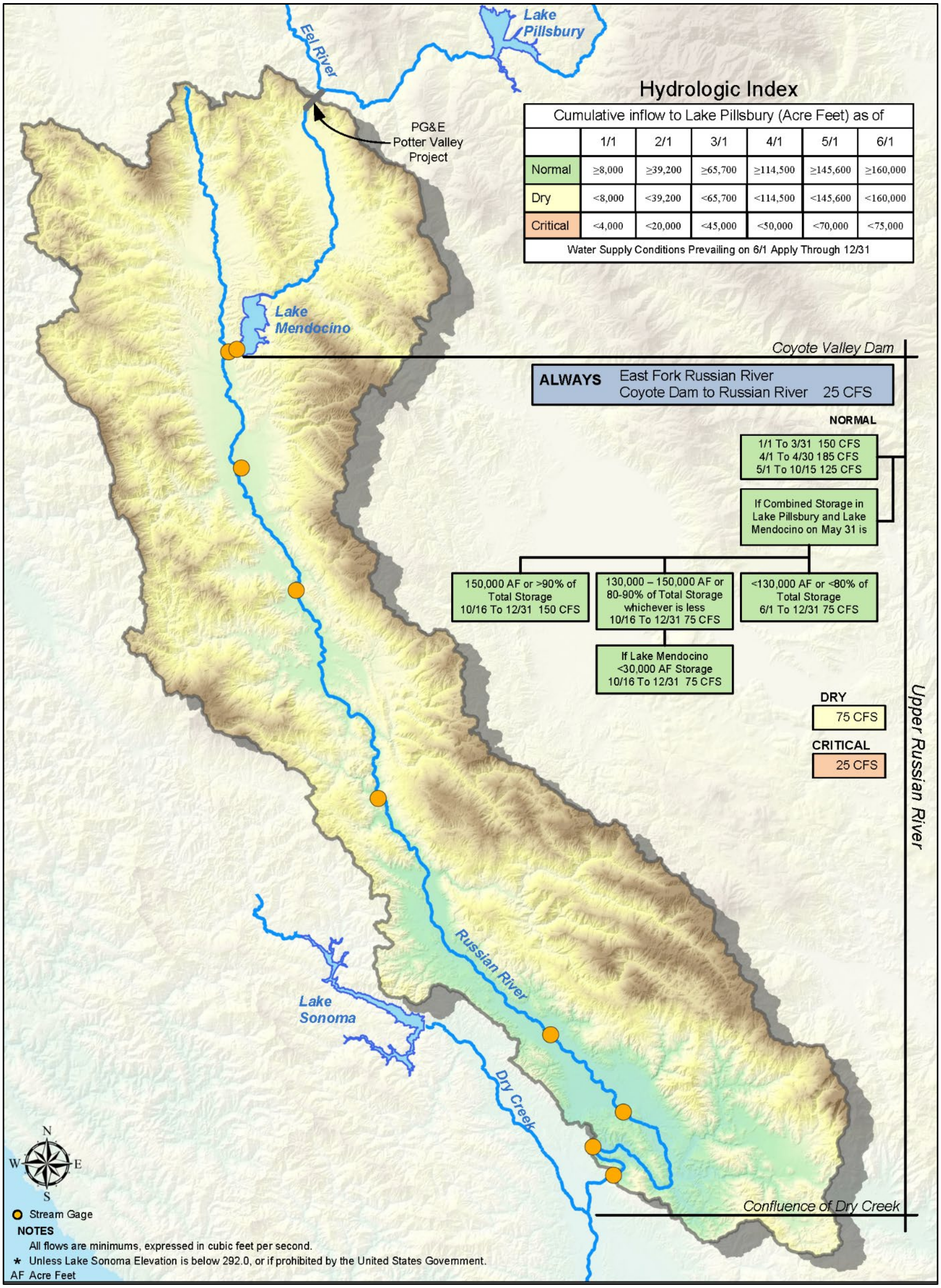


Figure 2-7. Russian River System Hydrologic Index and minimum instream flow requirements for the URR.

The Water Agency's water rights permits require a minimum flow of 25 cfs in the East Fork of the Russian River from CVD to the confluence with the West Fork of the Russian River under all water supply conditions. From this point to the confluence of Dry Creek, under existing operations (requirements of the Water Agency's water rights permits and the 2008 Biological Opinion) required minimum Russian River flows are 185 cfs for April, 125 cfs from May 1 through October 15 and 150 cfs from October 16 through March during *Normal* water supply conditions, 75 cfs year-round during *Dry* conditions and 25 cfs year-round during *Critical* conditions. The Water Agency's water rights permits further define two variations of the *Normal* water supply condition, commonly known as *Normal Dry Spring 1* and *Normal Dry Spring 2*. These conditions provide for lower required minimum flows in the URR during times when the combined storage in Lake Pillsbury and Lake Mendocino on May 31 is unusually low. *Normal Dry Spring 1* conditions exist if the combined storage in Lake Pillsbury and Lake Mendocino is less than 150,000 acre-feet on May 31. Under *Normal Dry Spring 1* conditions, the required minimum flow in the URR between the confluence of the East Fork and West Fork and Healdsburg is 125 cfs from June 1 October 15 and 150 cfs from October 16 to December 31. These minimum instream flows will be further reduced to 75 cfs during October through December if Lake Mendocino storage is less than 30,000 acre-feet during those months. *Normal Dry Spring 2* conditions exist if the combined storage in Lake Pillsbury and Lake Mendocino is less than 130,000 acre-feet on May 31. Under *Normal Dry Spring 2* conditions, the required minimum flows in the URR are 75 cfs from June through December.

The Water Agency makes releases from Lake Mendocino to maintain minimum instream flow requirements on the URR, meet demands of downstream water users and losses from evapotranspiration and surface water/groundwater interaction. Releases from Lake Mendocino made to satisfy the minimum instream flow requirements in the URR continue past the lowest instream compliance point on the upper river at the Healdsburg Gage and contribute to the total flow in the LRR downstream of Dry Creek. This URR flow contribution can sometimes be a significant portion of the total flow in the lower river reaches. Water supply releases from Lake Sonoma are made to meet the minimum instream flow requirements and water demands in Dry Creek and the LRR, which includes the Water Agency's diversions at the Wohler and Mirabel facilities.

Water Agency operational decisions for Lake Mendocino are based on preserving water in the reservoir's water supply pool to the extent possible while complying with the applicable minimum instream flow requirements and downstream demands. During times of sufficient rainfall and natural flows to meet minimum instream flow requirements at downstream gages (compliance points), the Water Agency limits releases from the conservation pool to the amounts needed to meet minimum release requirements.

During periods of insufficient unimpaired flow, the Water Agency must make releases to ensure that the required minimum instream flows are maintained at compliance points all along the URR. In the spring and early summer when there is typically contributing tributary flow, the Water Agency makes reservoir releases to meet minimum instream flow requirements at the closest compliance point downstream, which is the confluence of the East Fork and the West Fork of the Russian River (the Forks). As natural flows recede during the dry season, the compliance point for releases to maintain the minimum instream flow requirements transitions from upstream compliance points to points further downstream. For Lake Mendocino the farthest downstream compliance point is the Healdsburg Gage.

The Water Agency receives little information from other users of Russian River water such as other public water systems and agricultural diverters to help determine the necessary releases from Lake Mendocino to meet minimum instream flow requirements. Instead, the Water Agency makes release decisions based on frequent observation of data from USGS gaging stations on the URR, as well as reservoir operator's understandings of how reach losses change both with forecasted weather conditions and seasonality.

2.4.3.1 Public Water Systems

The Water Agency's Wohler and Mirabel water diversion facilities are located in the LRR approximately 8 miles downstream of the confluence to Dry Creek. The Water Agency does not typically operate Lake Mendocino to meet demands from its facilities, although flow from the URR does contribute to the balance of water to meet the minimum instream flow requirements in the LRR. Fluctuations in Water Agency water demands are typically met through adjustments to releases from Lake Sonoma.

The Water Agency does not have diversion facilities that directly divert water from the URR, although there are 22 public water systems which divert water along the URR or from Lake Mendocino. A list of the public water systems is provided in Table 2-3.

Table 2-3. Public Water Municipalities along the Upper reaches of the Russian River.

Upper Russian River Public Water Systems
Alexander Valley Acres Water Company
Bucher Water Company
Calpella County Water District
City of Cloverdale
City of Healdsburg
City of Ukiah
Geyserville Water Works (PUC)
Gill Creek Mutual Water Company
Hopland Public Utility District
Millview County Water District
Palomino Lakes Mutual Water Co.
Redwood Valley County Water District
Rio Lindo Adventist Academy
River Estates Mutual Water Company
Rogina Water Company Inc.
Russian river Flood Control
Russian River MWC
Six Acres Water Company
Sonoma County CSA-41 Fitch Mountain
South Cloverdale Water Company
West Water Company (PUC)
Willow County Water District

2.4.3.2 Agricultural Diversions for Irrigation

The Russian River Watershed is a well-known wine-growing region and has 122,000 acres of agricultural lands, the majority of which are vineyards. Water supplies from both direct diversions of surface water and off-stream wells are made for purposes of irrigation, frost protection and heat suppression throughout the URR. During the dry season, typically from July through October, the cumulative impact of agricultural diversions made along the URR, cause observed URR flows to decline from the release point at CVD to the Healdsburg Gage. Limited agricultural diversion data on daily and monthly time steps are available to help inform Lake Mendocino operations or planning studies for this region.

2.4.3.3 Other System Losses

Other sources of surface water loss in the system include lake evaporation, evapotranspiration from riparian vegetation adjacent to the river and loss to the adjacent aquifer through surface-groundwater interactions. These additional losses are likely from natural processes or the cumulative impact of water being pumped from groundwater wells or diverted from tributaries at varying distances from the river.

2.4.3.4 Minimum Instream Flow Compliance Buffer

Minimum instream flow compliance buffers are additional water that is released from a reservoir to account for the dynamic variability of flows rates in the system and help ensure that flows do not dip below the downstream minimum instream flow requirements. The variability of downstream flows can be attributed to a number of factors including surface water losses due to consumptive use and natural causes as well potential error in discharge measurements made at flow gaging stations. Flow travel times during the dry season can be several days to some compliance points downstream of Lake Mendocino and predicting the variability in flows can be challenging for operators. Therefore, extra releases are typically made (between 9 and 20 cfs) as buffers above minimum flows to ensure compliance with the instream flow requirements.

Compliance to minimum instream flows under the Water Agency's water right permits is evaluated against instantaneous flow data collected at the USGS flow gaging stations on an hourly basis. Beginning in 2010 as part of the Water Agency's petition to the State Water Board to reduce the minimum instream flows consistent with the requirements of the Biological Opinion, the Water Agency requested a 5-day moving average compliance to minimum instream flows with an instantaneous flow compliance floor. The State Water Board approved this request and has approved 5-day moving average compliance requested in petitions in subsequent years. The 5-day moving average compliance to minimum instream flows provides flexibility to reservoir operators because using the 5-day moving average as a compliance target helps to reduce some of the dynamic variability of the instantaneous flow measurements, and allows operators to reduce buffer releases to ensure minimum instream flow compliance.

2.4.4 Water Supply Challenges of a Multi-Purpose Reservoir

Multi-purpose reservoirs such as Lake Mendocino which provide both water supply and flood protection to downstream stakeholders can pose challenges in meeting both needs. For maximum flood control protection, ideally the reservoir is kept as empty as possible. For maximum water supply benefit, ideally the reservoir is kept as full as possible. The existing reservoir guide curve is designed to strike this balance to adequately satisfy both reservoir purposes.

Water supply capture in Lake Mendocino is sensitive to yearly timing or yearly distribution of rainfall due to the variable water conservation pool of Lake Mendocino that limits the amount of winter water that can be stored for later use for water supply. The Existing Guide Curve sets the maximum storage level of conservation water to 68,400 acre-feet from November through February. Given this constraint Lake Mendocino must receive rainfall after March 1, when the Existing Guide Curve conservation capacity begins increasing by approximately 600 acre-feet per day, in order to maintain *Normal* Water Supply Condition minimum instream flow requirements and downstream demands for the remainder of the water year. For example, in November and December 2012 the basin received significant rainfall that resulted in Lake Mendocino filling well above the water conservation pool. However, much of the inflow into Lake Mendocino was subsequently released for flood operations to maintain the flood control pool. In 2013 the basin received very little precipitation after January, resulting in a limited water supply for the URR for the remainder of the year. Additionally due to the high amounts of precipitation in December 2012, the hydrologic condition was determined to be *Normal* based on cumulative inflow into Lake Pillsbury. Due to low storage levels the reservoir could not sustain releases to meet the *Normal* schedule minimum instream flow requirements; therefore the Water Agency was forced to pursue emergency changes through the State Water Board in May of 2013 to reduce the minimum instream flow requirement to 75 cfs for the URR.

2.4.5 Lake Mendocino Water Supply Reliability Evaluation Report

In April 2015 the Water Agency completed the *Lake Mendocino Water Supply Reliability Evaluation Report* (Reliability Study) (SCWA, 2015), which was completed to fulfill a requirement of a May 1, 2013 Order issued by the State Water Board (SWRCB, 2013). The Reliability Study evaluates the long-term reliability of Lake Mendocino to meet water supply and environmental water demands.

To complete the Reliability Study, the Water Agency developed a model of the URR from the Potter Valley Project down to the Healdsburg Gage. The model was developed to evaluate conditions for both historical hydrology (1911-2013) and future climate change hydrology (2000-2099). Model scenarios were developed to evaluate reservoir reliability for both current demand conditions and projected (2045) demand conditions. To aid in the development of the system demand datasets for the model, the Water Agency worked closely with water users in the URR and held several meetings to discuss data availability for the study.

Eight model scenarios were evaluated with the Reliability Study Model. Each scenario represents a unique combination of assumptions and input datasets. Model scenarios were formulated to evaluate system reliability under: current conditions, current system demand with no diversions from the PVP, future (2045) demand with historical hydrology, and future (2045) demand with potential changes to hydrology due to climate change.

In summary, the analysis presented in Reliability Study indicates that Lake Mendocino’s water supply reliability has decreased in recent years, especially since the PVP operations were changed after 2006. Future growth projections for the areas that rely on Lake Mendocino for their water supply indicate modest growth through 2045. Even with only modest growth, Lake Mendocino’s water supply reliability is expected to continue to further decline, both under scenarios that assume historical climate conditions, and also under scenarios that assume potential changes to climate with climate change. A scenario evaluating the effect of no PVP diversions (with current demand conditions and historic climate conditions) shows that under that scenario, Lake Mendocino would go dry for some period during a majority of years (over 60 percent). If Lake Mendocino were to go dry with this frequency, there would be severe impacts to downstream water users, ecosystems, and groundwater aquifers. Among other regional projects, the Reliability Study identified FIRO as an important project to address both current and projected water supply reliability issues with Lake Mendocino.

2.5 Russian River Biological Opinion

Three species of salmon in the Russian River are listed as threatened or endangered under the ESA of 1973, as amended: Central California Coast (CCC) coho salmon, CCC steelhead, and California Coastal (CC) Chinook salmon. In 2008 NMFS issued a Biological Opinion for Water Supply, Flood Control Operations, and Channel Maintenance conducted by the USACE, the Water Agency, and the RRFC (NMFS, 2008). NMFS found that the continued operations of Warm Springs and Coyote Valley dams, together with proposed Dry Creek channel maintenance activities, and estuary management are likely to jeopardize the continued existence of threatened CCC steelhead and endangered CCC coho salmon and adversely modify their critical habitats.

The Biological Opinion includes a Reasonable and Prudent Alternative (RPA) to the operations evaluated in the Biological Opinion that, when implemented, would avoid the likelihood of jeopardizing steelhead and coho salmon populations and adversely modifying critical habitat. Implementation of the RPA allows NMFS to provide incidental take coverage to the USACE and the Water Agency for the operations described in the Biological Opinion for a period of 15 years. The RPA requires the Water Agency to petition the State Water Board to modify the Water Agency's water right permits to reduce minimum instream flow requirements in order to restore functional salmonid rearing habitat.

The Biological Opinion requires, as part of the RPA, that the Water Agency initiate a State Water Board process for permanent changes to the minimum instream flows required by Decision 1610 to improve rearing habitat conditions in the URR mainstem, LRR in the vicinity of the estuary, and Dry Creek for steelhead and coho salmon, which are listed species under the federal and state Endangered Species Acts. These changes were based on the NMFS findings that water supply operations resulted in flow rates that were higher than historic summer conditions and too high for optimal rearing habitat for young salmonids.

As an interim measure before the permanent changes are approved by the State Water Board, the Water Agency has been required, as part of the RPA, to file a petition with the State Water Board amending the Water Agency's water right permits to change summertime minimum instream flow requirements. From May 1 through October 15, the Biological Opinion's recommended minimum instream flow on the URR for *Normal* water supply conditions is 125 cfs. The State Board has approved the petitions filed by the Water Agency in 2010, 2011, 2012 and 2016.

A Reasonable and Prudent Measure (RPM 3) of the Biological Opinion requires that the USACE undertake measures to ensure that harm and mortality to listed salmonids from ramping procedures at CVD are low. Ramp down of flood releases can strand juvenile salmonids on gravel bar surfaces or off-channel habitats by reducing river stage elevation to quickly for juvenile salmons to follow the receding river elevation. Juvenile salmonids that are stranded in off-channel habitat or in cobble substrates are subject to increased mortality (NMFS, 2008). RPM 3 required that the USACE complete a hydraulic analysis of river conditions downstream of CVD to assess the vulnerability of dewatering juvenile salmonids with the existing ramping procedures. NMFS collaborated with the USACE to complete field studies to evaluate hydraulic conditions during flood operations of CVD, and, based on the results of the field studies, reached mutual agreement on modified ramp down procedures. These modified procedures are outlined in an April 2016 NMFS letter to the USACE (NMFS, 2016).

2.5.1 Fish Habitat Flows DEIR

In August 2016 the Water Agency released the *Fish Habitat Flows and Water Rights Project* Draft Environmental Impact Report (DEIR) (SCWA, July 2016) for public review. This DEIR was completed to comply with the Biological Opinion which requires the Water Agency to ask the State Water Board to lower the minimum instream flow requirements in the Russian River and Dry in order to improve conditions for coho and steelhead. The Water Agency evaluated many minimum instream flow alternatives in the development of the DEIR, and as a result of a detailed analysis of habitat and other beneficial uses, the minimum instream flows recommended in the DEIR are slightly lower than the minimum instream flows recommended in the Biological Opinion.

In addition to reducing the minimum instream flow requirements in the DEIR, the Water Agency is also proposing to modify the hydrologic index. The hydrologic index is a metric that is intended to represent hydrologic conditions of the RRS and is used to set the minimum instream flow schedule for the Russian River system. As previously discussed in Section 2.4.3, the current hydrologic index is based on inflow into Lake Pillsbury located on the Eel River. In the DEIR the Water Agency is proposing to replace the existing hydrologic index to a metric based on inflows and storage in Lake Mendocino.

Due to the changes in operations of the PVP in 2006, the existing hydrologic index defined in the Water Agency's water rights permits is no longer an accurate metric of available in the RRS. Based on the modeling analysis completed by the Water Agency for the preparation of the DEIR, it is anticipated that implementation of the hydrologic index and reductions to minimum instream flow requirements proposed in the DEIR would improve the water supply reliability of the Lake Mendocino relative to current operations. The Water Agency is working to finalize the DEIR and implement this project pending approval from the State Water Board.

2.6 CNRFC Forecasting for the Russian River

As a part of routine operational duties, the CNRFC forecasts runoff from precipitation throughout the Russian River watershed. Forecasts are made at least twice a day during the wet season and up to four times a day during forecasted flood events. Inflow volumes are forecasted into Lake Mendocino as well as all of the other contributing downstream watersheds extending down to Guerneville. There are a total of seven watersheds including Ukiah, Lake Mendocino, Hopland, Cloverdale, Dry Creek (Lake Sonoma), Healdsburg, and Guerneville, which are shown in Figure 2-8.

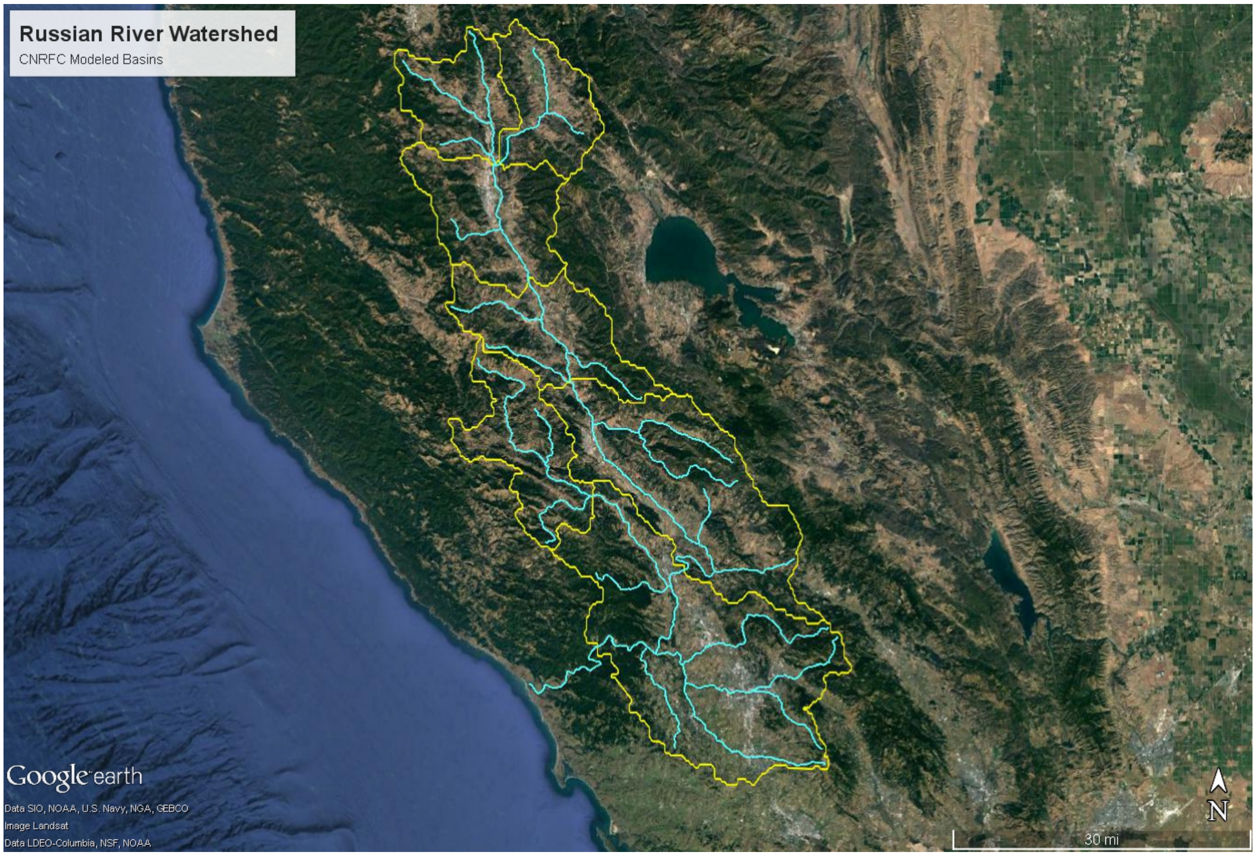


Figure 2-8. CNRFC hydrology model of the Russian River Watershed.

The CNRFC hydrology model is a continuous simulation model where watershed conditions are constantly being updated with observed precipitation and temperature. Consequently, the hydrology models are initiated with current basin states and forced with rainfall and temperature forecasts developed by the CNRFC meteorologists. These single value streamflow forecasts are considered a “best estimate” of future conditions known as a deterministic forecast and extend 5 days into the future.

In recent years, the CNRFC has implemented another forecast product that takes into account the uncertainty in the near-term weather forecasts. The result is an ensemble of streamflow forecasts generated from the Hydrologic Ensemble Forecast System (HEFS). Single value precipitation and temperature forecasts are input into the Meteorological Ensemble Forecast Processor (MEFP), and the outputs are ensembles of temperature and precipitation forecasts. All of these meteorological forecasts are run through the same hydrology models that the deterministic forecast uses, resulting in a 61-member ensemble of streamflow forecasts. Figure 2-9 depicts streamflow ensemble forecasts for Lake Mendocino known as a “spaghetti plot” where each hydrograph is a separate forecast with equal likelihood.

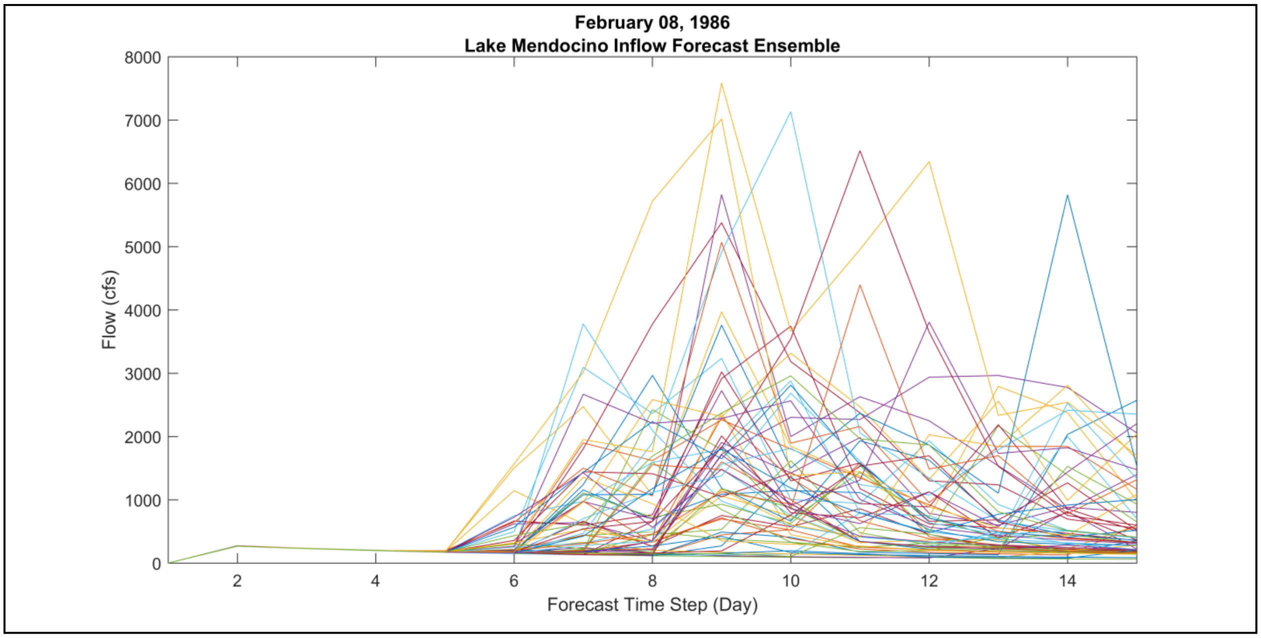


Figure 2-9. Lake Mendocino ensemble forecast example. Each hydrograph shown represents the runoff from a possible future precipitation and temperature condition.

3 Ensemble Forecast Operations

A risk based approach to flood control operations (Ensemble Forecast Operations) was developed by the Sonoma County Water Agency as a potential alternative for determining flood control releases from Lake Mendocino. Ensemble Forecast Operations utilizes the 61 member, 15-day flow forecast ensembles from the CNRFC to model and forecast Lake Mendocino storage conditions. This is illustrated in Figure 3-1 for the February 8, 1986 inflow hindcast, just days before the large flood event of 1986. Each inflow forecast (ensemble member) is modeled independently to develop a storage forecast ensemble. It can be seen from this figure that the storage forecast can include a broad array of potential outcomes, with some ensemble members forecasting storage to stay below the spillway crest storage level of 116,500 acre-feet while others forecast water levels to nearly reach or exceed top of the dam. The model developed to simulate Ensemble Forecast Operations is discussed further in Section 4.

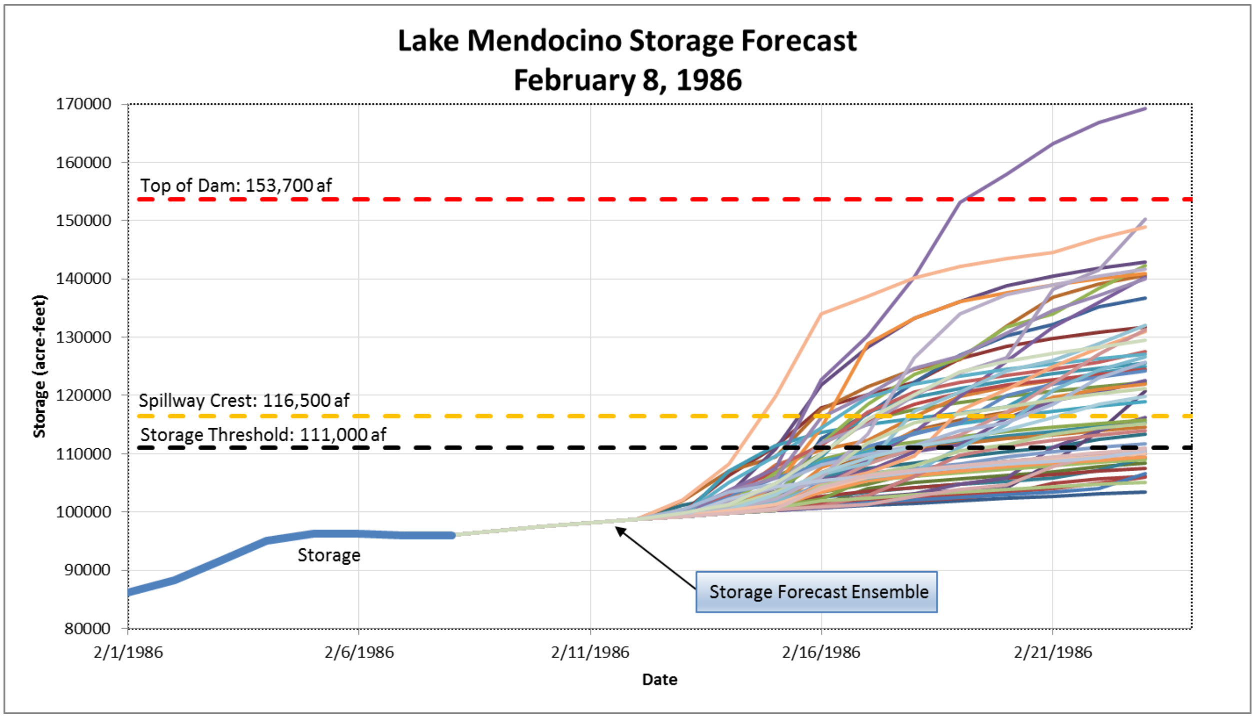


Figure 3-1. Ensemble Forecast Operations calculated storage forecast ensemble using CNRFC flow forecast ensembles for February 8, 1986.

Using the storage forecast ensemble, risk of exceeding a pre-defined storage level threshold is forecasted. The storage level threshold used for this analysis is 111,000 acre-feet (761.8 feet msl). This is the maximum storage level for conservation water in Lake Mendocino. Risk is estimated as the probability or percentage of forecasted storage ensemble members exceeding the storage level threshold. Model forecasted risk is evaluated against a future risk tolerance curve. The risk tolerance curve provides variable tolerance levels of risk for different forecast time steps. For forecast time steps closer to the current time (1 to 6 days), risk tolerance is zero. Forecast time steps from 7 to 15 days the risk tolerance levels increase each day to a level of 30% on day 15. An example of the risk tolerance curve is provided in Figure 3-2.

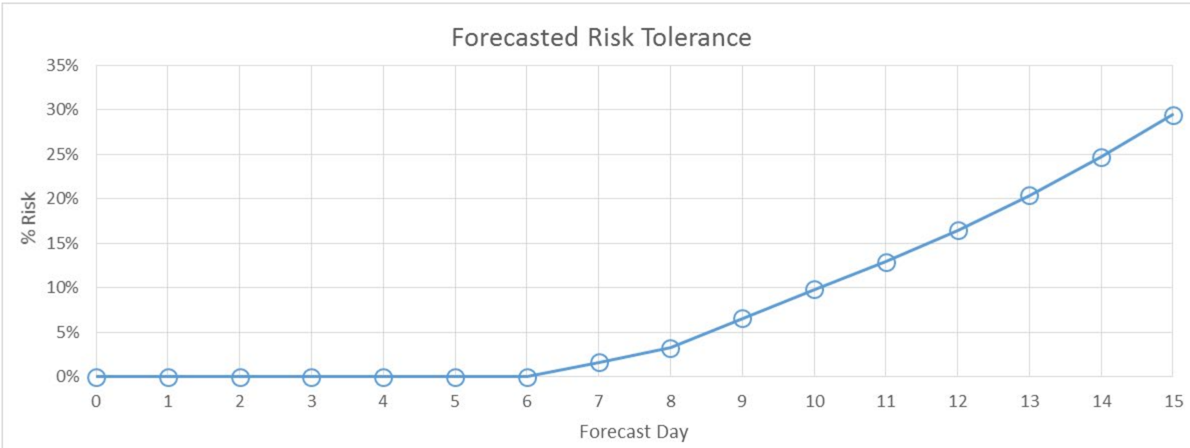


Figure 3-2. Plot of Ensemble Forecast Operations risk tolerance curve.

Reservoir releases are determined through an analysis that determines the required flood release that reduces forecasted risk below the risk tolerance curve for all forecast time steps. This process is illustrated in Figure 3-3 and Figure 3-4 for estimating flood releases for February 8, 1986. The top panel of Figure 3-3 provides a forecasted storage hydrograph, with the storage threshold of 111,000 acre-feet shown as a black dashed line. From this hydrograph it can be seen that many of the forecasted storage ensemble members predict storage to exceed the 111,000 ace-feet storage threshold. Forecasted risk is shown as the red solid line in the bottom panel of Figure 3-3. The risk tolerance curve is shown as the dashed blue line. It can be seen from this figure that forecasted risk exceeds the risk tolerance curve from day 6 of the forecast to day 15.

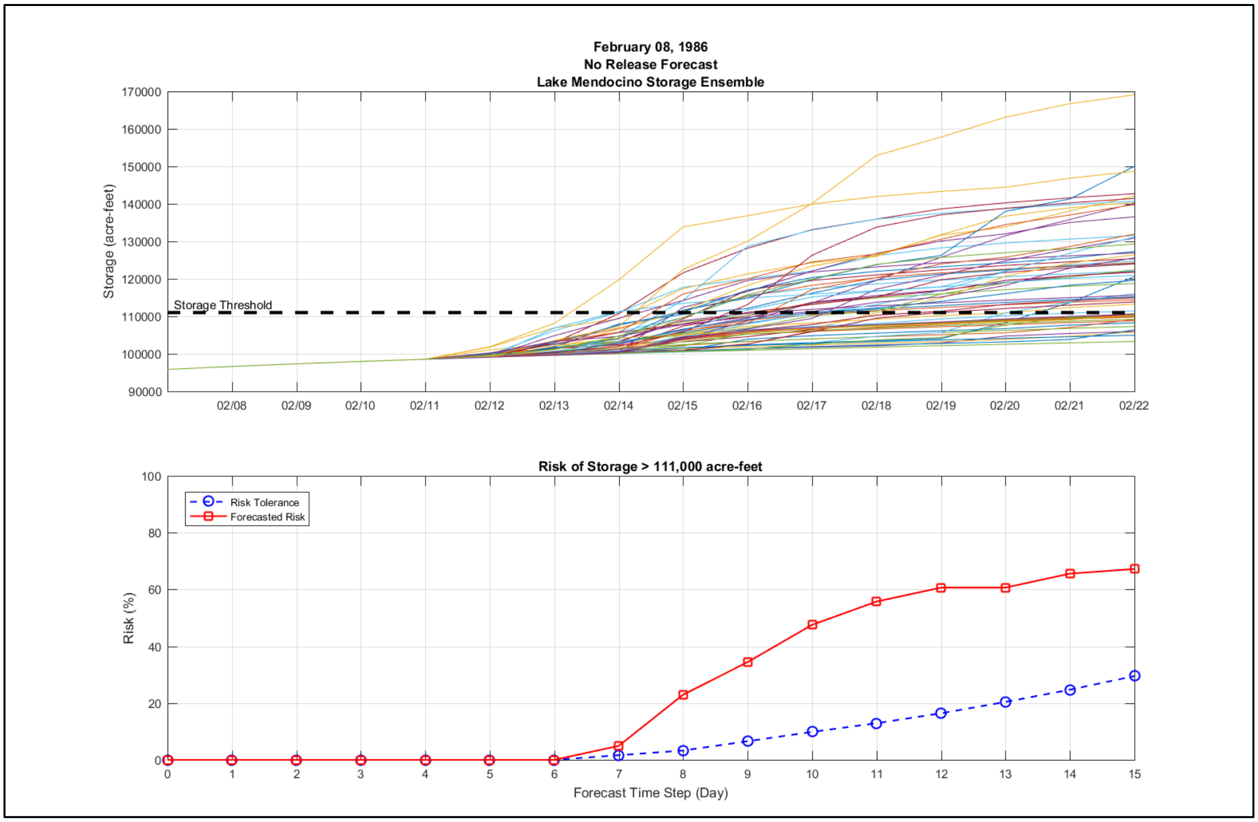


Figure 3-3. Ensemble Forecast Operations forecasted storage ensembles and forecasted risk BEFORE applying release calculation on February 8, 1986.

Through a ranking analysis, storage ensemble members are selected and required releases are calculated to bring the selected ensemble members below the 111,000 acre-foot storage threshold. This is illustrated in Figure 3-4, where the top panel shows the modeled storage ensemble members after the forecasted releases have been calculated. The release for the current time step is selected as the release that will satisfy the risk tolerance levels for all future forecast time steps. For this example, the simulated release was 1936 cfs. The bottom panel shows the forecasted risk with all time steps now falling below the risk tolerance curve. A more detailed discussion of how this process is modeled is provided in Section 4.11.

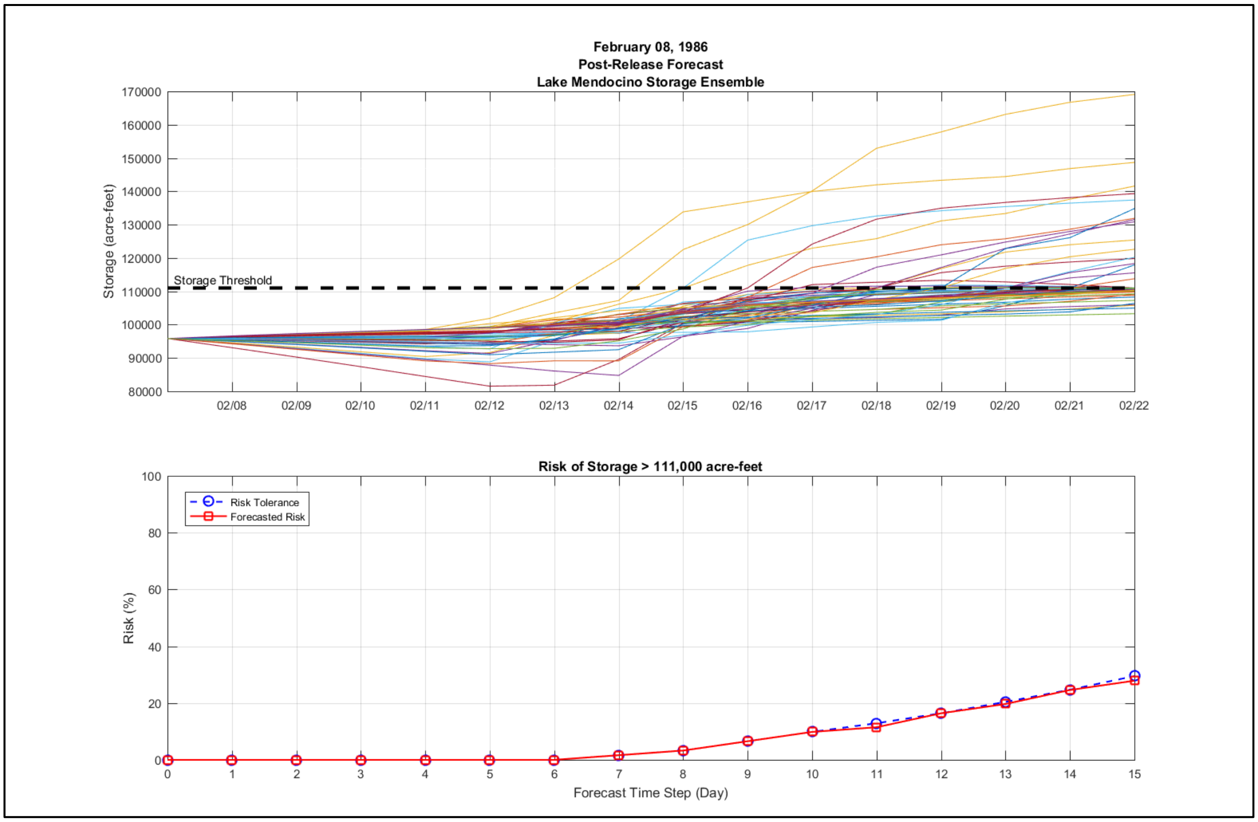
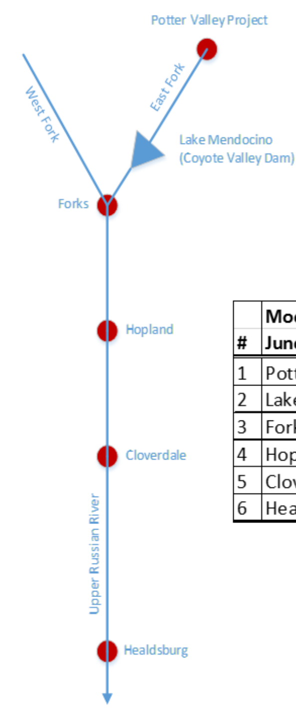


Figure 3-4. Ensemble Forecast Operations forecasted storage ensembles and forecasted risk AFTER applying release calculation on February 8, 1986.

4 Model Setup

4.1 General Description

The model developed by the Water Agency simulates hydrologic conditions on a daily time step in the URR from the PVP to the Healdsburg Gage from 1985 to 2010. The model code was developed using the MATLAB software package (MATLAB 2016b, The Mathworks Inc., Natick, MA, 2000). The model applies reservoir operation rules of Lake Mendocino and water balance calculations to simulate storage levels in Lake Mendocino and flow conditions at four points (junctions) downstream of the reservoir. The water balance calculation points or model junctions are listed and graphically shown in Figure 4-1.



#	Model Junction Name	Junction Type	Gage Name	Gage Owner	Gage ID
1	Potter Valley Project	Flow	East Fork of the Russian River and Potter Valley PH	USGS	11461501
2	Lake Mendocino	Reservoir	Coyote Valley Dam Release	USACE	COY
3	Forks	Flow	-		-
4	Hopland	Flow	Russian River Near Hopland	USGS	11462500
5	Cloverdale	Flow	Russian River Near Cloverdale	USGS	11463000
6	Healdsburg	Flow	Russian River Near Healdsburg	USGS	11464000

Figure 4-1. URR EFO Model junctions and associated USACE or USGS gage.

This model was developed to simulate operations using the Ensemble Forecast Operations decision support system discussed in Section 3, as well as other scenarios described in this study. This model has been named the URR Ensemble Forecast Operations Model (URR EFO Model), although it was also used in this study to simulate additional scenarios, such as existing operations, that do not incorporate the Ensemble Forecast Operations methodology.

At each model junction the water balance calculation accounts for unimpaired flow gains from rainfall runoff and groundwater (full natural flow) and losses caused by human consumptive use, water consumption by riparian vegetation and recharge of the underlying aquifer. Unimpaired flow gains used in the model were developed by the CNRFC and are further described in Section 4.2. Transbasin diversions from the PVP into the Russian River were analyzed using a separate Eel River model which is further described in Section 4-3. Model junction losses were estimated by the Water Agency using observed flows and metered diversions. Development of the junction loss datasets in further described in Section 4-4.

4.2 CNRFC Historical and Hindcast Unimpaired Flows

4.2.1 Lake Mendocino Historical Unimpaired Inflow

The CNRFC created an unimpaired observed Lake Mendocino inflow data set used for assessing forecast quality and reliability. The calculation used daily estimated inflows from the US Army Corps of Engineers Sacramento District (USACE-SPK). Diversions into the East Fork Russian River from the Potter Valley Diversion were subtracted from the inflow data set to estimate the unimpaired flow. Evapotranspiration was not considered in determining the unimpaired flow estimates, because it is not a significant factor in the lake water balance during winter high flow conditions. The historical Potter Valley Diversion data came from the PVP Powerhouse Gage. The data for this gage was missing for water years 1983-1986. For that period, USGS Gage 11471000 was used. The unimpaired data was then smoothed manually to remove large swings in negative and positive inflows. A mass balance was preserved during this smoothing process.

4.2.2 CNRFC Hindcast Ensemble Flow

In support of the FIRO PVA, retrospective ensemble forecasts (hindcasts) of Lake Mendocino inflow and the downstream watersheds were generated by the CNRFC using the HEFS software over a 25 year period. This set of hindcasts was used in this study to simulate the Ensemble Forecasts Operations method for Lake Mendocino.

To create the hindcasts for the Russian River, CNRFC staff first generated simulated historical flows by running the Russian River hydrology model continuously with historical observed weather conditions (temperature and precipitation) from water year 1948 through 2010. The watershed states (warm states) of the model were then stored for every day during that period prior to running the hindcasts. The streamflow hindcasts were generated by looping through the Russian River forecasting model one day at a time. For a given hindcast day, appropriate warm states were selected from the stored data set. The hydrology models were then forced with an ensemble of MEFP meteorological forecasts (precipitation and temperature) based off of the NCEP operational Global Ensemble Forecast System (GEFS) reforecast data set for that day. This utilized the 2012 reforecast dataset as described by Hamill et al (2013) which utilizes the same version of the GEFS run currently for the CNRFC. The inflow hindcasts were computed one day at a time, and archived for verification purposes and reservoir re-operation analysis.

The hindcast simulates an hourly, 61 member flow forecast from 1985 to 2010, resulting in over 9,000 days of ensemble flow forecasts at lead times of 1-15 days. The hydrology and atmospheric models used in the hindcast process are consistent with what is used operationally; however the hindcasting procedure is automated, so it does not include information added in practice by operational hydrologic forecasters. Therefore, it is not an exact representation of operational methods, but is a very large, consistent, realistic sample of forecasts for testing alternative reoperation strategies. If anything, the reforecasts provide a conservative estimate of the current real time forecast skill. The corresponding hydrographs also provide a systematic data set that can be compared with observed hydrographs to assess forecast quality and utility.

The historical unimpaired flow estimates were applied in the URR EFO Model from 1985 to 2010 for the Lake Mendocino, West Fork, Hopland, Cloverdale and Healdsburg model junctions (junctions 2 to 6) as shown in Figure 4-1. Additionally for the modeling of the Ensemble Forecast Operations completed in this study, daily average hindcasted flows were calculated from the hourly hindcasted flows.

4.2.3 Review of CNRFC Historical Unimpaired Flows

The Water Agency conducted a review of the historical unimpaired flow datasets prepared by the CNRFC to assess the accuracy of these datasets to represent the hydrology of the Russian River System. To complete this review, modeled monthly CNRFC unimpaired flows were compared to observed monthly flow gains between model junctions. This analysis was conducted for the period of December to April of each of the years analyzed because of the relatively low volume of consumptive use of water during this period. Consequently, the accuracy of the unimpaired flows developed by the CNRFC can be compared to the observed flow gains for the same period. This analysis was completed for the period beginning with the construction of CVD (1959) and ending with final year of the CNRFC unimpaired flows (2010).

4.2.3.1 Lake Mendocino Unimpaired Inflows

Observed daily local flows into Lake Mendocino were estimated by subtracting daily observed PVP diversions from daily observed Lake Mendocino inflows recorded by the USACE for the years 1959 to 2010. Monthly flow rates in acre-feet were calculated for the period December to April for each year for both the observed local flows and the estimated unimpaired flows developed by the CNRFC. A scatter plot of the CNRFC unimpaired flows and observed local flows for Lake Mendocino is provided in Figure 4-2. These results show that the CNRFC unimpaired flows compare very well with the observed local flows with a least-squares linear regression fit of approximately 1.01 to 1 correlation and a coefficient of determination (R^2) of 0.96. A percent exceedance plot of December to April monthly flow rates for the CNRFC unimpaired flows and the observed local flows is provided in Figure 4-3. These results show that the distribution of the modeled unimpaired monthly flows matches very closely with the observed local monthly flows.

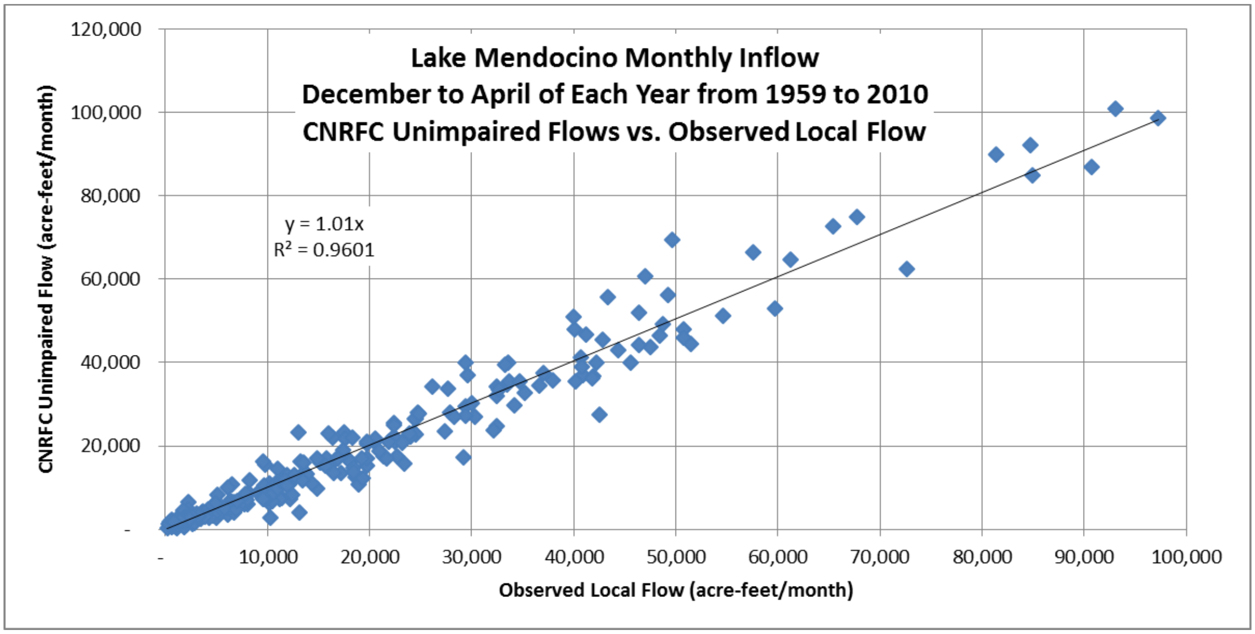


Figure 4-2. Scatter plot of 1959 to 2013 December to April Lake Mendocino monthly unimpaired inflows simulated by the CNRFC versus observed Lake Mendocino inflow volumes.

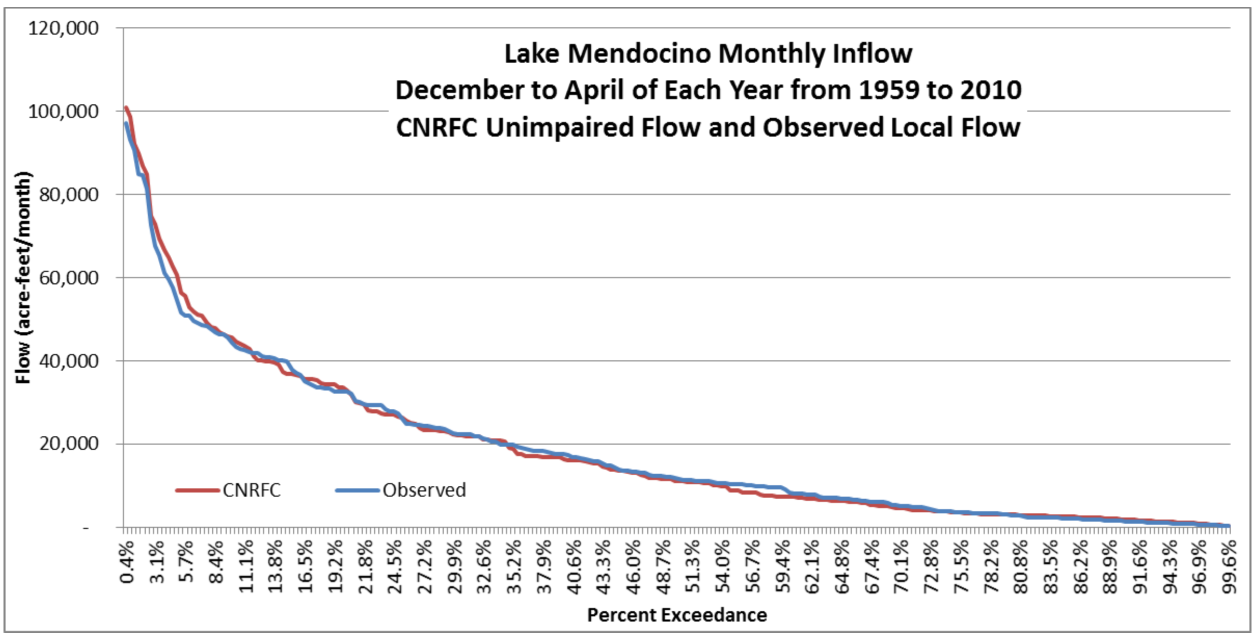


Figure 4-3. Percent exceedance of 1959 to 2010 December to April Lake Mendocino monthly unimpaired inflows simulated by the CNRFC and observed local flows.

4.2.3.2 Upper Russian River Unimpaired Flows

Observed daily local flows for the URR reach (Forks to the Healdsburg Gage) were estimated for the Forks, Hopland, Cloverdale, and Healdsburg flow Gages for the years 1959 to 2010. With the exception of the Forks flows, observed daily local flows were calculated for each gage by subtracting upstream observed flows from downstream observed flows. For the Forks, it was assumed that the observed local flows are equal to the observed flows from the West Fork Gage which is just a short distance from the Forks. Monthly URR flows were calculated for both the observed local flows and the CNRFC estimated unimpaired for the period December to April of each year. A scatter plot of the monthly CNRFC unimpaired flows and observed local flows for the URR is provided in Figure 4-4. These results show that the CNRFC unimpaired flows compare very well with the observed local flows with a least-squares linear regression fit of approximately 1.01 to 1 correlation and a R2 of 0.98. A percent exceedance plot of December to April monthly flow rates for the CNRFC unimpaired flows and the observed local flows is provided in Figure 4-5. These results show that the distribution of the modeled unimpaired flow volumes matches very closely with the observed local flow volumes.

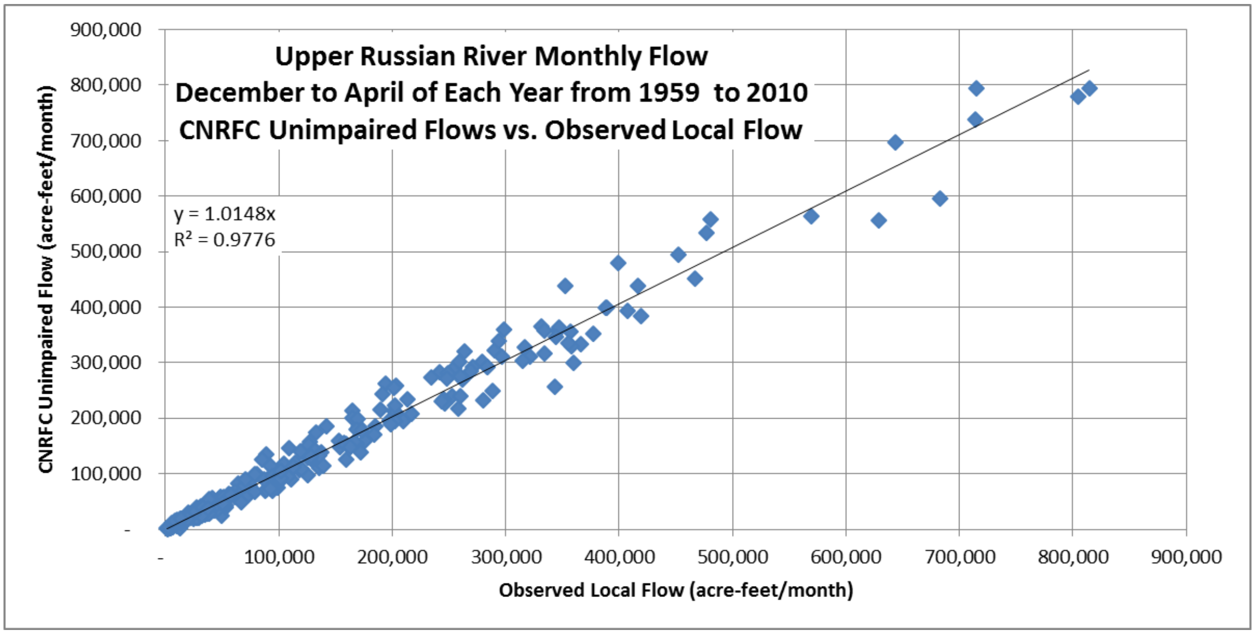


Figure 4-4. Scatter plot of 1959 to 2013 December to April URR unimpaired inflow volumes simulated by the CNRFC versus observed URR inflow volumes.

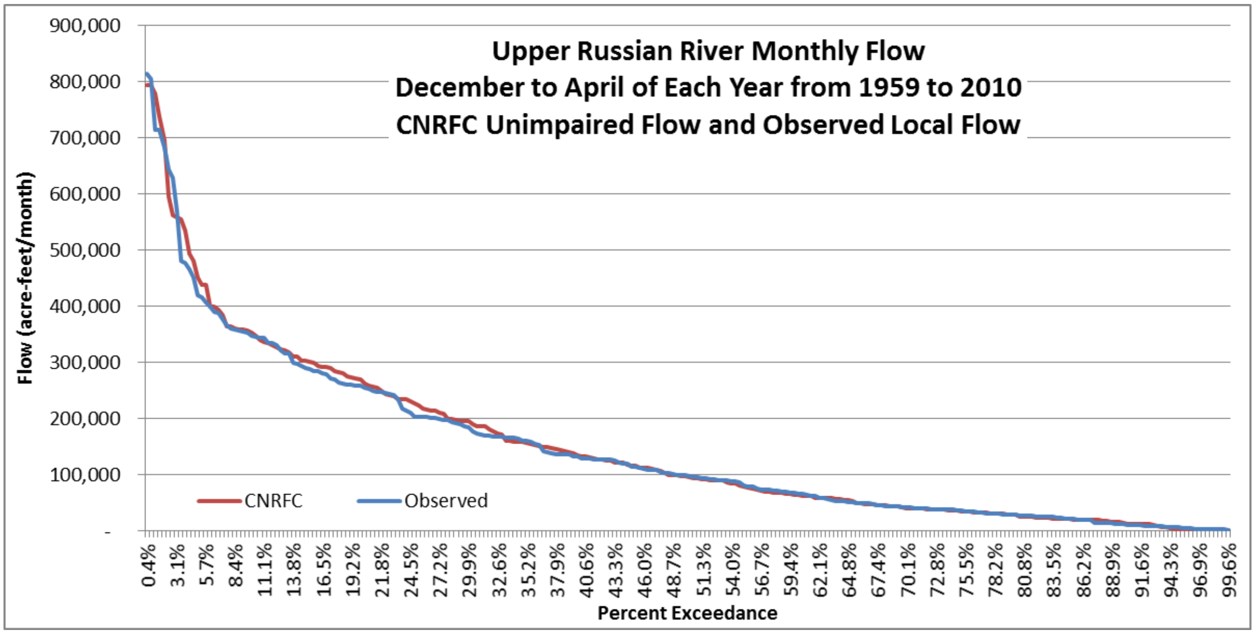


Figure 4-5. Percent exceedance of 1959 to 2013 December to April URR unimpaired inflow volumes simulated by the CNRFC and observed local inflow volumes.

4.3 Potter Valley Project Diversions

Trans-basin water imports from the Eel River into the Russian River through the PVP were estimated using the Eel River Model version 2.5 (ER2.5). Due to the substantial changes in operations of the PVP during the historical period simulated by the model (1985 – 2010), observed historical diversions were not used for this entire period. As discussed in Section 2.3, in the fall of 2006 operations of the PVP changed significantly as a result of a 2004 FERC license amendment for the PVP. Consequently, historical diversions from 1985 to 2006 would not be representative of existing operations of the PVP. Modeled PVP diversions were developed to approximate current, post-fall 2006 operational constraints and practices (Existing Conditions). The estimated PVP diversions from the Eel River Model are provided as input into the RR ResSim at Potter Valley Project model junction (junction 1) as shown in Figure 4-1.

The Eel River Model version 2.2, developed by Natural Resources Consulting Engineers (Oakland, CA), was used for the alternatives analysis that resulted in the 2004 FERC license amendment. Eel River Model version 2.5 (ER2.5) was developed by the Water Agency through refinements to the model code and input datasets to better simulate existing operations of the PVP. ER2.5 was used to estimate PVP Tunnel diversions and Lake Pillsbury storage levels for the URR EFO Model under existing management practices of the PVP for historical hydrology for water years 1959 to 2006. Because PVP operations during water years 2007 to 2010 are consistent with existing management practices, observed Tunnel diversions recorded at the PVP Powerhouse Gage were used for those years.

4.3.1 Eel River Model Verification

Simulated PVP Tunnel diversions from ER2.5 were compared to recent observed Tunnel diversions to assess the accuracy of the model to simulate existing PVP operations. This model verification was completed for the period beginning with implementation of the 2004 FERC license amendment (water year 2007) and ending with final year that ER2.5 is currently parameterized (2014). Results of the updated ER2.5 were compared to observed PVP Tunnel diversions for this period. A scatter plot of modeled monthly diversions versus observed monthly diversions is provided as Figure 4-6. Model results show very good agreement with observed diversions. As provided in Figure 4-6, a least-squares linear regression fit shows a R^2 of 0.71 and also approximately 1 to 1 correlation. Model results correlate best for values below 8,000 acre-feet per month, which captures the range of operations for compliance (non-power production) diversions. Actual power production diversions are a function of numerous factors not accounted for in the model, such as operational constraints due to facility maintenance, energy demand, and energy market prices. Therefore, the increase in scatter for diversions above 8,000 acre-feet per month is expected. Percent occurrence of monthly PVP diversions is provided in Figure 4-7, which shows that the distribution of the simulated monthly diversions matches well with observed, although for flows above 90% observed diversions exceed simulated diversions. When comparing water year cumulative diversions as provided in Figure 4-8, model results compare very well with observed diversions. It should be noted that while modeled diversions for water years 2007 to 2014 were compared here to actual diversions to assess model performance, modeled diversions for these years were not actually used in the in the URR EFO Model. Instead actual observed diversions from the PVP Powerhouse Gage were used for water years 2007 to 2010 as these most accurately reflect current, post FERC license amendment operations of the PVP.

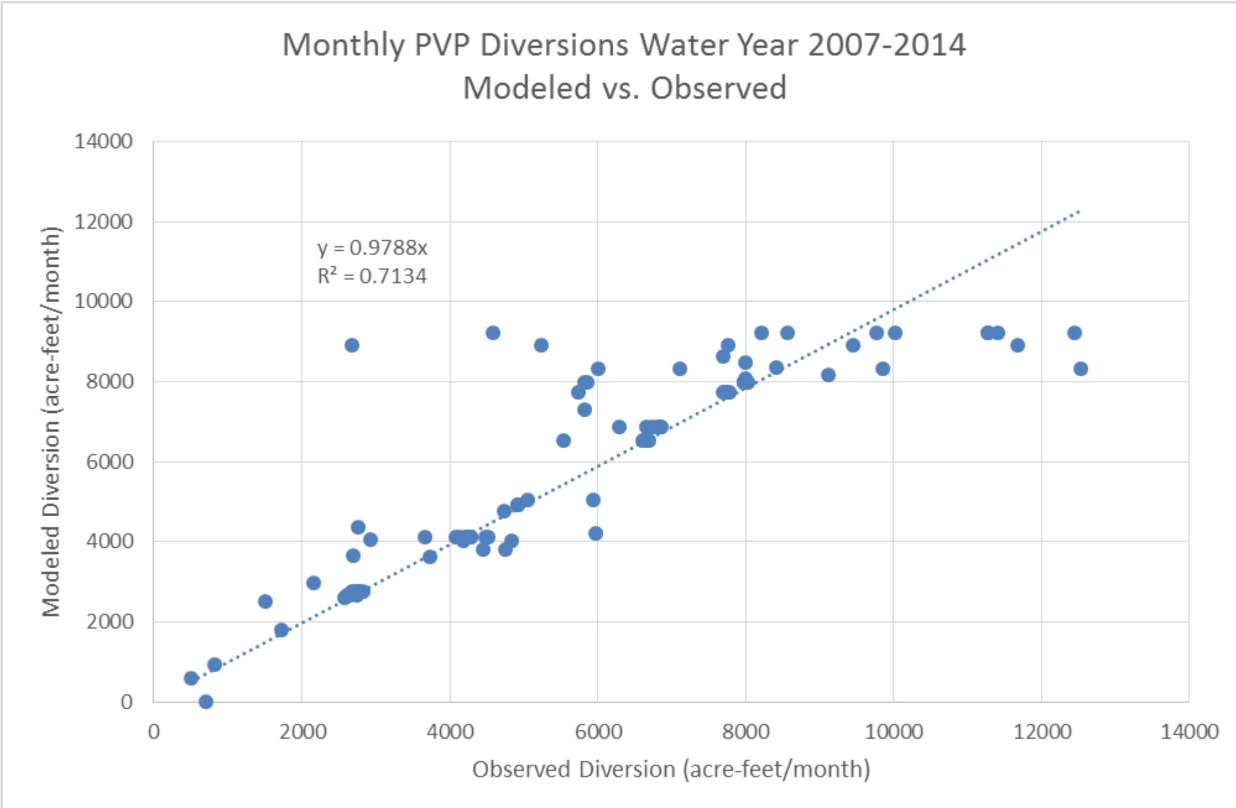


Figure 4-6. Scatter plot of monthly Potter Valley Project Tunnel diversions modeled with ER2.5 versus observed in acre-feet/month.

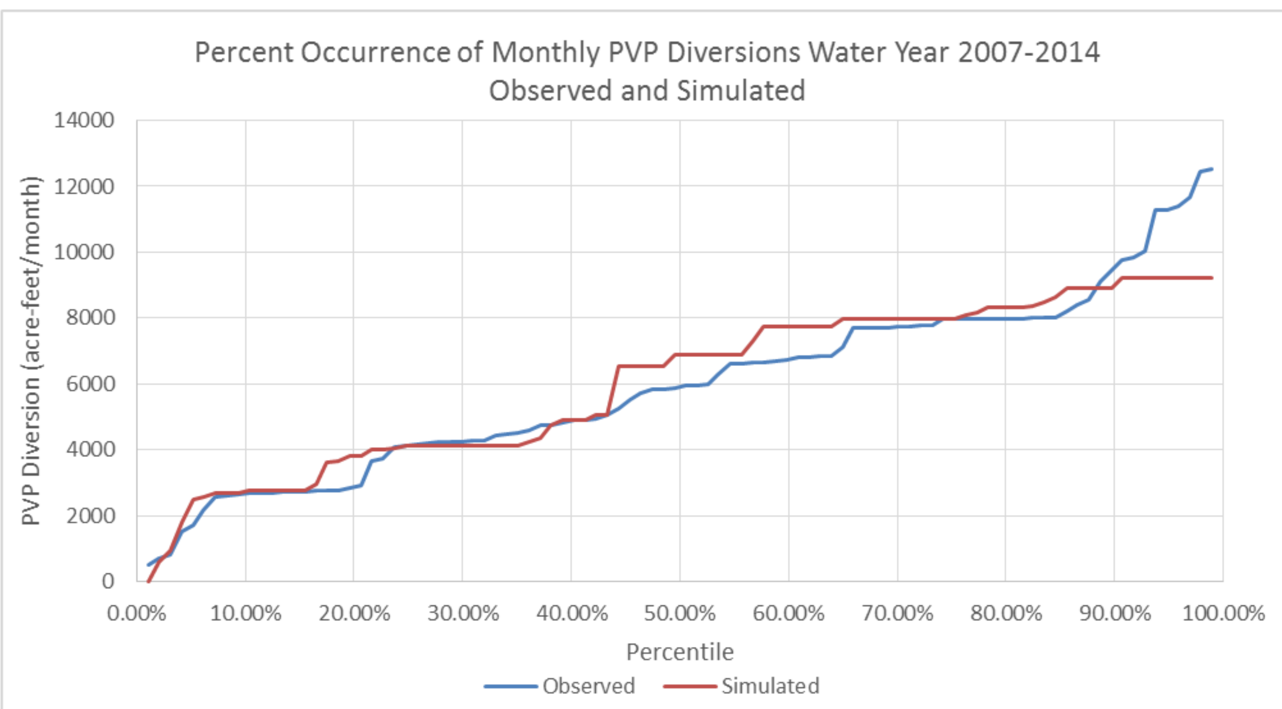


Figure 4-7. Percent occurrence of monthly Potter Valley Project Tunnel diversions modeled with ER2.5 and observed in acre-feet/month.

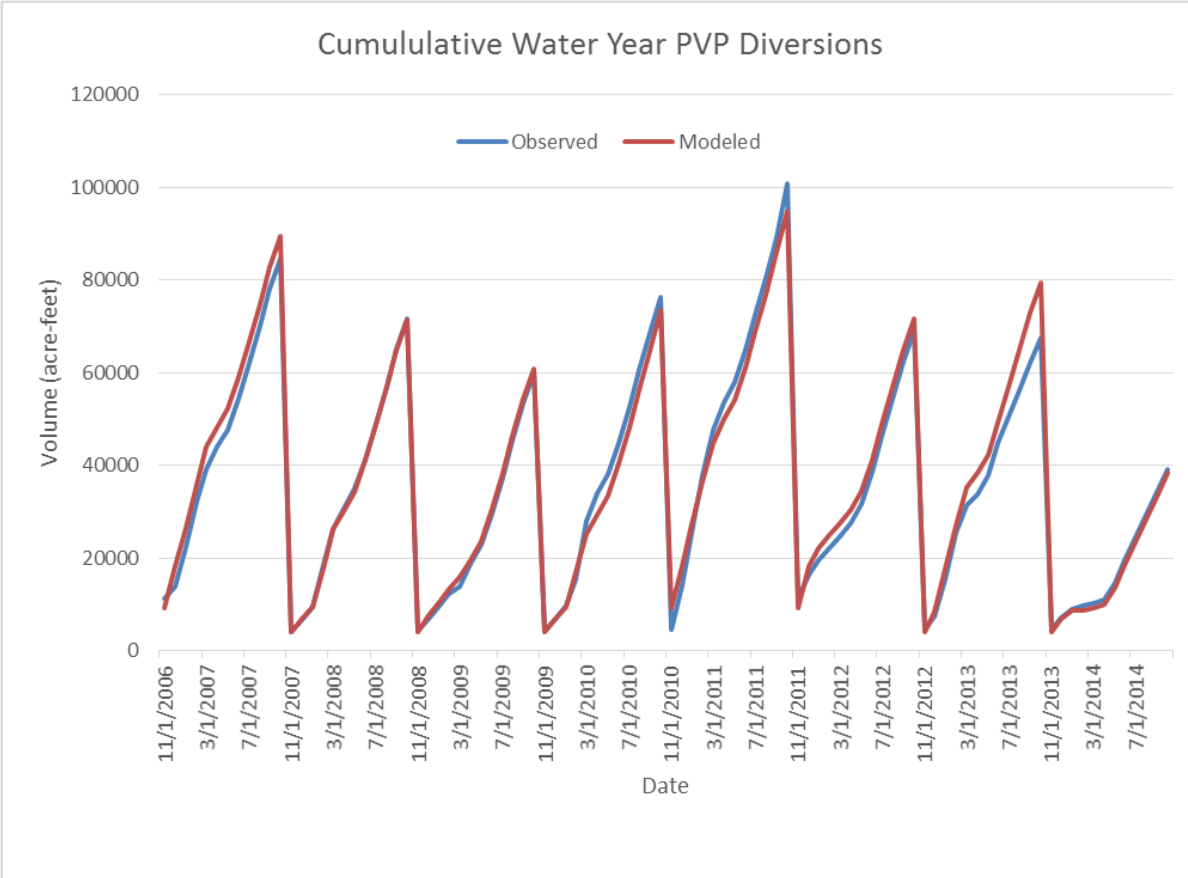


Figure 4-8. Hydrograph of water year cumulative (beginning October 1 and ending September 30) Potter Valley Project Tunnel Diversions modeled with ER2.5 and observed.

4.4 Model Junction Loss Estimates

The model accounts for system losses at four model junctions: Lake Mendocino, Hopland, Cloverdale, and Healdsburg (junctions 2, 4, 5 and 6 as shown in Figure 4-1). The losses accounted for in the model include municipal and industrial (M&I) diversions, reservoir surface evaporation and water depletions for each upstream reach. In previous studies the Water Agency in partnership with others has completed more in depth analysis of reach depletions in the Russian River. These studies were more focused on characterizing the sources of water loss. In contrast, the goal of the loss analysis for this project is to accurately characterize the system water balance and the simulated annual water duty caused by water loss in Lake Mendocino and the downstream reaches.

4.4.1 Water Balance Losses

Water balance losses are estimates of the total reach depletions and include riparian evapotranspiration, evaporation, surface water/groundwater interactions, and consumptive use from agricultural diversions and M&I diversions. The unimpaired flow for most reaches typically diminishes to low or no flow conditions by early to mid-May in dry years and June in wetter years. During the wet season unimpaired flows are large and the magnitude of these flows is significantly greater than the magnitude of losses. Because of these differences, gage error and unimpaired flow estimation error can be significant compared with the magnitude of losses and obscure a reliable calculation of water balance derived losses. Additionally, in the springtime of wetter years, agricultural water use is very low so that corresponding stream losses are also low making water balance loss calculations unreliable. For these reasons, water balance losses are only calculated for the months of May through October for incorporation into the total loss time series.

Water balance losses were calculated for water years 2000 through 2010 using daily observed diversions from the Potter Valley Project, releases from Lake Mendocino, flow data from USGS gages, and modeled unimpaired flow from the CNRFC. Daily water balance losses were calculated at each model junction using the following equation:

$$Loss_{WaterBalance} = Q_{Upstream} - Q_{Downstream} + Q_{Unimpaired}$$

Where $Q_{upstream}$ and $Q_{downstream}$ are the observed flows at the USGS gages corresponding to the model junctions, and $Q_{unimpaired}$ is the RFC modeled unimpaired flow in the reach between the upstream and downstream model junctions.

Water balance losses are meant to capture the total cumulative loss in the river reach. The accuracy of the water balance calculation is a function of the accuracy of observed measurements, travel time, and modeled unimpaired flows. To account for these potential inaccuracies, outliers were identified and removed from the daily loss data.

Outliers in the daily water balance losses were identified for each month of the eleven years of data. The interquartile (IQ) was estimated for each month by calculating the difference between the third quartile (P75) and the first quartile (P25). Outliers were defined by the following equations:

$$Outlier > P_{75} + 1.5 * IQ \text{ or}$$

$$< P_{25} - 1.5 * IQ$$

Monthly median values were calculated with the outliers removed. Outliers were replaced with the monthly median and total monthly water balance losses were calculated for each month. Average monthly water balance losses were calculated for May through October from eleven years of total monthly losses.

4.4.2 Municipal and Industrial Losses

Losses due to M&I diversions were estimated from metered diversion data collected from 11 public water systems, listed in Table 4-1, in the URR basin for the years 2009 through 2013 for which pumping data was available. Total monthly M&I diversions were calculated for each reach using pumping data for the points of diversions located in that reach. Monthly average diversions were estimated for the months of April through November.

Table 4-1. Public water systems in the Russian River watershed that metered diversions were used for the estimation of model junction losses

Public Water Systems in Upper Russian River	Russian River Reach
Calpella County Water District	Hopland
Redwood Valley County Water District	Lake Mendocino
Millview County Water District	Hopland
River Estates Mutual Water Company	Hopland
Rogina Water Company Inc.	Hopland
City of Ukiah	Hopland
Hopland Public Utility District	Cloverdale
City of Cloverdale	Healdburg
Clear Creek Water Company	Healdburg
Geyserville Water Works (PUC)	Healdburg
Gill Creek Mutual Water Company	Healdburg

4.4.3 Model Junction Annual Loss Estimates

Model junction losses applied in the model consist of water balance derived losses and metered M&I diversions. Water balance losses are incorporated for the for the dry season months from May to October. Due to the nature of how water balance losses were estimated as discussed in Section 4.4.1, these losses include the total reach depletions. Therefore M&I loss estimates as discussed in Section 4.4.2, were not added to the water balance losses for the period of May through October. Potential error in gage flow or unimpaired flow estimation limit incorporating water balance losses for the remaining months of the year. During the remaining months, November through April, it is assumed that water loss due to agricultural diversions, riparian evapotranspiration, evaporation, and surface water/groundwater interactions decline significantly. For these months it is assumed that M&I loss estimates are accurate estimates of the total reach depletions.

The average monthly losses are shown for each model junction in Figure 4-9 to Figure 4-12 . Water balance losses are represented in each figure by the blue bars from May through October and M&I losses are represented with the orange bars from November through April. It should be noted that the analysis resulted in high estimated water balance losses for May and June for the Cloverdale junction and June for the Healdsburg junction as shown in Figure 4-11 and Figure 4-12. It is suspected that these high loss estimates for May are not the results of actual reach depletions but more likely due to unrealistically high unimpaired flows for this month for the years analyzed.

The annual monthly losses shown in Figure 4-9 to Figure 4-12 were applied in the model by equally distributing the monthly average loss to each day of the month to develop daily loss estimates.

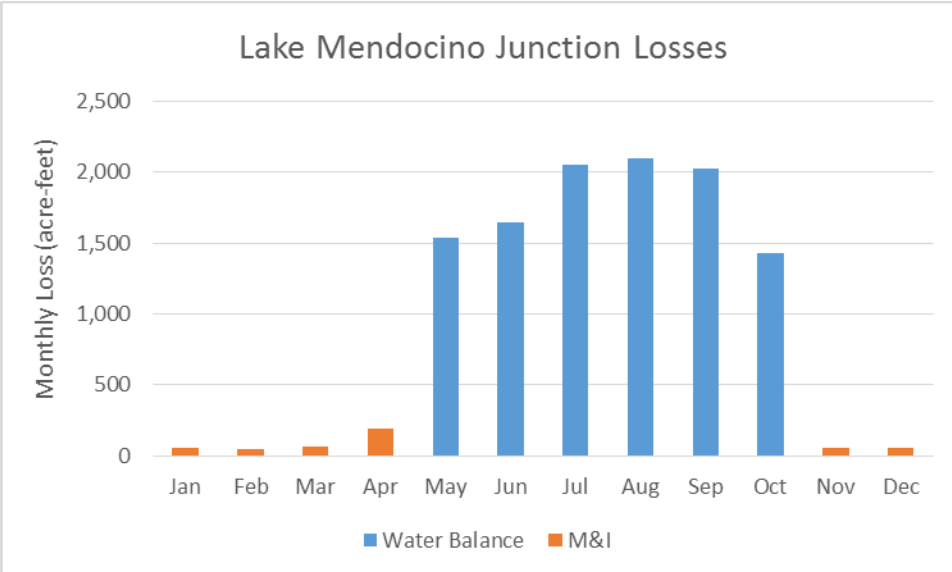


Figure 4-9. Monthly model loss pattern for Lake Mendocino model junction

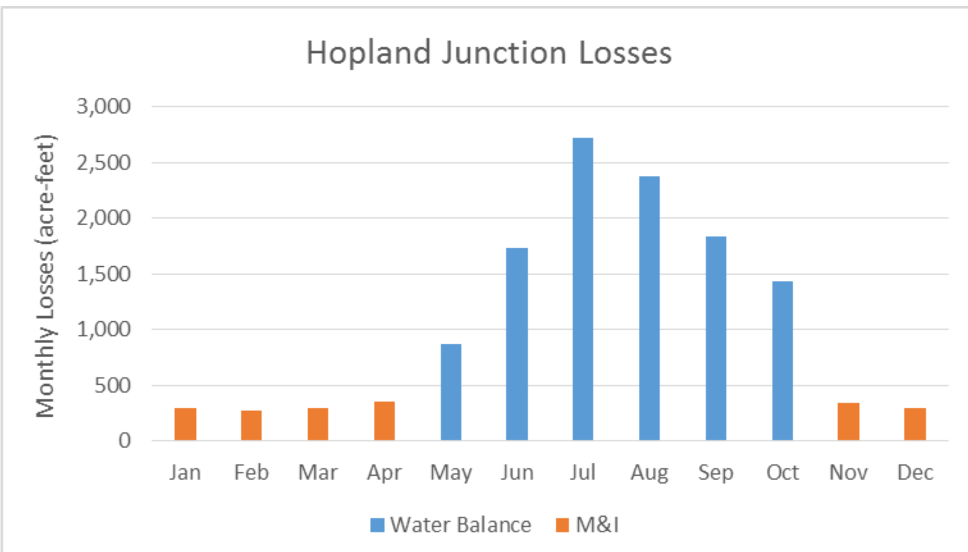


Figure 4-10. Monthly model loss pattern for Hopland model junction

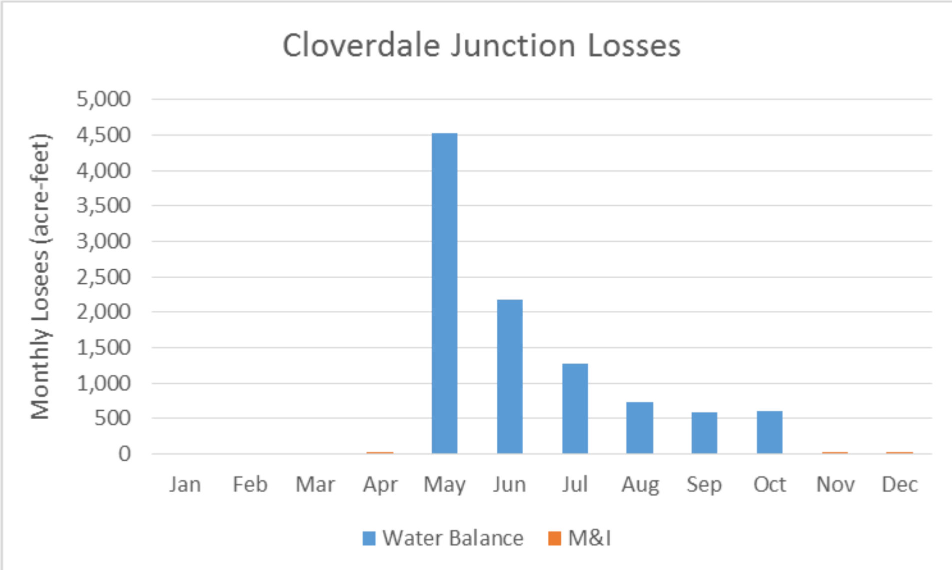


Figure 4-11. Monthly model loss pattern for Cloverdale model junction

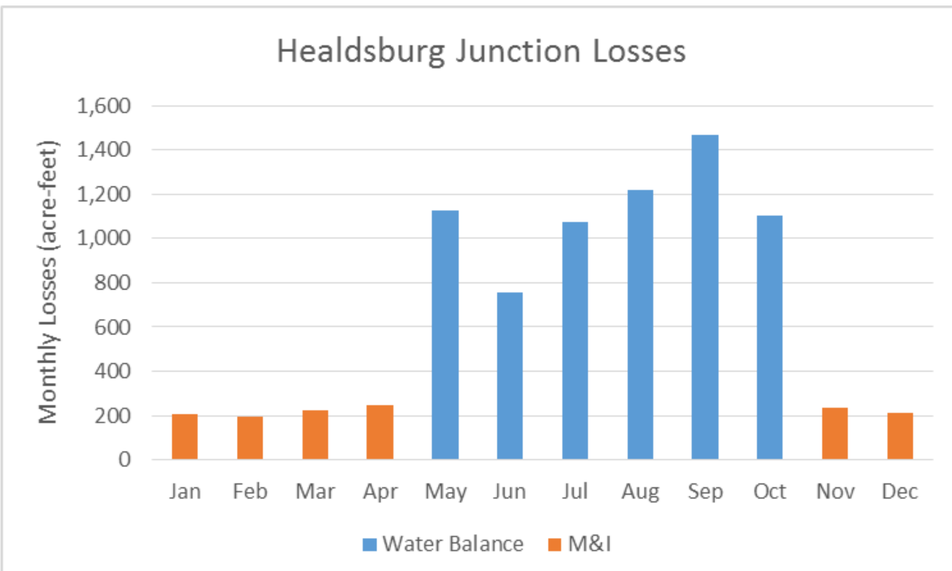


Figure 4-12. Monthly model loss pattern for Healdsburg model junction

4.4.4 Reservoir Evaporation

Losses due to reservoir surface evaporation were accounted for in the model using an annually repeating pattern of monthly evaporation rates. The monthly evaporation rates, shown in Figure 4-13, were calculated based on monthly mean pan evaporation estimates and the monthly evaporation coefficients provided in the CVD WCM. Daily reservoir surface water evaporation is simulated in the URR EFO Model by taking the product of simulated water surface area of Lake Mendocino by the monthly evaporation rate.

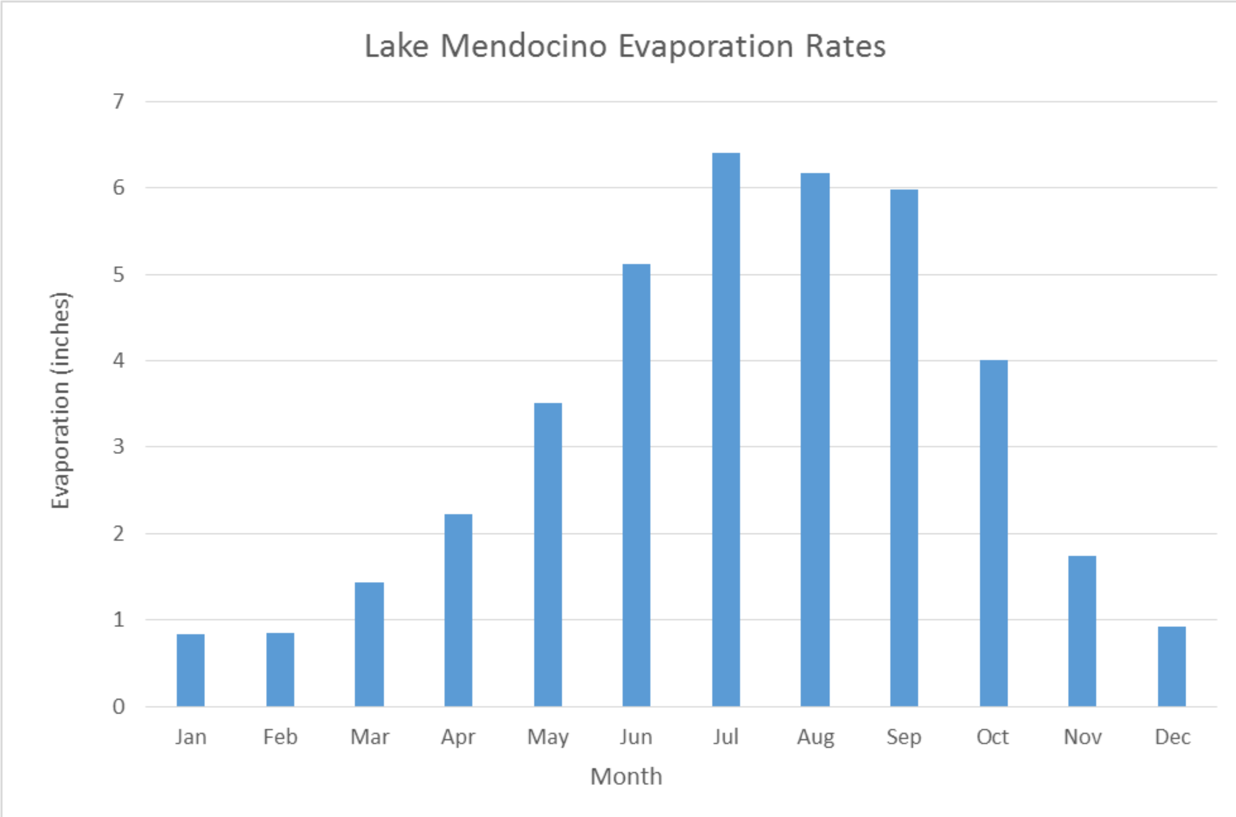


Figure 4-13. Lake Mendocino monthly evaporation rates

4.5 Flow Routing

The URR EFO Model uses a constant lag routing method to account for flow travel times between model junctions. Using this methodology for flow travel times is assumed to be constant and rounded to the nearest day for all flow rates. Model travel times were estimated using travel times provided in the CVD WCM and were selected to target high flow rates downstream of CVD, from 8,000 cfs at Hopland to 20,000 cfs at Healdsburg. In order to most accurately simulate these high flow rates the model assumes a zero day or same day travel time for all model junctions in the URR.

4.6 Water Supply Operations

When simulated storage is within the conservation pool in Lake Mendocino the URR EFO Model simulates releases according to the constraints defined for water supply operations. For this study the Water Agency simulated water supply operations consistent with current operations which comply with the Water Agency's water rights permits and the Russian River Biological Opinion.

4.6.1 Hydrologic Index

The hydrologic index is a metric that sets the *Water Supply Condition* and the corresponding minimum instream flow schedule for the Russian River system. For this study existing water supply operations were simulated using the hydrologic index defined in the Water Agency's water rights permits. This hydrologic index is determined through evaluation of Lake Pillsbury cumulative inflow at the beginning of the water year (October 1) and evaluated against a series of threshold values on the first of the month from January to June. The index determines three hydrologic conditions, *Normal*, *Dry* and *Critical*. Historical hydrologic conditions were estimated using observed Lake Pillsbury inflow from 1985 to 2010. Lake Pillsbury inflow was used to calculate water year cumulative inflow and evaluated against the water supply condition thresholds defined in the Water Agency's water rights permits as shown in Table 4-2. The historical hydrologic condition dataset, as shown in Figure 4-14, is defined as a boundary condition in the URR EFO Model. The model uses hydrologic condition values to set the appropriate downstream minimum instream flow requirement.

Table 4-2. Water supply condition thresholds of Lake Pillsbury cumulative inflow (acre-feet) as defined by the Water Agency's water rights permits.

Water Supply	Date					
Condition	1-Jan	1-Feb	1-Mar	1-Apr	1-May	1-Jun
Normal ≥	8,000	39,200	65,700	114,500	145,600	160,000
Dry <	8,000	39,200	65,700	114,500	145,600	160,000
Critical <	4,000	20,000	45,000	50,000	70,000	75,000

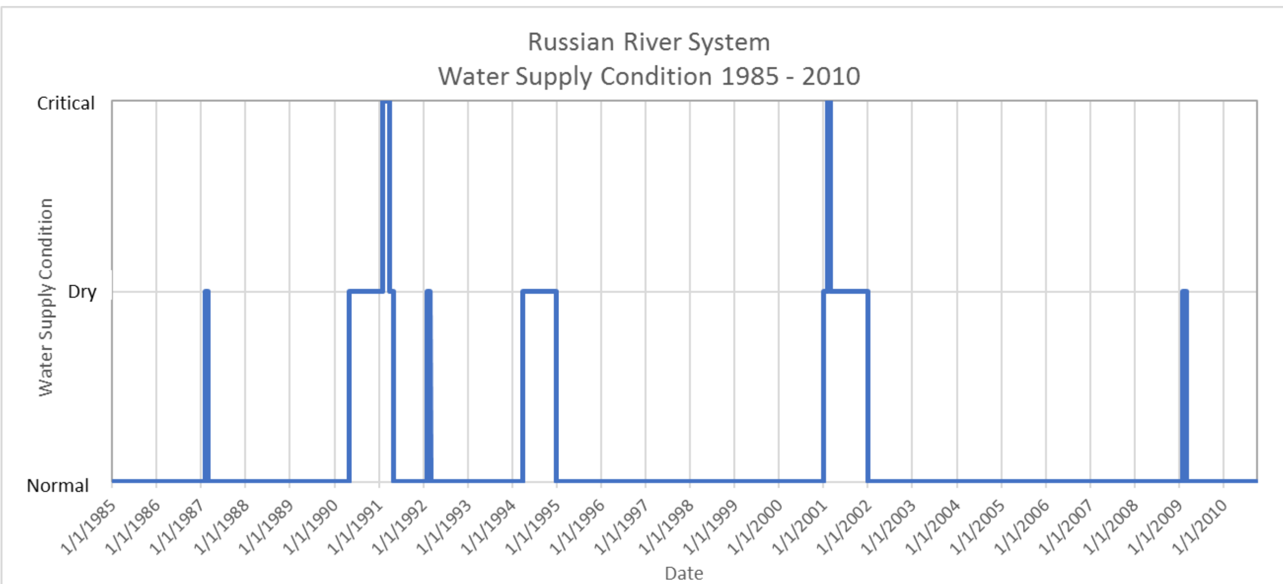


Figure 4-14, Russian River System Water Supply Conditions from 1985 to 2010 calculated from observed Lake Pillsbury inflows.

On June 1 of each year the URR EFO Model evaluates combined simulated storage in Lake Mendocino and Lake Pillsbury to set the minimum instream flows from June 1 to December 31. Lake Pillsbury storage levels from 1985 to 2010 were simulated using ER2.5 as discussed in Section 4.3 and are explicitly defined in the URR EFO Model. If May 31 combined storage level of Lake Mendocino and Lake Pillsbury is below 130,000 acre-feet or less than 80% of total combined storage capacity then a *Normal-Dry Spring 2 Water Supply Condition* is set. Additionally if simulated storage levels fall below 30,000 acre-feet any day between October 1 and December 31 then a *Normal-Dry Spring 1 Water Supply Condition* is set. These changes to the hydrologic condition set reduced minimum instream flow requirements as discussed in Section 4.6.2 below.

4.6.2 Minimum Instream Flow Requirements

As discussed in Section 2.4.3, the minimum instream flow requirements set the floor for flows for the URR. The appropriate flow schedule is determined using current *hydrologic condition* as determined by the hydrologic index and storage conditions in Lake Mendocino and Lake Pillsbury. The minimum instream flows used in this study are consistent with existing water supply operations. From October 16 to April 30, under periods of *Normal* hydrologic conditions, the minimum instream flow requirements are consistent with the requirements of the Water Agency's water rights permits. From May 1 to October 15, under periods of *Normal* hydrologic conditions, the minimum instream flows are consistent with the requirements of the Biological Opinion. The Water Agency is required to request the minimum instream flows of the Biological Opinion from the State Water Board each year if the current hydrologic condition doesn't already require a lower minimum instream flow requirement. The URR minimum instream flows used for this analysis are summarized in Table 4-3.

Table 4-3. Minimum instream flows requirements (cfs) used in the URR EFO Model.

Water Supply	Month												
Condition	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct 1-15	Oct 16-31	Nov	Dec
Normal	150	150	150	185	125	125	125	125	125	125	150	150	150
Normal-Dry Spring 1										75	75	75	75
Normal-Dry Spring 2						75	75	75	75	75	75	75	75
Dry	75	75	75	75	75	75	75	75	75	75	75	75	75
Critical	25	25	25	25	25	25	25	25	25	25	25	25	25

4.6.3 Minimum Instream Flow Compliance Buffer

The model simulates the operational practice of meeting minimum instream flow requirements by setting the required reservoir releases to exactly meet the minimum flows. Operationally this is not feasible because unlike the model, reservoir operators do not have perfect knowledge of the unimpaired flows and downstream reach losses. In the operations of Lake Mendocino, extra releases are typically made as buffers above minimum flows to ensure compliance with the instream flow requirements. Operationally this buffer release is made to account for the dynamic variability of flows downstream of the reservoir and to help prevent flows from dropping below the minimum instream flow requirements. The dynamic nature of flows within the system is typically caused by direct diversions from the river, diversions of underflow made by wells in close proximity to the river, consumption of water by riparian vegetation, and potential error in discharge measurements.

Minimum flow compliance buffers were estimated for the URR EFO Model to approximate how this operational practice impacts reservoir releases. To estimate compliance buffers an analysis of observed flow variability was completed for the Hopland, Cloverdale and Healdsburg model junctions using observed flow and reservoir release data from 2000 to 2012. To analyze the impact of downstream flow variability on reservoir releases, day to day increases in net reach loss were analyzed for the period each year that a particular discharge gage was a compliance point for maintaining minimum instream flows. Additionally, to analyze the model flow buffers for 5-day moving average minimum flow compliance (the buffer assumed for the compliance to the flows required by the Biological Opinion) the analysis also looked at daily increases in 5-day moving average net reach loss. From this analysis an instantaneous compliance buffer of 20 cfs and a 5-day moving average compliance buffer of 9 cfs were estimated for all URR minimum flow compliance model junctions. The instantaneous compliance buffer is applied for *Normal Dry Spring 1 & 2*, *Dry* and *Critical* hydrologic conditions. For *Normal* hydrologic conditions from instantaneous compliance buffer is applied from November 1 to April 30 to simulate operations for the D1610 minimum instream flow requirements and the 5-day moving average compliance buffer is applied from May 1 to October 15 to simulate compliance to Biological Opinion minimum instream flow requirements.

4.7 Reservoir Storage Capacity and Water Surface Area

The Lake Mendocino hypsometry used in URR EFO Model was developed by the USACE from a 2001 bathymetric survey. The 2001 hypsometry was also used to develop the January 2003 revisions to the CVD WCM (USACE, 2003) and is currently used by the USACE and the Water

Agency to inform flood control and water supply operations. Storage versus elevation plot based on the 2001 bathymetric survey is provided in Figure 4-15. Water surface area versus elevation plot for existing conditions is provided in Figure 4-16.

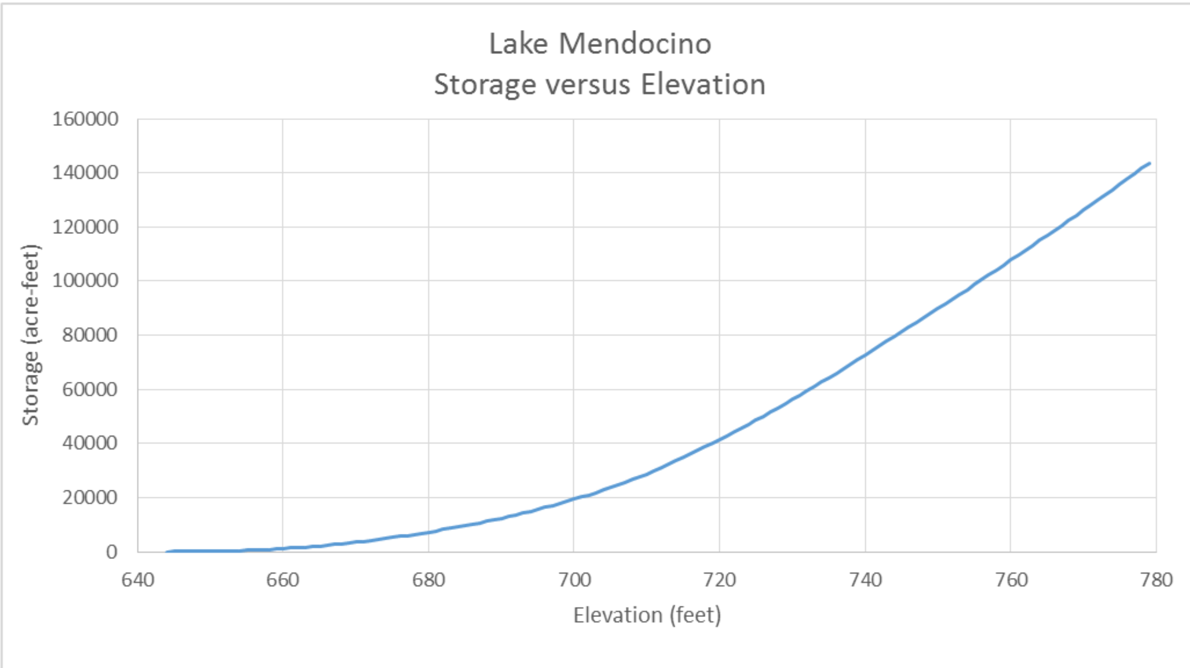


Figure 4-15. Lake Mendocino storage versus elevation for 2001 survey.

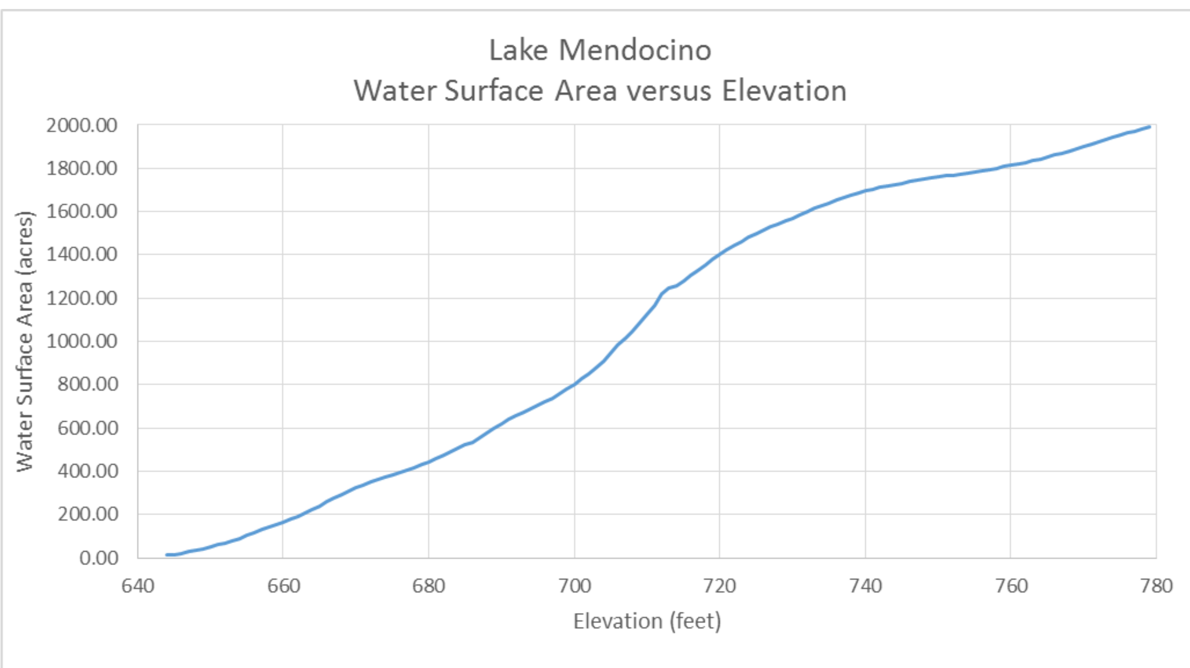


Figure 4-16. Lake Mendocino water surface area versus elevation for 2001 survey.

4.8 Uncontrolled Spillway

The spillway crest for Lake Mendocino is at elevation 764.8 feet msl or storage level 116,500 acre-feet. When storage levels are above the spillway crest the URR EFO Model simulates uncontrolled spillway releases according to the spillway rating curve defined in the CVD WCM and provided in Figure 4-16.

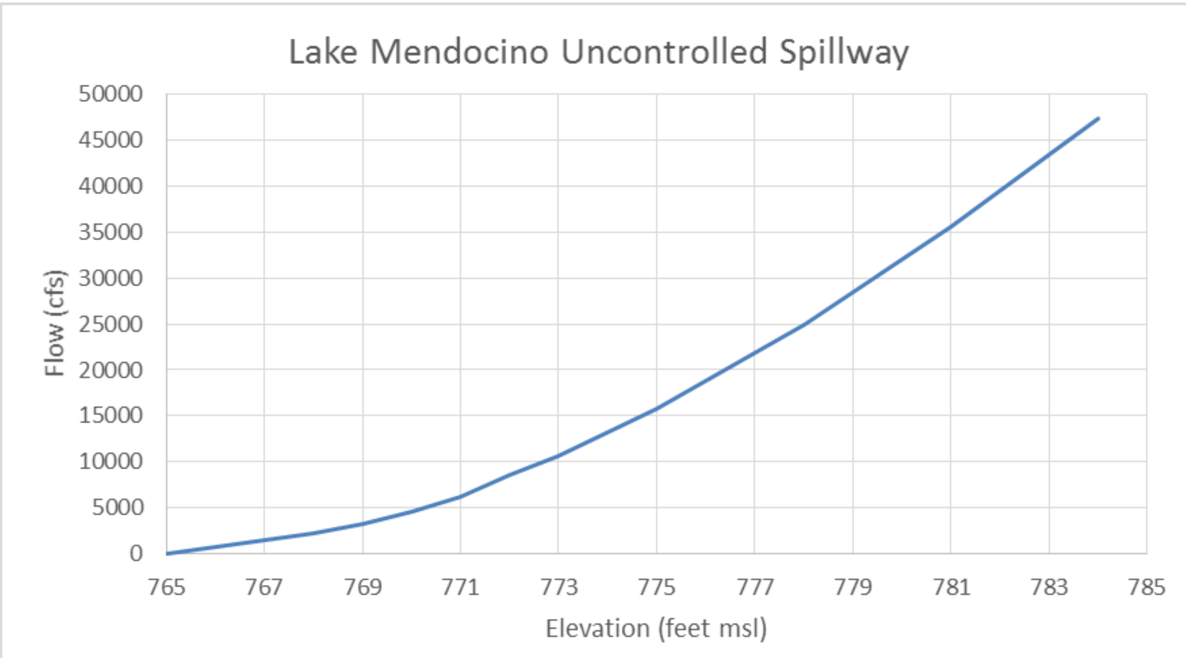


Figure 4-17. Lake Mendocino spillway rating curve.

4.9 Emergency Operations

When simulated reservoir storage levels are within the emergency pool, reservoir emergency operations are simulated consistent with the requirements of the CVD WCM. The Lake Mendocino Emergency Pool is defined as the zone of the reservoir pool, which extends from the top of the Flood Control Pool (771 feet msl or 128,100 acre-feet storage) to the top of CVD (784 feet above msl). The different zones of the Lake Mendocino pool are provided in Figure 2-6. The emergency release requirements are provided in Table 4-4.

Table 4-4. Lake Mendocino Emergency release schedule.

Elevation (feet)	Release (cfs)
764.8	0
771	800
771.3	1,700
771.5	2,500
771.8	3,300
772	4,200
772.3	5000
772.5	5,800
772.8	6,600
773	7,500

4.10 Existing Flood Control Operations

A model scenario was developed that simulates existing flood control operations as a basis for comparing alternative flood operation scenarios. Existing flood control operations are defined in the CVD WCM which is discussed further in Section 2.4.1. As discussed in Section 2.4.2, in 2015 the USACE has approved a deviation to flood control operations to benefit water supply capture. As this deviation needs to be requested and approved by the USACE on an annual basis, it was not incorporated into the modeling of existing conditions.

4.10.1 Downstream Flow Constraints

As discussed in Section 2.4.1, the CVD WCM defines flow limits downstream of CVD which are used to constrain flood control releases. If flows exceed 8,000 cfs at the Hopland Gage then flood control releases are not made. Due to the dynamic nature of flows, actual operations of the reservoir to conform to this operational rule require an assessment of observed and forecasted conditions.

In effort to develop a model rule which simulates actual flood operations to meet downstream flow limits, the USACE and the Water Agency worked closely with dam operators to better understand real time flood operations. Through this collaboration a proxy rule (Hopland Proxy Rule) was developed to simulate actual flood operations for the Hopland maximum flow rule given known constraints in real time operations. Currently the USACE analyze West Fork Gage flows to estimate flows at Hopland and determine flood releases accordingly. Development of the Hopland Proxy Rule was segregated into three separate phases: (1) stage is rising on the West Fork Gage, (2) stage is declining on the West Fork Gage and Lake Mendocino stage is below 755 feet, and (3) stage is declining on the West Fork Gage and the Lake Mendocino stage is above 755 feet. For each phase a relationship between West Fork flow and Hopland flow was developed to calculate a maximum allowable release from Lake Mendocino. The maximum releases based on West Fork flows developed from this analysis are provided in Figure 4-18.

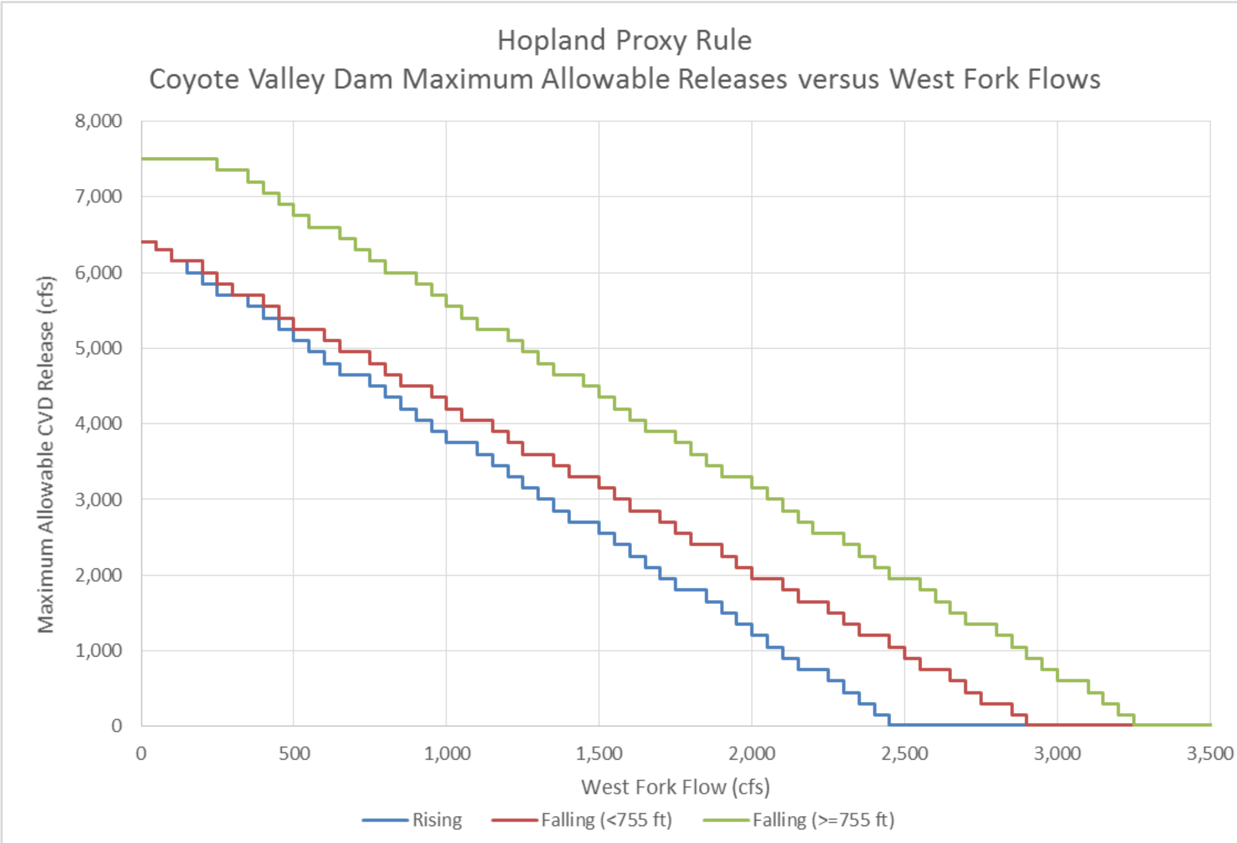


Figure 4-18. Relationship between West Fork flow and maximum allowable Lake Mendocino flood release used in the Hopland Proxy Rule.

4.10.2 Existing Guide Curve Operations

The Flood Control Pool is defined as the zone of the reservoir pool which extends from the top of the conservation pool to an elevation of 771 feet msl or 128,100 acre-feet storage. The top of the conservation pool (provided in Figure 4-19) is seasonally varying with a wet season storage threshold of 68,400 acre-feet (737.5 feet msl) from November 1 to February 28 and a dry season storage threshold of 111,000 acre-feet (761.8 feet msl) from May 10 to September 30. When simulated storage levels are within the Flood Control Pool the model estimates releases from storage until levels are returned back to the top of the conservation pool. These flood control release are subject to the constraints of the Hopland Proxy Rule as discussed in Section 4.10.1, flood control release schedules discussed in Section 4.10.3, and the release ramping rate restrictions discussed in Section 4.12.

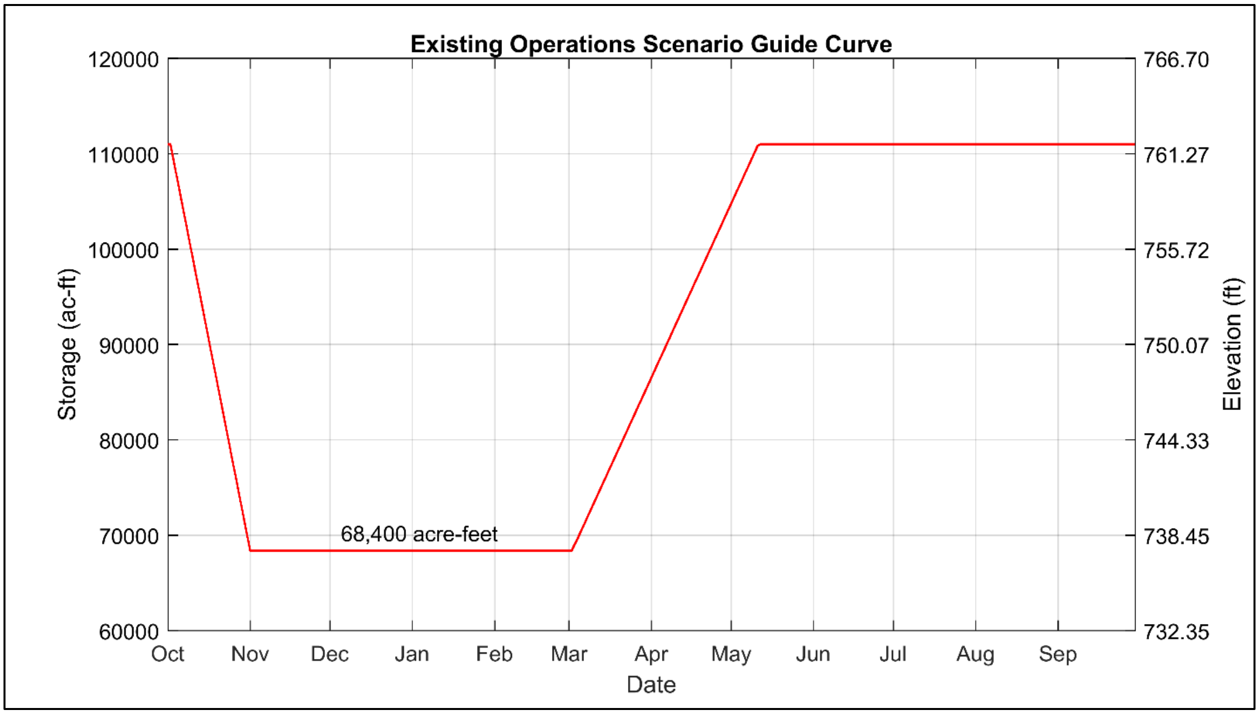


Figure 4-19. Lake Mendocino Existing Guide Curve used for the Existing Operations scenario.

4.10.3 Flood Release Schedules

Each scenario analyzed in this study assumed the flood release schedules as shown in Table 4-5. The release schedules define the maximum release rates from the controlled outlet for different reservoir pool elevations. The release schedules for Schedule 2 and 3 are consistent with those defined in the CVD WCM (USACE, 2003). For Schedule 1 the WCM allows releases up to 4,000 cfs, but based on a review of observed releases a Schedule 1 maximum release of 2,000 cfs was assumed.

Table 4-5. Lake Mendocino maximum flood release schedule.

Flood Release Schedule	Elevation (feet)	Storage (acre-feet)	Max Release (cfs)
Schedule 1	737.5 to 746	68,400 to 82,900	2,000
Schedule 2	746 to 755	82,900 to 98,700	4,000
Schedule 3	755 to 771	98700 to 128,100	6,400

4.11 Modeling of Ensemble Forecast Operations

As a potential alternative to Existing Guide Curve flood control operations this study analyzed Ensemble Forecast Operations which is a risk based flood operations approach developed by the Water Agency that incorporates ensemble flow forecasts prepared by the CNRFC to assess risk of exceeding a reservoir storage threshold.

4.11.1 CNRFC Flow Hindcast

Flow hindcasts developed by the CNRFC are incorporated into the model to approximate 15-day unimpaired flow forecasts for each day in the modeling period from 1985 to 2010. Hindcasted unimpaired flows incorporated into the model include inflows into Lake Mendocino, West Fork flows, and Hopland junction flows. Development of the flow hindcasts by CNRFC is discussed above in Section 4.2.2.

To simulate Ensemble Forecast Operations the URR EFO Model uses the ensemble flow hindcast only to estimate the flood release for each time step. Once a flood release is calculated the model calculates end of period storage using the estimated actual unimpaired flows as well as other components of the water balance such evaporation and other losses and other potential releases such as uncontrolled spillway releases, emergency releases and water supply releases. This approach is consistent with how an operator would actually use Ensemble Forecast Operations. The only knowledge of future unimpaired hydrology an operator would have to set releases would be the flow forecast, but actual storage levels and downstream flow conditions would be resultant from actual hydrology.

4.11.2 Risk Analysis of Modeled Storage Ensembles

With the Ensemble Forecast Operations scenario the URR EFO Model uses the CNRFC ensemble flow hindcast to forecasts Lake Mendocino daily storage levels and flood releases for each of the 61 hindcasted flow ensemble members for the period of 15 days from the current model time step. The 15-day 61 member ensemble forecast is completed for each simulation day of the model simulation period, 1985 to 2010. To aid in the explanation of modeling the Ensemble Forecast Operations scenario an example simulation day, February 8, 1986, is used to describe the computational steps of the model to simulate flood releases. This date is just 10 days prior to the February 18, 1986 flood event, the largest event in the model simulation period, where simulated Hopland junction flows exceeded 25,000 cfs. A hydrograph of simulated Lake Mendocino storage from January 1 to the end of the simulation time step for February 7, 1986 (which is the beginning of the of February 8 simulation time step) is provided in Figure 4-20. The storage level for the beginning of simulation time step February 8, 1986 is 95,842 acre-feet it. Explanation of this example will demonstrate how flood releases are determined and storage is calculated for the Ensemble Forecast Operations scenario.

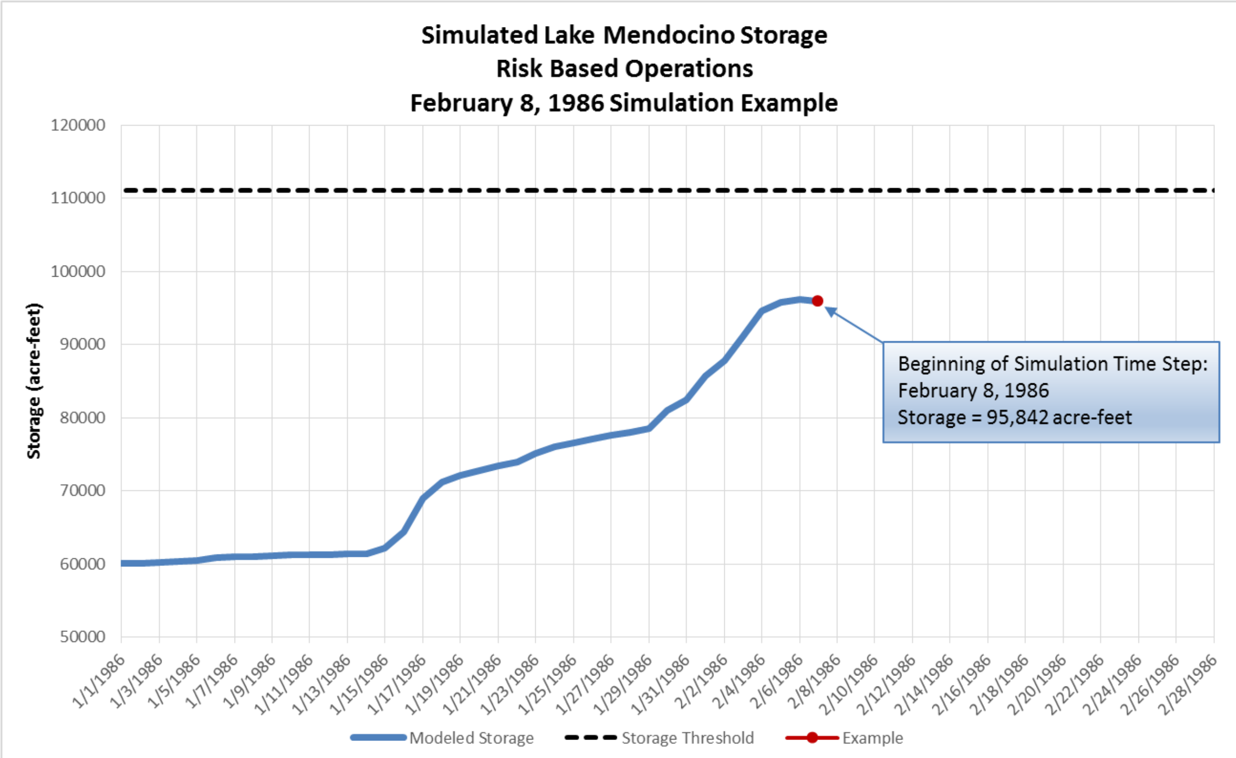


Figure 4-20. Simulated Lake Mendocino storage using Ensemble Forecast Operations URR EFO Model.

Through the modeling of each hindcast ensemble member, the URR EFO Model develops a storage forecast ensemble beginning from the current time step and incrementally moves forward each day of the 15-day forecast one day at a time. Each forecast day the storage forecast ensemble members are evaluated to determine if they exceed the identified storage threshold of 111,000 acre-feet. The percentage of storage forecast ensemble members that exceed the storage threshold is considered the forecasted risk of exceeding the storage threshold. If the forecasted risk exceeds the risk tolerance specified for that forecast day then the URR EFO Model calculates a release that will reduce the forecasted risk below the risk tolerance. This can be illustrated in the example provided in Figure 4-21, which shows the forecasted storage ensemble in the top panel and the forecasted risk in the bottom panel for the example simulation day, February 8, 1986. In this example, 14 of the storage forecast members exceed the storage threshold on day 8 of the forecast, resulting in a risk of 23% which exceeds the risk tolerance of 3.3% for this forecast day.

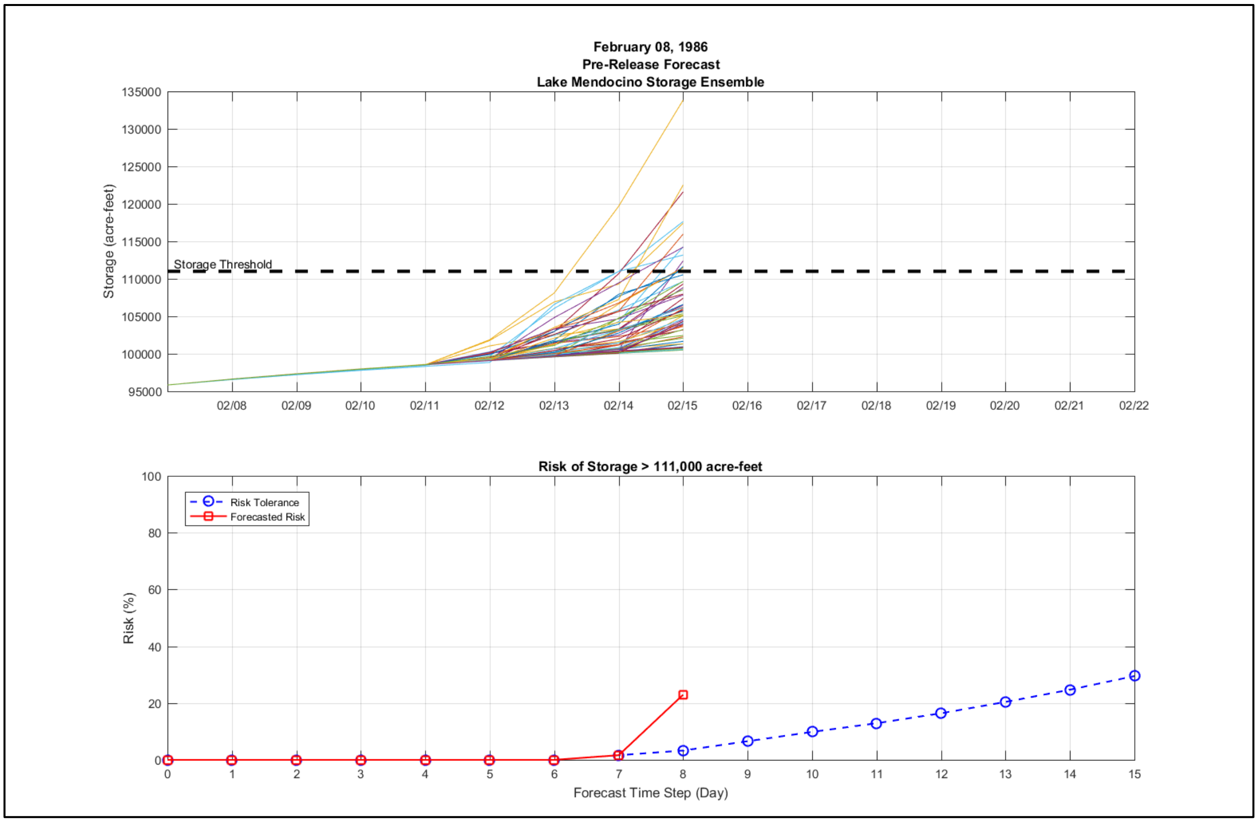


Figure 4-21. Ensemble Forecast Operations forecasted storage ensembles and forecasted risk for time step 8 for February 8, 1986.

If forecasted risk exceeds the forecast risk tolerance, certain ensemble members (Risky Members) are selected to calculate forecast release schedules sufficient to reduce the forecasted storage below the 111,000 acre-feet storage threshold. To select the Risky Members for evaluation of forecast release schedules, ensemble members that exceed the storage threshold are ranked by the level of storage in which they exceed the storage threshold. The minimum number of lowest ranked storage ensemble members is selected that are required to bring the forecasted risk below the risk tolerance for that time step. This can be illustrated for the example simulation day in Figure 4-22. The top panel shows the red highlighted ensemble members (Risky Members) that the model selected for forecasting flood release schedules. The forecast risk tolerance for time step 8 is 3.3% therefore only 2 of the 61 forecasted storage ensemble members can exceed the storage threshold. In this example 14 ensemble members exceeded the storage threshold; therefore the lowest 12 ranked ensemble members were selected as Risky Members.

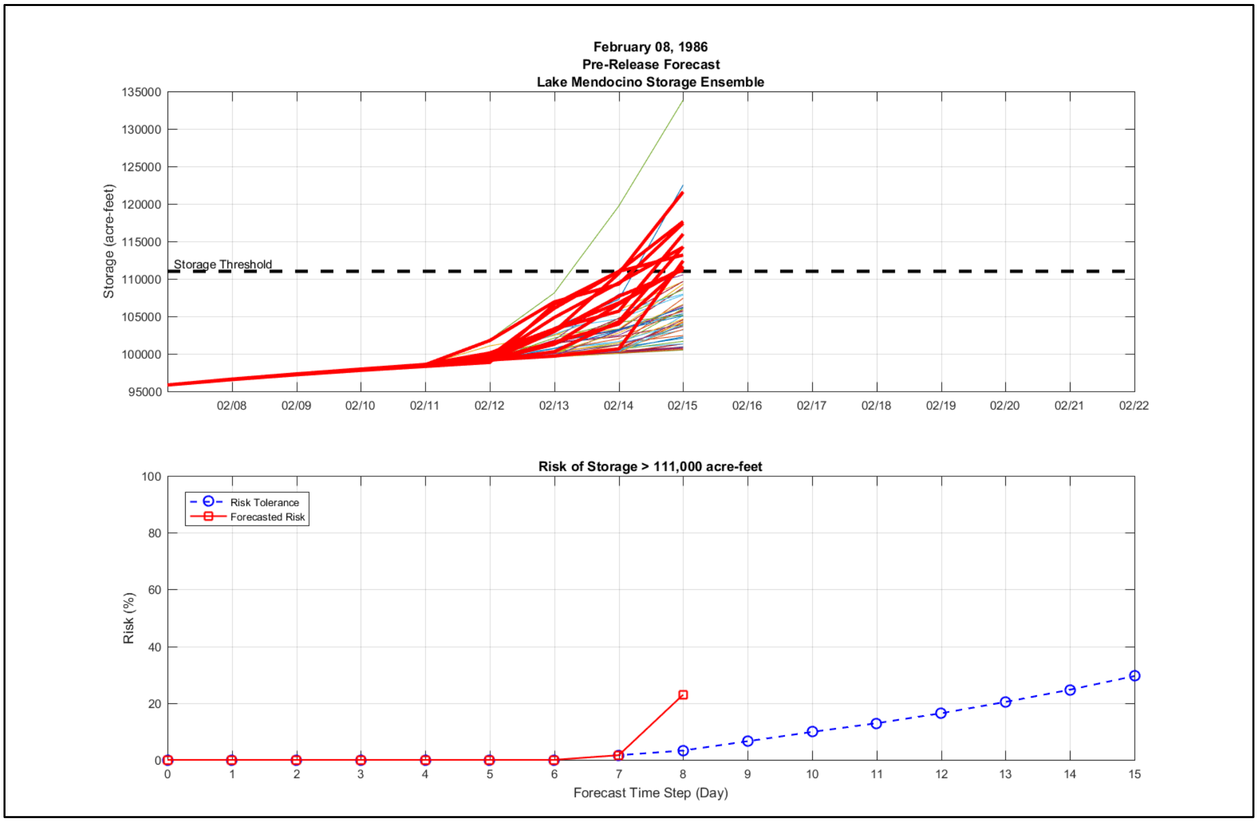


Figure 4-22. Ensemble Forecast Operations forecasted storage ensembles with Risky Members highlighted in red for time step 8 for February 8, 1986.

Release schedules are calculated for each of the Risky Members to bring the forecasted storage to the storage threshold level. The total release required to bring a Risky Member to the level of the storage threshold is simply the level that the member exceeds the storage threshold. This is illustrated for a single Risky Member for the February 8 1986 example in Figure 4-23. In this example this Risky Member exceeds the storage threshold by 10,603 acre-feet, which is the total release volume required to bring this storage ensemble member to the level of the storage threshold.

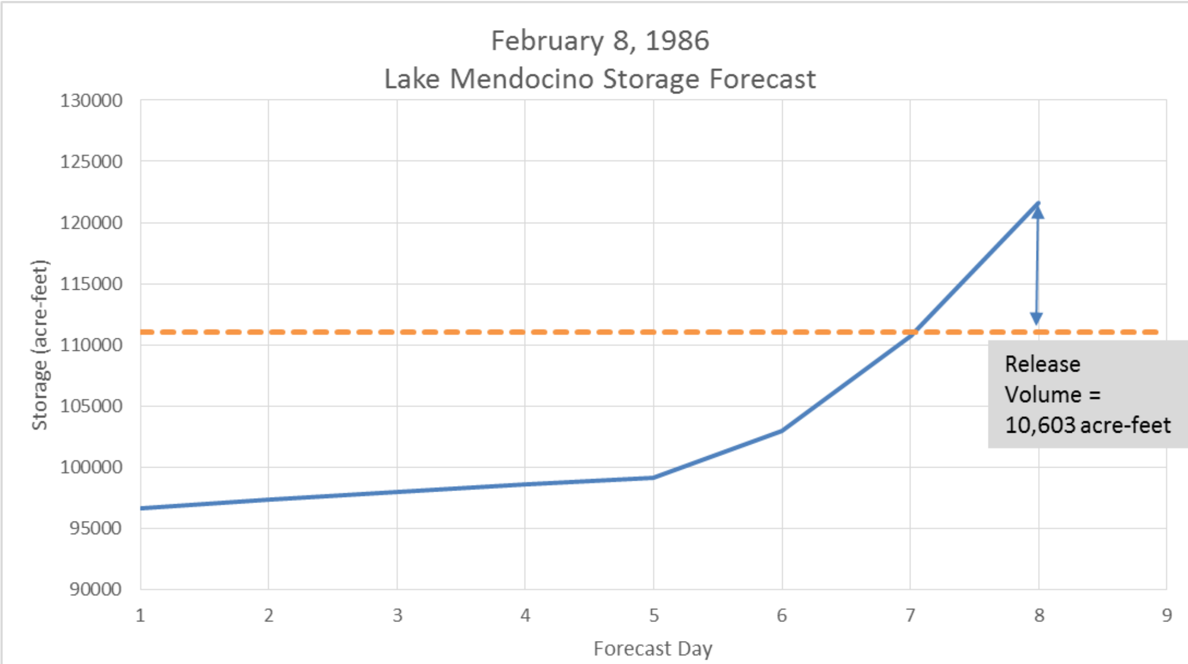


Figure 4-23. Ensemble Forecast Operations calculated release volume of a Risky Member for forecast time step 8 of February 8, 1986.

An initial release schedule is calculated by equally distributing the total release volume to each day of the forecast, from day 1 to the current forecast time step. This is illustrated for a single Risky Member for the example simulation day in Figure 4-24, which shows the initial 8-day forecasted release schedule for February 8, 1986. The total release of 10,603 acre-feet has been equally distributed with a release of 668 cfs to each of the 8 days of the forecast.

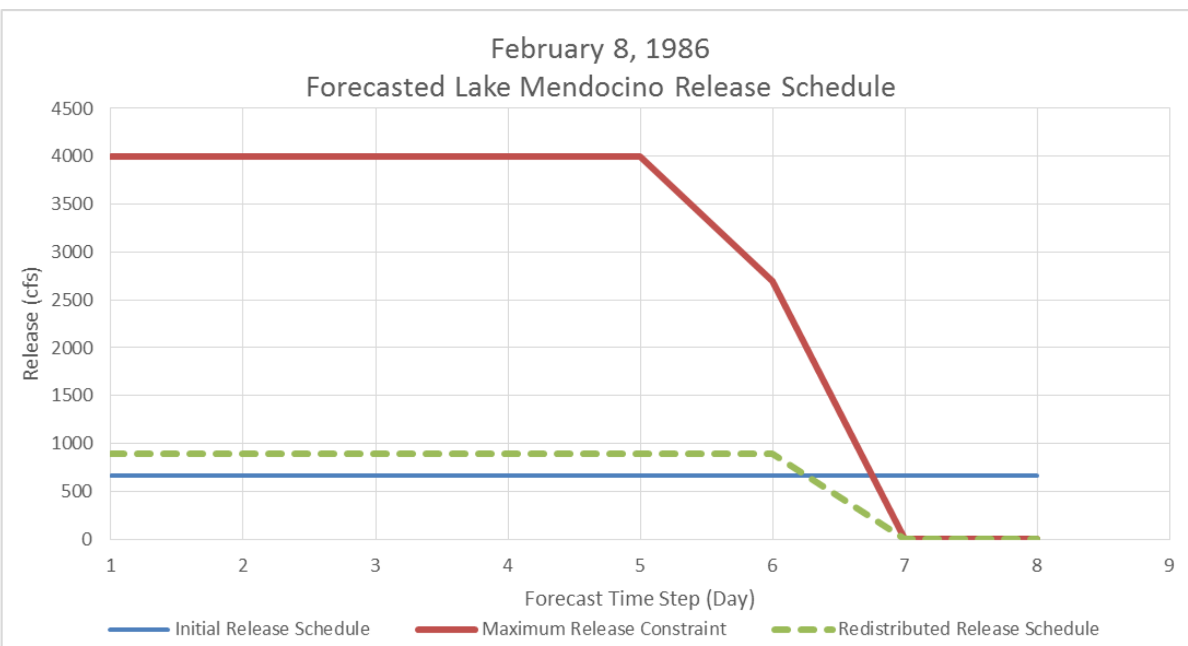


Figure 4-24. Ensemble Forecast Operations calculated release schedule of a single Risky Member for time step 8 for February 8, 1986.

The initial forecasted release schedule is evaluated against the forecasted maximum release limits to assess whether this initial release is feasible based on forecasted storage and downstream flow conditions. The forecasted maximum release limit is simulated taking into consideration the flood release constraints of the flood release schedules as discussed in Section 4.10.3, the downstream flow limit of 8,000 cfs at the Hopland Gage as discussed in Section 2.4.1, and ramping rates discussed in Section 4.12. It should be noted that the Hopland Proxy Rule is not incorporated in the Ensemble Forecast Operations for estimating the forecasted maximum release limit. The Hopland Proxy Rule was designed to simulate operations without a forecast. Since the Ensemble Forecast Operations scenario fully incorporates a hydrologic forecast, the model forecasts the release limit based on forecasted downstream conditions reaching the 8,000 cfs limit at the Hopland junction

If the initial forecasted release schedule exceeds the forecasted maximum release limit for any of the forecast time steps, then the release schedule is adjusted to the release limit for that time step. The adjusted volume is then equally redistributed to the preceding time steps. This can be illustrated for a single Risky Member in Figure 4-24, which shows the forecasted initial release schedule, maximum release limit and the adjusted release. In this figure we see that the initial release exceeds the maximum allowable at forecast time steps 7 and 8. The adjusted release is set to the release limit for forecast time steps 7 and 8 and the volume that the release was adjusted is then equally redistributed to forecast days 1 to 6.

This process of calculating a release schedule is completed for each of the Risky Members. For the February 8, 1986 example simulation, the release schedules for forecast time step 8 are provided in Table 4-6. Although the model estimates future release schedules for the Risky Members for all future time steps, the release of primary interest is the release for forecast day 1. The release schedule is calculated for all future time steps to help ensure that the total volume to bring a Risky Member below the 111,000 acre-feet storage threshold is accounted for in the formulation of the release schedule given the constraints of the forecasted max allowable release. Once the release schedule is calculated for each of the selected ensemble members the most important forecast schedule time step is the day 1 because this is the flood release for the end of the current simulation time step (February 8, 1986 for the simulation example). The maximum release for forecast time step 1 is considered the release required to bring the forecasted risk below the risk tolerance for the given forecast time step. As shown in Table 4-6, the green highlighted release schedule for ensemble member 14 has the maximum day 1 release of 891 cfs.

Table 4-6. Ensemble Forecast Operations calculated release schedules for the Risky Members and the selected release for forecast timestep 8 of the February 8, 1986 example.

Forecast	Release Schedule per Ensemble Member (cfs)											
Time Step	6	10	11	14	27	30	31	34	36	39	44	50
1	679	554	101	891	217	32	39	237	11	272	359	47
2	679	554	101	891	217	32	39	237	11	272	359	47
3	679	554	101	891	217	32	39	237	11	272	359	47
4	679	554	101	891	217	32	39	237	11	272	359	47
5	679	554	101	891	217	32	39	237	11	272	359	47
6	0	0	101	891	0	32	39	237	11	272	359	47
7	0	462	101	0	0	32	0	237	11	0	359	47
8	0	0	0	0	155	32	0	0	11	0	0	0

The forecasted release schedules are applied to each of the selected risky ensemble members to recalculate storage levels to the current forecast time step. This is illustrated for the example simulation in Figure 4-25. This figure shows that forecasted storage levels have been reduced to the storage threshold (111,000 acre-feet) for the Risky Members and forecasted risk has been reduced below the risk tolerance level for forecast time step 8. The green highlighted storage ensemble member corresponds to the highlighted release schedule in Table 4-6. In this example the maximum release for forecast time step 1 is 891 cfs which is therefore the release required to reduce forecasted risk for time step 8 below the risk tolerance level of 3.3%.

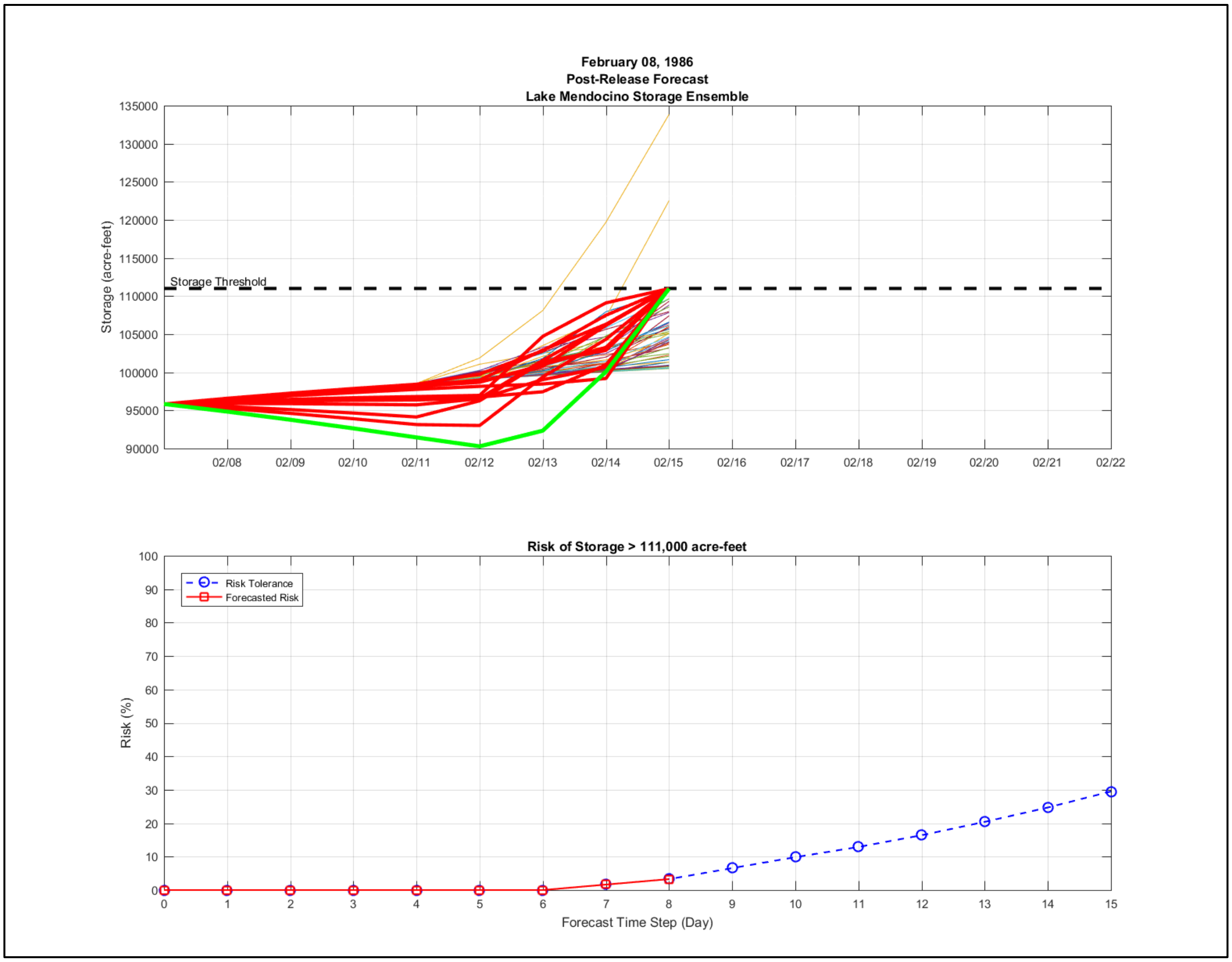
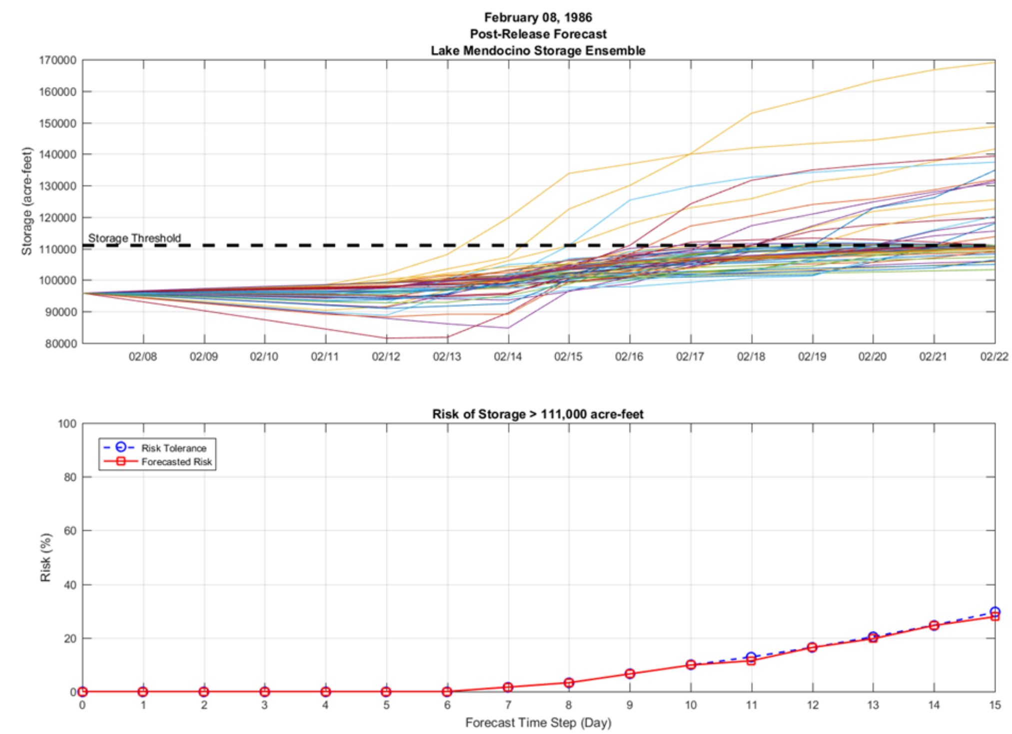


Figure 4-25. Ensemble Forecast Operations URR EFO Model forecasted storage for time step 8 with calculated release applied for February 8, 1986.

The URR EFO Model then moves to the next forecast time step (for the February 8, 1986 simulation example this would be forecast time step 9) and repeats the process of estimating releases schedules for selected risky storage ensemble members. The model iterates through each forecast time step until it reaches time step 15. The model selects the release for the current time step as the maximum forecast day 1 release for all forecast time steps. This is illustrated for the February 8, 1986 example in Figure 4-26, which shows the maximum day 1 release for all forecast time steps in the table on the right hand side of the figure and the forecast day 15 storage ensembles and risk on the left hand side of the figure. For this example forecast day 12 had the highest day 1 flood release of 1936 cfs (highlighted in green in the table). This is the maximum release for all forecast time steps therefore this is required release to reduce the modeled risk below the risk tolerance levels for all forecast time steps. The risk plot in the lower left panel of Figure 4-26 shows that forecasted risk has been reduced below the risk tolerance levels for all forecast time steps.



Time Step	Release (cfs)
1	0
2	0
3	0
4	0
5	0
6	0
7	28
8	891
9	1442
10	1858
11	1905
12	1936
13	1892
14	1838
15	1776

Figure 4-26. Ensemble Forecast Operations URR EFO Model forecasted storage for all time steps with calculated release applied for February 8, 1986.

The estimated flood release is applied for the current model time step and the model calculates the lake water balance to determine the end of time step storage. This calculation is made by the following equation:

$$Storage_{eop} = Storage_{bop} - Evap + 1.9835 \times (Inflow - Release_{flood} - Release_{comp} - Release_{spill})$$

Where:

$Storage_{eop}$ is the end of time step storage in acre-feet;
$Storage_{bop}$ is the beginning of time step storage in acre-feet;
$Evap$ is lake evaporation in acr-feet;
$Inflow$ is the resvoir inflow including natural flow and PVP imports in cfs;
$Release_{flood}$ is the flood release in cfs;
$Release_{comp}$ is the total compliance release in cfs; and
$Release_{spill}$ is the uncontrolled spillway release in cfs.

For the February 8, 1986 example the $Storage_{bop}$ is 95,842 acre-feet, the $Evap$ is 4 acre-feet, the $Inflow$ is 415 cfs, the $Release_{flood}$ is 1936 cfs, and the $Release_{comp}$ and $Release_{spill}$ are 0 acre-feet. This calculation of $Storage_{eop}$ illustrated for the February 8, 1986 simulation example in Figure 4-27 in which the end of time step storage is 92,821 acre-feet.

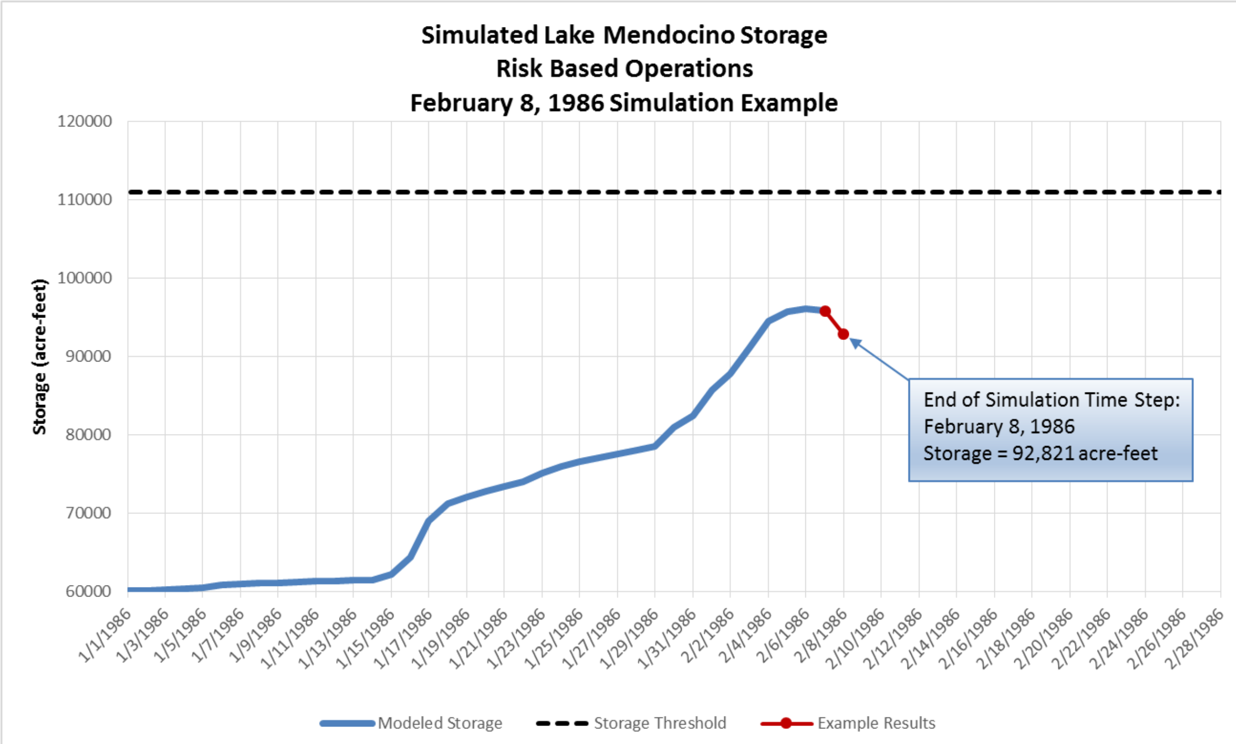


Figure 4-27. Ensemble Forecast Operations simulated storage with the calculated release of 1,936 cfs applied for the February 8, 1986 time step.

The model iterates to the next simulation time step (February 9, 1986 for the simulation example) and completes the Ensemble Forecast Operations process again to determine a flood control release.

4.11.3 Risk Tolerance Curve Development

The risk tolerance curve used as for the Ensemble Forecast Operations scenario, as shown in Figure 3-2 and other figures in Sections 3 and 4.11.2, was developed through an iterative modeling process. The risk tolerance curve water iteratively modified and analyzed with the URR EFO Model to develop a curve which seeks to maximize water capture in Lake Mendocino for the benefit of water supply yet results in no increase in occurrences of uncontrolled spillway releases over simulated existing operations.

4.12 Release Ramping Rates

All scenarios modeled for this study incorporated the same increasing and decreasing rate of change release constraints (ramping rates). These ramping rates only apply to compliance and flood control releases made through the controlled outlet and do not apply to uncontrolled spillway releases or emergency releases. Increasing rate of change constraints are consistent with the CVD WCM and summarized in Table 4-7.

The decreasing rate of change constraints were defined in a 2016 letter to the USACE from NMFS. The decreasing rate of change constraints were developed through a collaborative analysis completed by NMFS and the USACE as part of the Biological Opinion. The decreasing rate of change constraints are summarized in Table 4-7.

Table 4-7. Release ramping rates used in the URR EFO Model.

Period	Release	Hourly IROC	Hourly DROC	Daily DROC
	(cfs)	(cfs/hour)	(cfs/hour)	(cfs/day)
March 15 to May 15	>0 & ≤250	1,000	25	50
May 16 to March 14	>0 & ≤250	1,000	25	-
All Year	>250 & ≤1,000	1,000	100	-
All Year	>1,000 & ≤2,500	2,000	100	-
All Year	>2,500	2,000	250	-

IROC - Increasing Rate of Change

DROC - Decreasing Rate of Change

4.13 Model Verification

To assess model accuracy, a historical verification model scenario was developed. The period of analysis for the historical simulation is from 2000 to 2010. The primary purpose of this historical simulation is to demonstrate that the primary model assumptions, such as the unimpaired, estimated reach losses, and reservoir release constraints accurately simulate observed conditions in the URR during water supply and flood control operations of Lake Mendocino. Development of the datasets for the historical simulation scenario is described below.

4.13.1 Verification Scenario Setup

4.13.1.1 System Gains and Losses

The modeled PVP diversions described above in Section 4.3 are designed to simulate existing conditions, post-2007 operations of the PVP. This dataset was not used for the verification simulation, because it would not accurately simulate PVP operations from 2000 to 2006. For this reason, observed PVP releases were used for the 2000 to 2010 simulation period.

The unimpaired flow dataset developed by the CNRFC was used for verification simulation. This dataset is discussed in Section 4.2.

The model junction losses used for the verification simulation were the losses discussed in Section 4.4.

4.13.1.2 Lake Mendocino Guide Curve

In the spring of 2007, at the request of the Water Agency, the USACE began operating to an alternative guide curve schedule for Lake Mendocino. This alternative schedule is the Existing Guide Curve currently used for reservoir operations and is further discussed in Section 4.10.2. Prior to 2007, the maximum conservation storage was 86,400 acre-feet by March 30. Review of historical Lake Mendocino storage for the verification scenario simulation period shows that periodically the USACE allowed water to be stored in the lake above the guide curve to approximately 90,000 acre-feet to improve water supply capture. The URR EFO Model does not allow for encroachment of storage beyond the top of the conservation pool except for short periods during simulated flood operations. To improve simulation of historical flood control operations, the verification simulation uses the pre-2007 guide curve with a maximum conservation storage of 90,000 acre-feet for the simulation period from 2000 to 2006 and the currently used Existing Guide Curve from 2007 to 2010.

4.13.1.3 Minimum Instream Flow Requirements

Historical water supply operations of the Russian River System from 2000 to 2010 have varied due to changes in regulatory compliance such as temporary emergency actions taken for conservation of water supply and/or changes in minimum flows to comply with the Biological Opinion. The Biological Opinion was issued in 2008 and before this the Water Agency operated Lake Mendocino consistent with the requirements of the Water Agency's water right permits. Additionally, for a number of years within the verification simulation period Temporary Urgency Change Orders (TUCOs) were issued by the State Water Board to reduce minimum instream flows to conserve storage in Lake Mendocino in response to drought conditions. The years within the verification simulation that TUCOs were issued by the State Water Board include 2004, 2007, 2009 and 2010. To improve simulation of historical water supply operations, actual historical minimum instream flow requirements were used for the verification scenario.

The URR EFO Model assumes consistent minimum instream flow compliance buffers for each reach of the URR and for each year of the model simulation, as discussed in Section 4.6.3. This assumption is consistent with present day water supply operations where operators frequently make changes to releases from Lake Mendocino in an effort to minimize the buffer and conserve Lake Mendocino storage. Review of historical operations shows that the compliance buffer has varied considerably, especially prior to water year 2007, before full implementation of the 2004 PVP license amendment. In certain years, such as 2004, flows were managed at rates well above the minimum instream flow requirements likely due to sufficient storage levels in Lake Mendocino and high levels of releases from the PVP. To account for this variability in historic water supply operations, minimum instream flow buffers were adjusted for the verification scenario to better approximate observed historic buffers.

4.13.2 Verification Scenario Results

4.13.2.1 Lake Mendocino

Results of simulated Lake Mendocino storage for the verification scenario were compared to observed storage from 2000 to 2010, as shown in Figure 4-28. Simulated storage levels closely trend observed storage levels, however, water years 2000-2003, 2008 and 2010 show lower peak simulated storage than observed storage. The higher observed storage for these years is the result of encroaching into the Lake Mendocino flood pool that was not accounted for in the model.

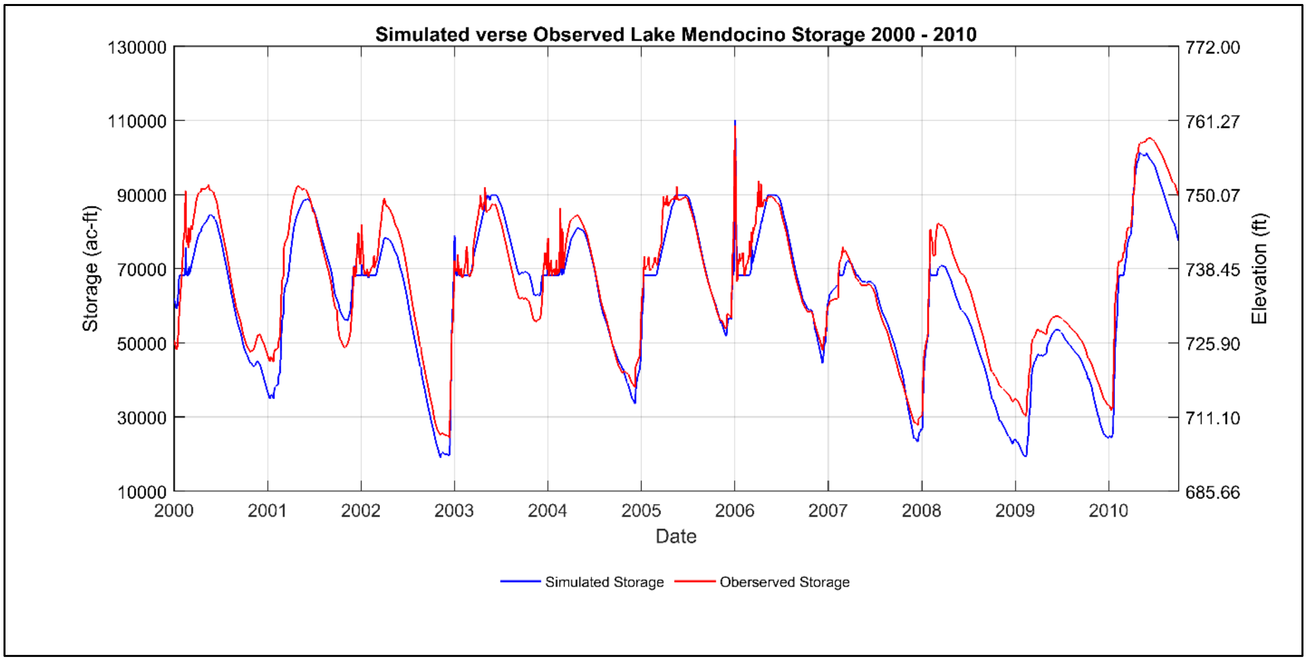


Figure 4-28. Lake Mendocino storage (acre-feet) levels for the simulated Verification scenario observed conditions for 2000-2010.

4.13.2.2 Hopland Junction

Results of the daily simulated flows at the Hopland model junction from the verification scenario were compared to observed flows at the Hopland Gage from 2000 to 2010. A scatter plot of simulated flows versus observed Hopland Gage flows is provided in Figure 4-29. These results show a least-squares linear regression fit of approximately 0.9 to 1 correlation and a R^2 of 0.89. Some of the unexplained variation in the simulated flows is the results of the timing of simulated releases and flow travel times not matching observed conditions. An exceedance probability plot of simulated and observed flows is provided in Figure 4-30. These results show that the distribution of the simulated flows matches closely with the observed flows. These results also indicate that while the model may not exactly match daily observed flows due timing as shown in Figure 4-29, the full range of flows is accurately represented with the model as shown in Figure 4-30.

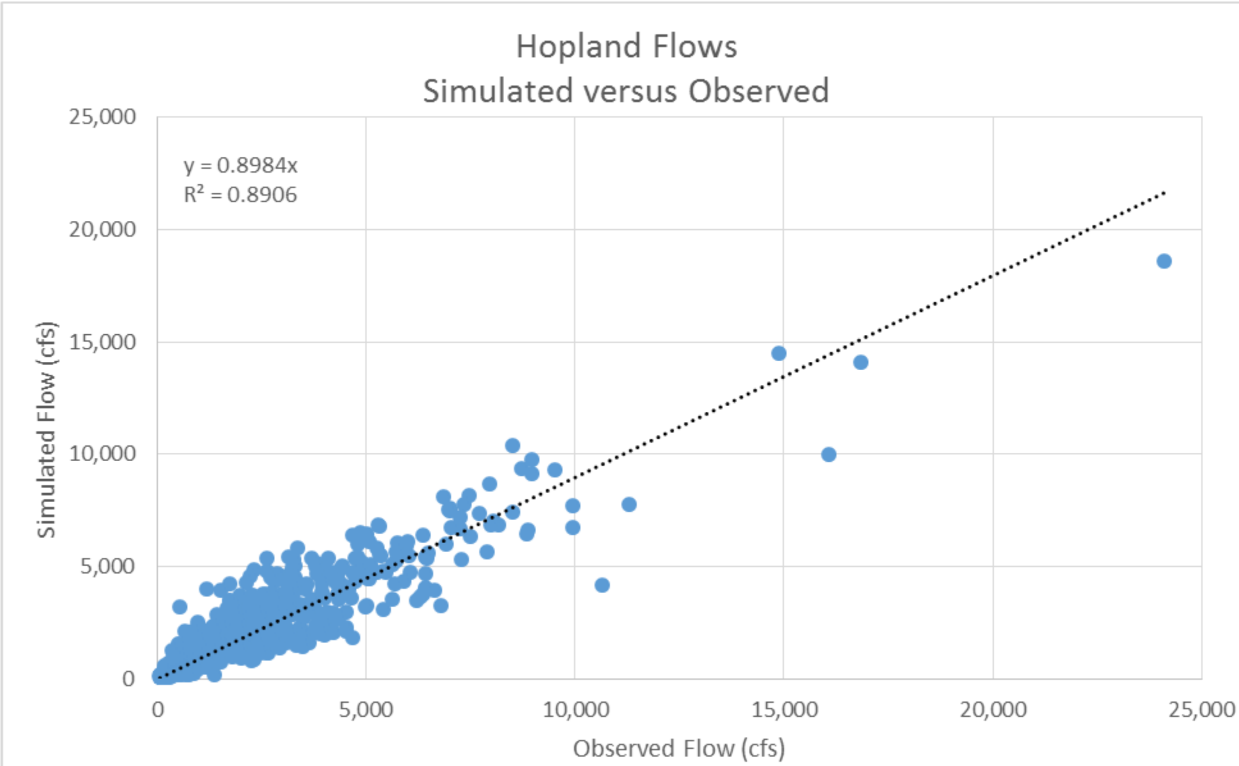


Figure 4-29. Scatter plot of model verification results comparing daily observed and simulated Hopland flow from 2000 to 2010

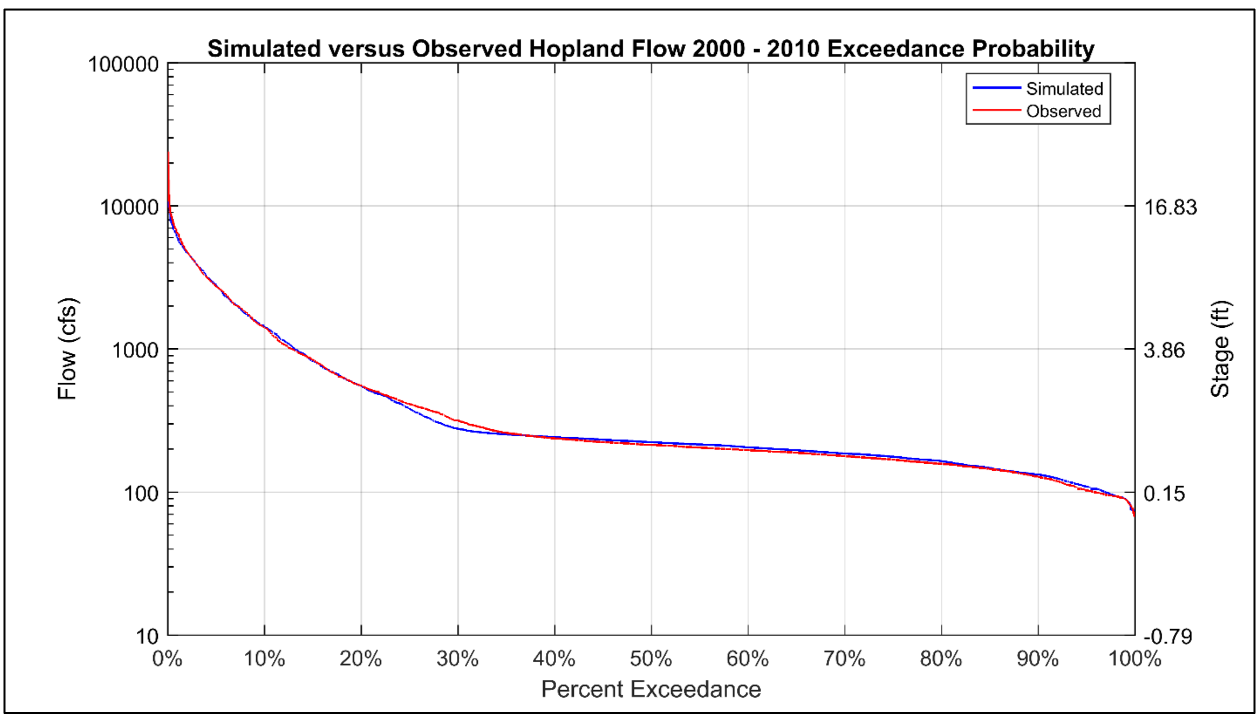


Figure 4-30. Exceedance probability plot of model verification results comparing daily observed and simulated Hopland flow from 2000 to 2010

A hydrograph of Hopland junction flow for the New Year's Day event is shown in Figure 4-31. This flow event is the largest in the verification simulation period. Observed flows reach a peak flow of 24,100 cfs on New Year's Day. Simulated flows fall below observed conditions for this event reaching a peak flow of 18,600 cfs, but trend very well with observed flows for the days leading up to and following the peak flow event.

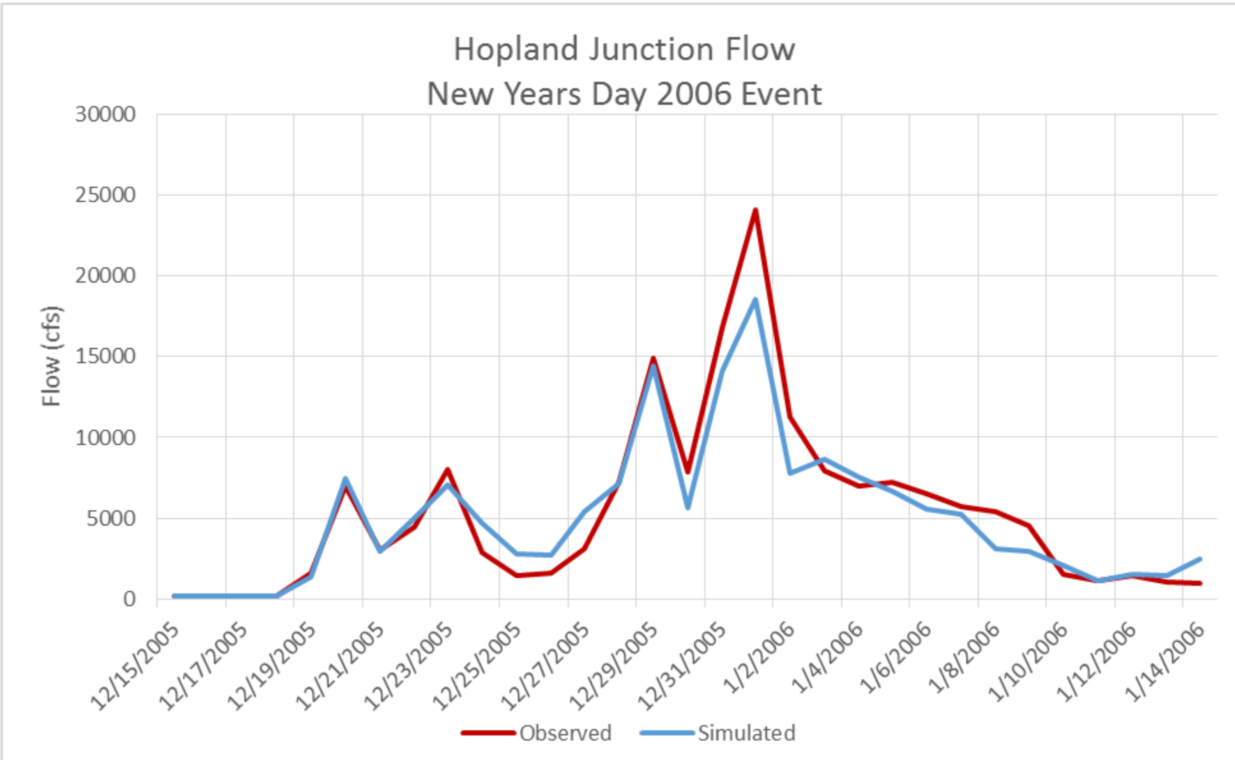


Figure 4-31. New Year's Day 2006 flood event Simulated and Observed flows for the Hopland model junction for the verification scenario.

4.13.2.3 Cloverdale Junction

Results of the daily simulated flows at the Cloverdale model junction were compared to observed flows at the Cloverdale Gage from 2000 to 2010. A scatter plot of simulated flows versus observed flows is provided in Figure 4-32. These results show a least-squares linear regression fit of approximately 0.99 to 1 correlation and a R^2 of 0.93. An exceedance probability plot of simulated and observed flows is provided in Figure 4-33. These results indicate that the fit and distribution of the simulated flows matches closely with observed flows.

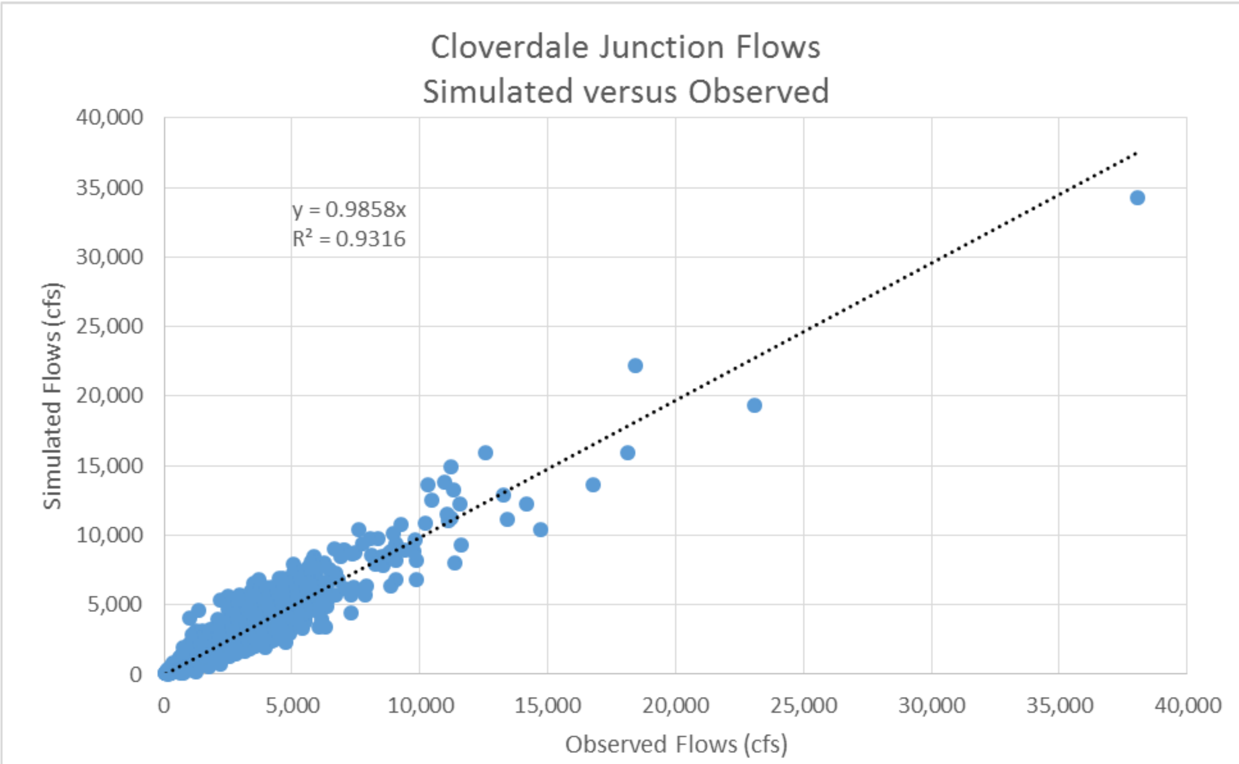


Figure 4-32. Scatter plot of model verification results comparing daily observed and simulated Cloverdale flow from 2000 to 2010

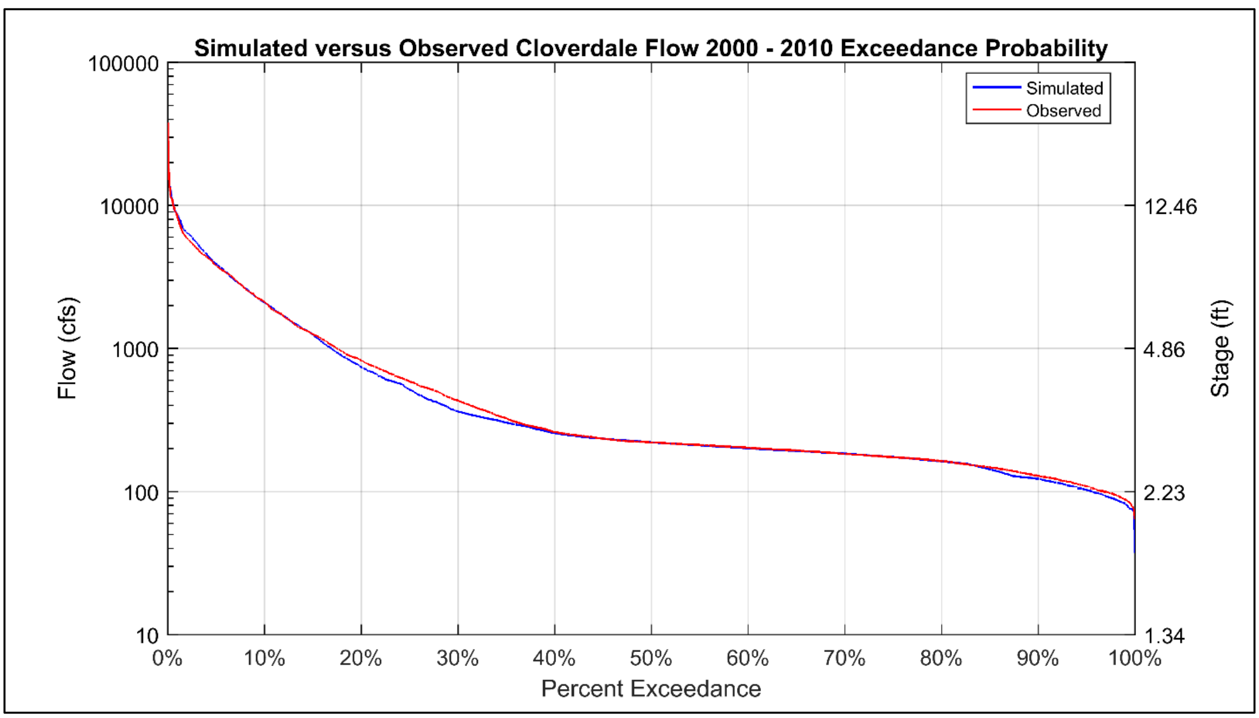


Figure 4-33. Exceedance probability plot of model verification results comparing daily observed and simulated Cloverdale flow from 2000 to 2010

A hydrograph of flow at the Cloverdale junction for the New Year's Day event is shown in Figure 4-34. Observed flows reach a peak flow of 38,100 cfs on New Year's Day. As with simulated flows at the upstream Hopland junction, simulated flows at the Cloverdale junction fall below observed conditions for this event reaching a peak flow of 34,200 cfs, but also trend very well with observed flows for the days leading up to and following the peak flow event.

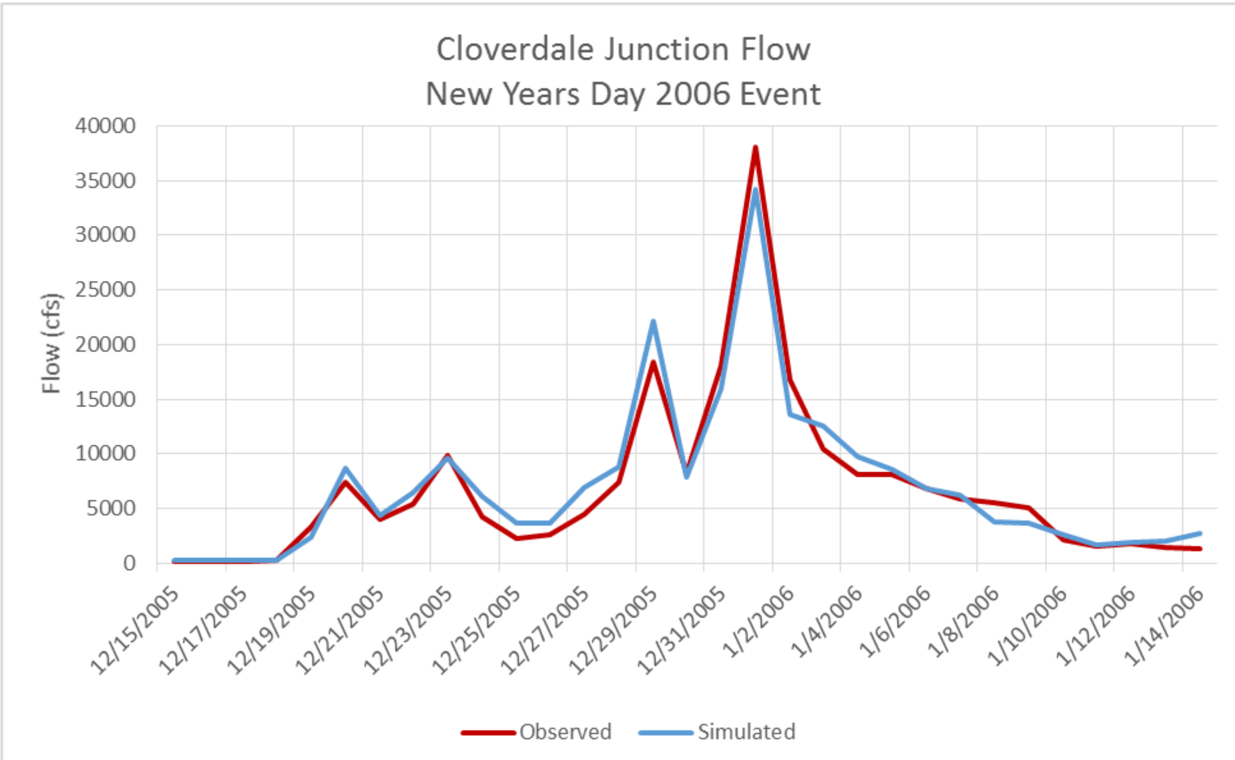


Figure 4-34. New Year's Day 2006 flood event Simulated and Observed flows for the Cloverdale model junction for the verification scenario.

4.13.2.4 Healdsburg Junction

Results of the simulated flows at the Healdsburg model junction were compared to observed flows at the Healdsburg Gage from 2000 to 2010. A scatter plot of simulated flows versus observed flows is provided in Figure 4-35. These results show a least-squares linear regression fit of approximately 1.02 to 1 correlation and a R^2 of 0.95. An exceedance probability plot of simulated and observed flows is provided in Figure 4-36. These results show that the distribution of the simulated flows matches closely with the observed flows, although for the 20% - 60% exceedance range simulated flows fall slightly below observed flows. As with the Hopland and Cloverdale junctions discussed above, these results also indicate that the fit and distribution of the simulated flows matches closely with observed flows.

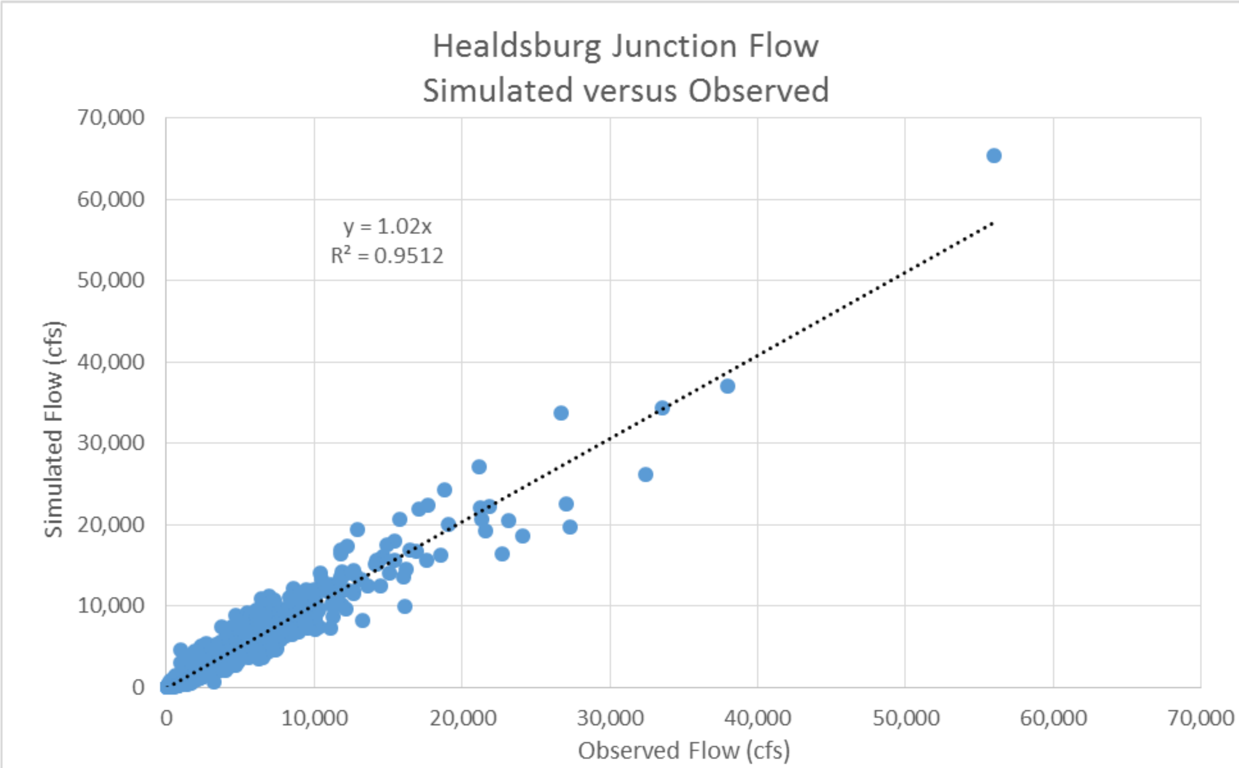


Figure 4-35. Scatter plot of model verification results comparing daily observed and simulated Healdsburg flow from 2000 to 2010

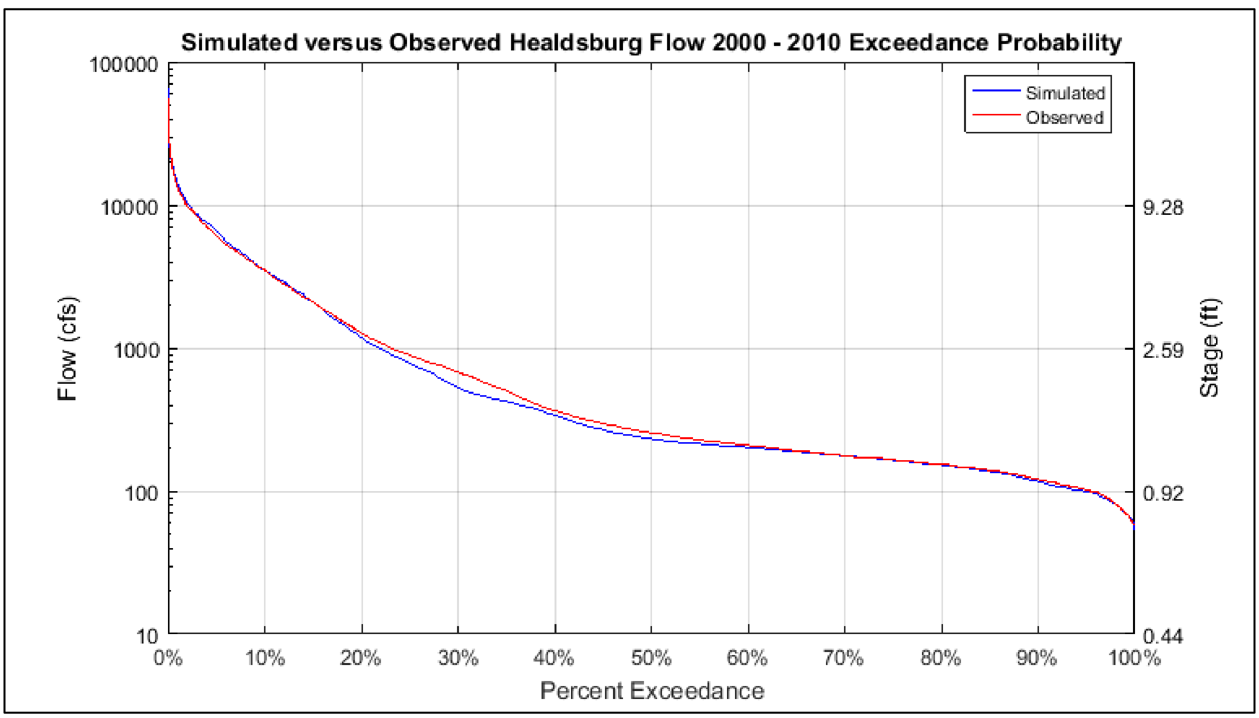


Figure 4-36. Exceedance probability plot of model verification results comparing daily observed and simulated Healdsburg flow from 2000 to 2010.

A hydrograph of Healdsburg junction flow for the New Year's Day event is shown in Figure 4-37. Observed flows reach a peak flow of 56,000 cfs on New Year's Day. Simulated flows at the Healdsburg junction peak at a level above observed conditions for this event reaching a peak flow of 65,400 cfs. As with the upstream Hopland and Cloverdale junctions, simulated flows trend very well with observed flows for the days leading up to and following the peak flow event.

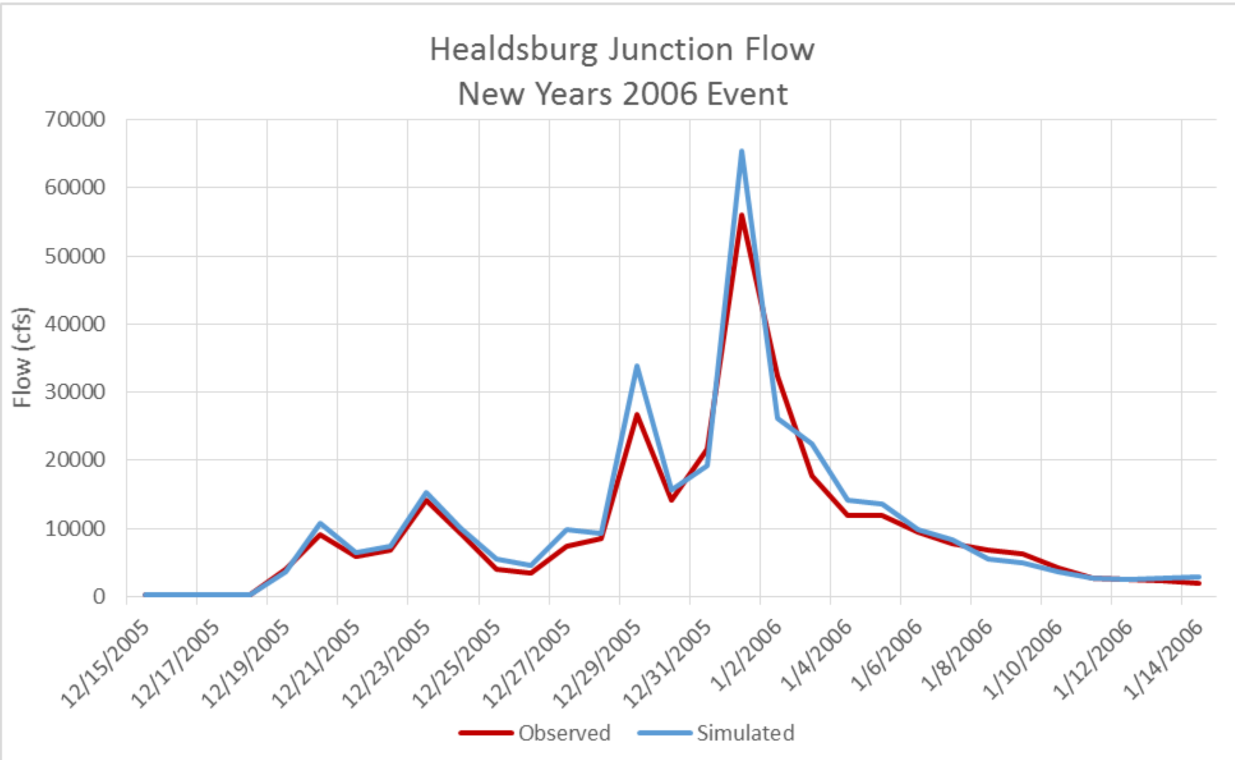


Figure 4-37. New Year's Day 2006 flood event Simulated and Observed flows for the Healdsburg model junction for the verification scenario.

4.13.3 Independent Review of the URR EFO Model

David Ford Consulting Engineers (David Ford) completed a review of the URR EFO Model developed for this study. This was considered the first phase of the review process, which was to review this model used to support the PVA and ensure that physical properties, reservoir rules and operations are properly simulated. In August 2016, David Ford submitted a memorandum to the Water Agency summarizing their review process and findings. In summary, David Ford found that the reservoir physical properties and rules of the model are consistent with those in the HEC-ResSim model developed by HEC (HEC, 2017), the CVD WCM, and Water Control Diagram of the WCM with a few minor noted exceptions (Ford, August 2016). The Water Agency worked with David Ford to make minor modifications to the code to correct the issues identified in this review.

4.14 Flood Operations Scenarios

For this study 4 scenarios of flood operations of Lake Mendocino were developed as summarized below:

1. Existing Operations: this scenario incorporates current flood control operational practices by the USACE;
2. Ensemble Forecast Operations: this scenario incorporates Ensemble Forecast Operations for calculating flood control releases;
3. Hybrid Operations: this scenario incorporates a hybrid operation utilizing both guide curve operations and Ensemble Forecast Operations; and
4. Perfect Forecast Operations: this scenario incorporates a similar methodology to the Ensemble Forecast Operations scenario, but incorporates a perfect forecast to inform release decisions.

All of the scenarios incorporated the same assumptions for the following boundary conditions:

- Unimpaired flows,
- PVP transfers,
- System losses,
- Reservoir hypsometry,
- Water Agency water supply operations,
- Flood control release schedules,
- Release ramping rates,
- Emergency operations, and
- Uncontrolled spillway.

The development of these scenarios is further described in the following sections.

4.14.1 Existing Operations

The Existing Operations scenario simulates the existing flood control operations practiced by the USACE. This scenario incorporate this Existing Guide Curve described in Section 4.10.2, and the Hopland Proxy Rule for downstream flow constraints as described in Section 4.10.1.

4.14.2 Ensemble Forecast Operations

The Ensemble Forecast Operations scenario simulates flood control operations according to the risk based approach developed by the Water Agency and described in Section 4.11. This is a non-guide curve approach to flood control operations and flood control releases are determined with the risk based approach for the entire reservoir conservation pool and flood control pool. This scenario incorporates a risk storage threshold of 111,000 acre-feet and the risk tolerance curve shown in Figure 3-2.

4.14.3 Hybrid Operations

The Hybrid Operations scenario is designed to incorporate both the risk based approach used in the Ensemble Forecast Operations scenario and guide curve operations similar to the Existing Operations scenario. The Hybrid Operations scenario incorporates a modified flood control guide curve (Modified Guide Curve) with the November 1 to March 1 storage level increased by 10% of the total pool storage (116,500 acre-feet). As shown in Figure 4-38, this increases the November 1 to March 1 storage level from 68,400 acre-feet to 80,050 acre-feet. When simulated storage levels exceed the level of the Modified Guide Curve, this scenario calculates flood control releases using guide curve operations. For releases calculated according to the Modified Guide Curve, maximum downstream flow constraints at the Hopland junction are accounted for using the Hopland Proxy Rule. The Modified Guide Curve developed for this scenario is just an example to demonstrate how a possible Hybrid Operations could work and might serve as an initial or incremental step in the implementation of FIRO for Lake Mendocino.

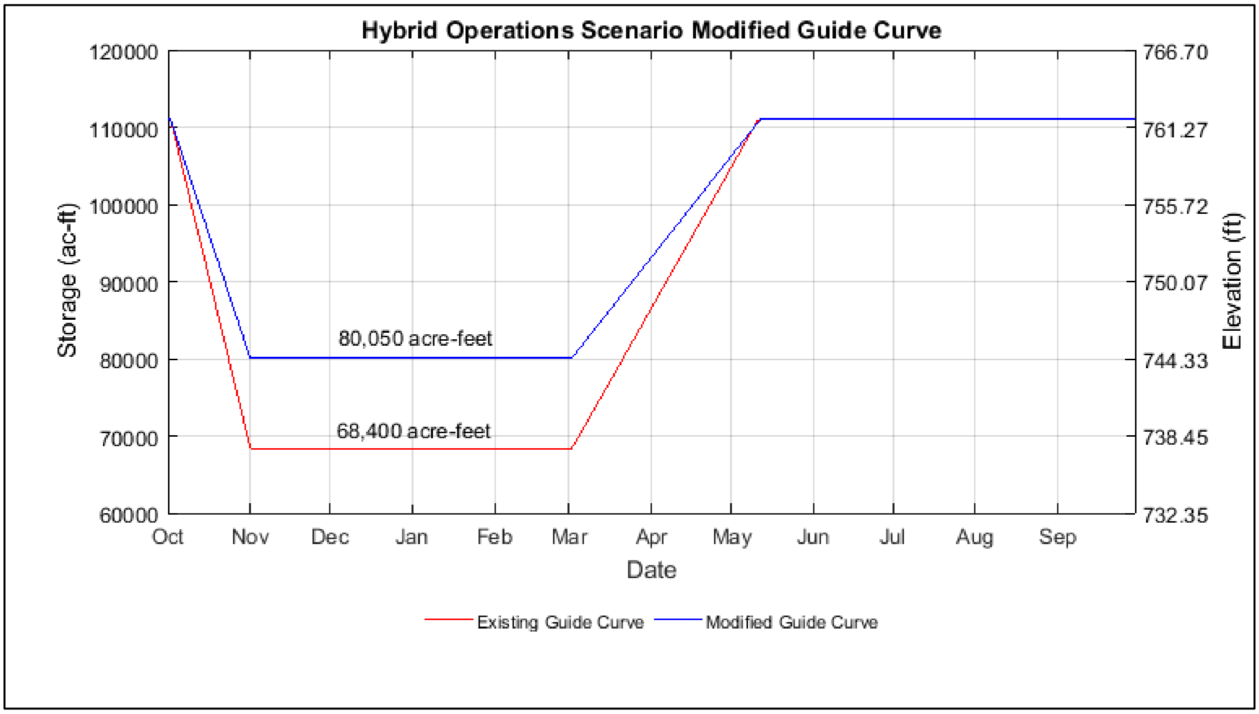


Figure 4-38. Lake Mendocino Modified Guide Curve for hybrid operations.

Additionally, similar to the Ensemble Forecast Operations scenario, the Hybrid scenario also calculates flood control releases with the risk based approach any time storage levels are within the conservation pool or the flood control pool. This scenario also incorporates risk storage threshold of 111,000 acre-feet and the risk tolerance curve shown in Figure 3-2. For any simulation time step where both Ensemble Forecast Operation and guide curve operation flood control releases have been calculated because storage levels are above the level of the Modified Guide Curve, the flood control release applied for the time step is the maximum of the two, Ensemble Forecast Operations release or the Modified Guide Curve operations release.

4.14.4 Perfect Forecast Operations

The Perfect Forecast Operations scenario is designed to simulate operations that incorporate a theoretical perfect forecast skill and represent the upper end or maximum that can be achieved both for water supply and flood protection. The perfect forecast scenario simulates flood control releases similar to the risk based approach, but in place of using the flow ensemble hindcast, this scenario uses the actual unimpaired flows for 15 days ahead of each simulation time step. The perfect forecast is just a single member dataset therefore the risk tolerance is assumed to be 0% for all forecast time steps. Similar to the Risk Based and Hybrid Operations scenarios, this Perfect Forecast Operations scenario incorporates risk storage threshold of 111,000 acre-feet.

5 Model Results and Findings

5.1 Lake Mendocino

5.1.1 Simulated Historical Storage 1985 to 2010

A hydrograph of simulated daily Lake Mendocino storage levels from 1985 to 2010 is provided in Figure 5-1. The hydrograph demonstrates a significant increase in simulated storage for the Perfect Forecast, Risk Based, and Hybrid Operations scenarios relative to the Existing Operations scenarios for almost all of the year simulated. Certain wet years such as 1998, 2003, 2006 and 2010 do not demonstrate a benefit. These years were all characterized by high late season rainfall after March 1 allowing the reservoir to fill to the level of the Existing Guide Curve.

The years 1997, 2002, and 2007 to 2009 show a decline in minimum annual storage for the Hybrid Operations scenario compared to Existing Operations scenario even though the winter peak storage is higher for the Hybrid Operations scenario. A similar result is observed for 2009 for the Ensemble Forecast Operations scenario. The Ensemble Forecast Operations and Hybrid Operations scenarios have more water available for all years of the simulation which can result in the model simulating wetter Hydrologic Conditions (*Normal* instead of *Normal Dry Spring 1 or Normal Dry Spring 2*). This wetter Water Supply Condition results in higher minimum instream flow requirements downstream of Lake Mendocino and therefore higher water supply releases. The higher release and downstream flows cause storage levels for 1997, 2002 and 2007 to 2009 for the Hybrid Operations scenario and 2009 for the Ensemble Forecast Operations scenario to draw below the Existing Conditions scenario.

With the exception of 1986, the Ensemble Forecast Operations, Hybrid and Perfect Forecast Operations scenarios show no increase in occurrence of uncontrolled spillway releases, with storage levels exceeding the crest of the uncontrolled spillway as shown with the black dashed line in Figure 5-1. Water year 1986 is discussed in further detail in Section 5.1.2.

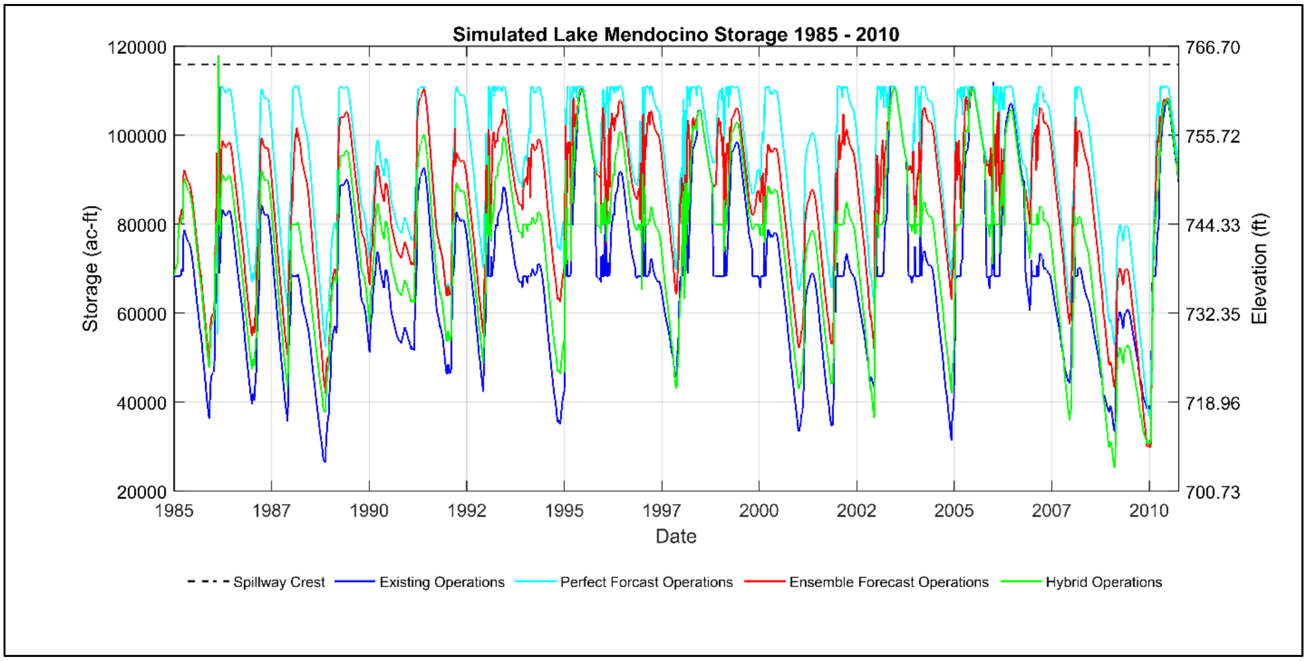


Figure 5-1. Lake Mendocino simulated storage levels for all scenarios from 1985 to 2010.

5.1.2 Water Year 1986

The largest flood event within the simulation domain occurs in February, 1986. A hydrograph of simulated daily Lake Mendocino storage levels for water year 1986 is provided in Figure 5-2. Additionally Figure 5-3 provides a more focused illustration of conditions for the February, 1986 flood event. As shown in the top panel of Figure 5-3, the Ensemble Forecast, Hybrid and Perfect Forecast Operations scenario show storage levels well above the Existing Guide Curve in the beginning of February. Due to forecasted high inflows for mid-February the Ensemble Forecast, Hybrid and Perfect Forecast Operations scenarios increase releases to draw down storage in advance of the forecasted high inflow event to reduce the forecasted risk of exceeding the 111,000 acre-feet storage threshold. The Perfect Forecast Operations scenario draws down storage the most with storage levels dropping well below the Existing Guide Curve in advance of the high flow event. The Ensemble Forecast and Hybrid Operations scenarios draw down storage to about the level of the Existing Guide Curve. This is due to the flow forecast under-forecasting inflow for this event.

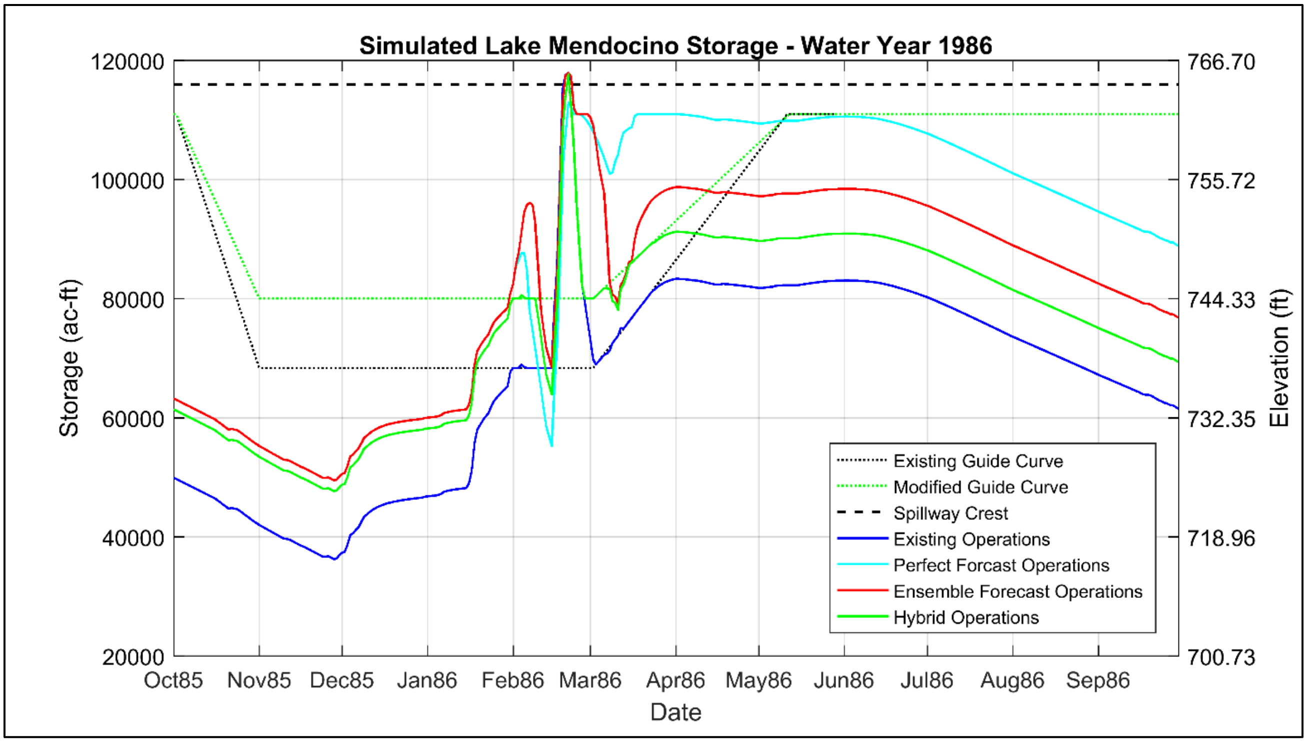


Figure 5-2. Lake Mendocino simulated storage of all scenarios for water year 1986.

Due to high downstream flows at the Hopland Gage above 8,000 cfs, minimal releases are made from February 16 to 21 for all of the model scenarios. As shown in the top panel of Figure 5-3, this results in storage levels rapidly rising. With the exception of the Perfect Forecast scenario, all of the model scenarios including the Existing Operations scenario simulate storage levels rising above the crest of the uncontrolled spillway resulting in uncontrolled spillway releases. A hydrograph of uncontrolled spillway releases for February, 1986 is provided in the middle panel of Figure 5-3. As shown in this figure, the uncontrolled spillway releases reach a peak release of 2,677 cfs for the Existing Operations scenario, 2,605 cfs for the Ensemble Forecast Operations scenario and 1,723 cfs for the Hybrid Operations scenario. The Ensemble Forecast Operations scenario spills for a total of 4 days which is 1 day longer than the Existing Operations scenario and 2 days longer than the Hybrid Operations scenario. The total volume of the uncontrolled spillway release is 11,720 acre-feet for the Existing Operations scenario, 11,900 acre-feet for the Ensemble Forecast Operations scenario and 5,333 acre-feet for the Hybrid Operations scenario. Although the duration of the uncontrolled spillway release is 1 day longer for the Ensemble Forecast Operations scenario compared to the Existing Conditions scenario, the peak spill release and total volume release is very close for the two scenarios. It should be noted that uncontrolled spillway releases were not observed for the February 1986 event, so the model hydrology is conservative for this event since 3 of the scenarios including Existing Operations simulate spillway releases.

None of the alternatives result in an increase in downstream flows at Hopland over Existing Operations. This is illustrated in bottom panel Figure 5-3, a hydrograph of Hopland junction flows. All of the scenarios reach a peak flow of 25,636 cfs on February 18.

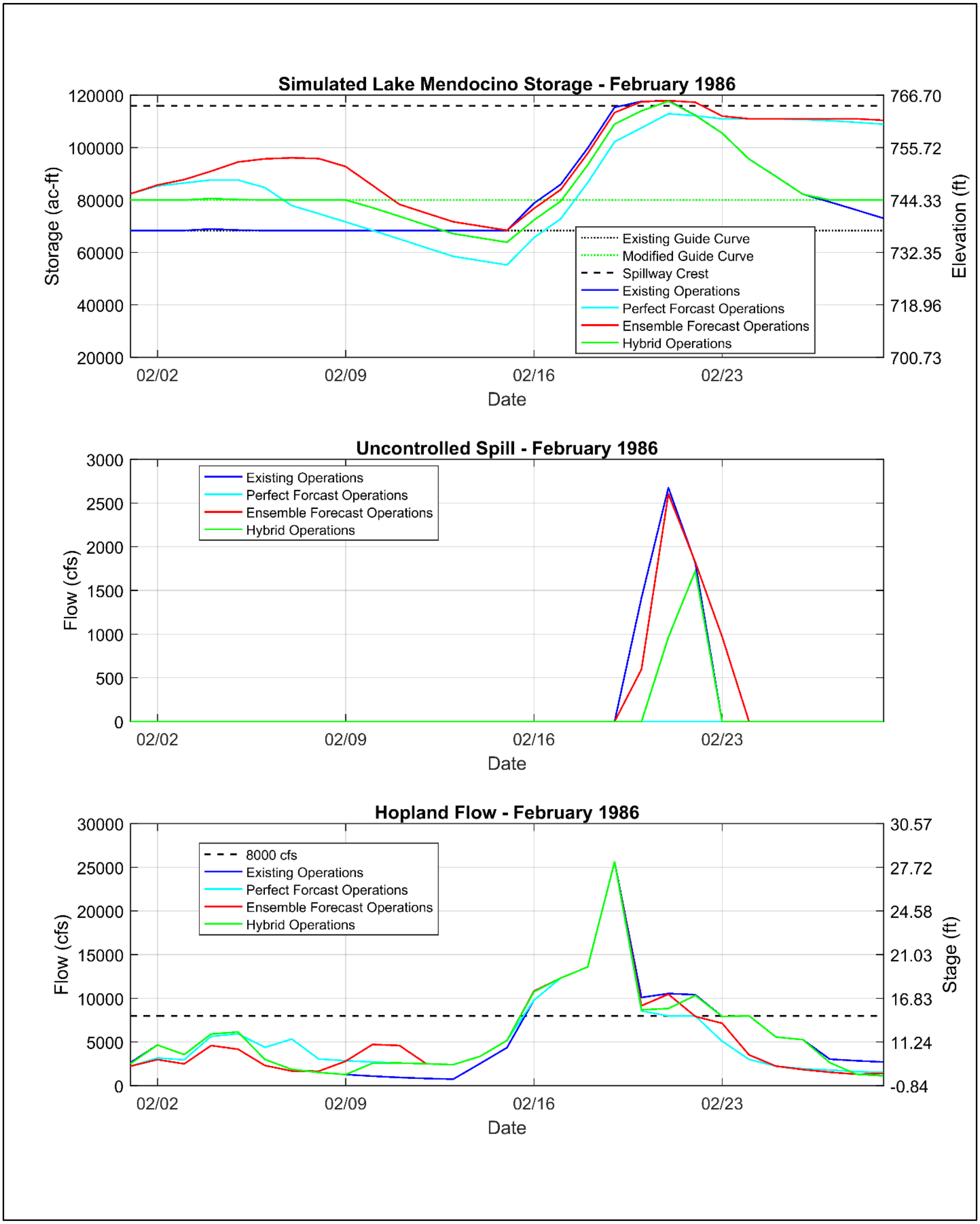


Figure 5-3. Lake Mendocino simulated storage, uncontrolled spillway release, and Hopland flow of all scenarios for the storm in February 1986.

As illustrated in Figure 5-2, peak spring season (post March 1) storage levels are greatest for the Perfect Forecast with a storage level close to 111,000 acre-feet. This alternative represents the upper bound for potential storage of water for this year. The Ensemble Forecast and Hybrid Operations scenarios reach a peak spring season storage levels of approximately 98,500 acre-feet and 91,000 acre-feet respectively. Both of these scenarios show significant gains in water capture for water supply purposes relative to the Existing Operations scenario which reaches a peak spring season storage level of approximately 83,100 acre-feet.

5.1.3 Water Year 1988

Due to the timing of rainfall for water year 1988, this year represents a challenging year for water supply under existing operations of Lake Mendocino. The Ukiah rain gage (National Weather Service station GHCND:USC00049122) received 29.8 inches of rain in water year 1988 which is approximately 81% of the 30-year average for this station. The majority of the rainfall (82%) was received in before the end of January with very little rainfall occurring after February. A hydrograph of simulated Lake Mendocino storage for water year 1988 is provided in Figure 5-4. Due to the constraints of the Existing Guide Curve for the Existing Operations scenario, Lake Mendocino is unable to store conservation water during the wet season (November through February) beyond the 68,400 acre-foot threshold allowed with the guide curve. Because there was very little rainfall after March 1 of 1988, storage levels peak at approximately 68,900 acre-feet in early March and begin declining soon thereafter for the remainder of the water year. The Perfect Forecast and Ensemble Forecast Operations scenarios are not constrained by the Existing Guide Curve and therefore store much more water during the wet season than the Existing Operations scenario with the Perfect Forecast scenario reaching 111,000 acre-feet (top of conservation pool) and the Ensemble Forecast scenario reaching a peak storage level of approximately 101,700 acre-feet. Similar to the Existing Operations scenario, the Hybrid Operations scenario is limited by the Modified Guide Curve developed for this scenario which has a November 1 to March 1 storage level of 80,050 acre-feet. Because the guide curve storage level is increased for the wet season months the Hybrid Operations scenario, simulated storage reaches a higher peak storage (80,500 acre-feet) level than the Existing Operations scenario.

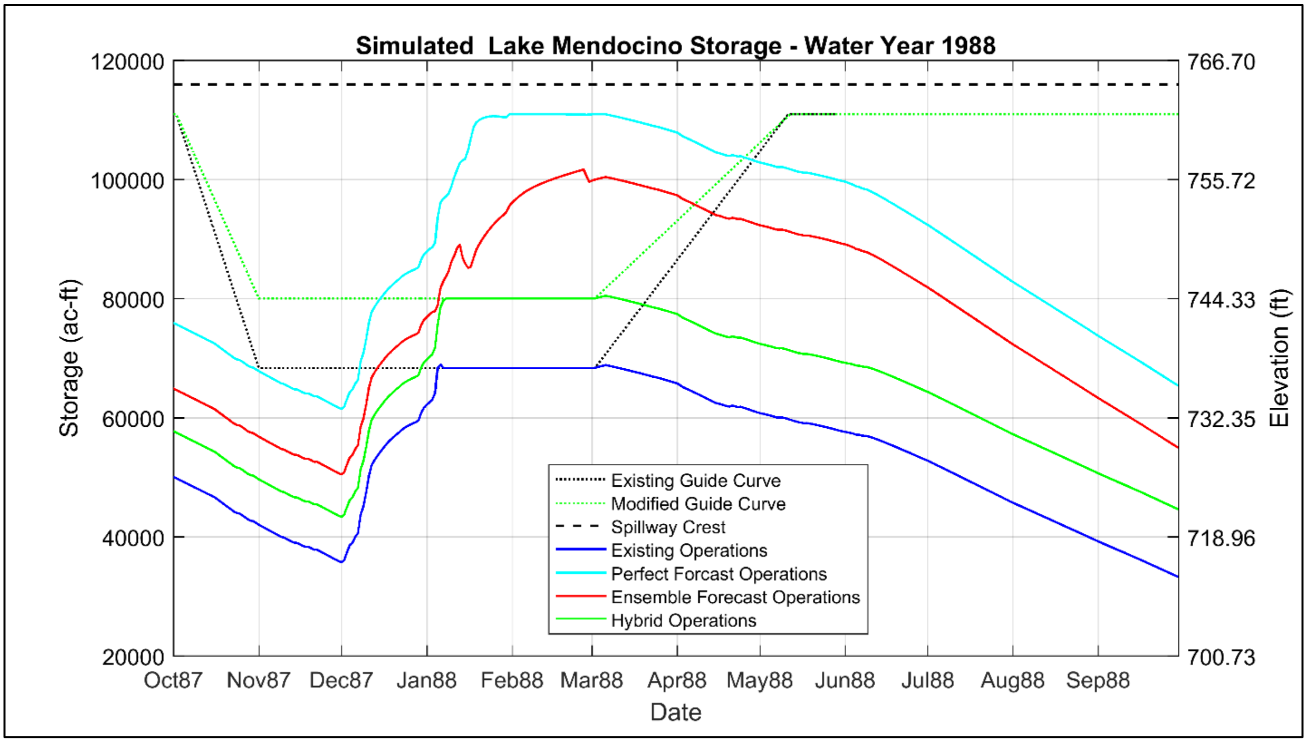


Figure 5-4. Lake Mendocino simulated storage of all scenarios for water year 1988.

End of water year storage declines to approximately 33,100 acre-feet for the Existing Operations scenario. End of water year storage for the Hybrid Operations scenario shows an improvement over the Existing Operations scenario with a storage level approximately 11,300 acre-feet higher, which is approximately the level that the guide curve was raised for the wet season for the Hybrid Operations scenario (116,500 acre-feet). End of water year storage levels for the Perfect Forecast and Ensemble Forecast Operations scenarios are approximately 65,100 and 54,700 acre-feet respectively, which is a significant improvement over the Existing Operations scenario. It should be noted that the rate of storage decline in the dry season months (June through September) for the Perfect Forecast and Ensemble Forecast Operations scenarios is greater than the Existing Conditions and Hybrid Operations scenarios. Due to higher storage levels on May 31 for the Perfect Forecast and Ensemble Forecast Operations scenarios, the water supply condition remains *Normal* from June through December resulting in higher minimum instream flow requirements (125 cfs) than the Existing Conditions and Hybrid Operations scenario, which transition to a *Normal-Dry Spring 2* condition with a lower minimum instream flow requirement (75 cfs). Due to the higher flows for the Perfect Forecast and Ensemble Forecast Operations scenarios also provide improved downstream flow conditions for rearing salmonids from June 1 to September 30.

5.1.4 End of Water Year Storage

A chart of Lake Mendocino end of water year storage exceedance probability is provided in Figure 5-5. Model simulation results for the Perfect Forecast Operations scenario demonstrate the largest increases in end of water year storage from the 11% to the 96% exceedance levels (almost all years of the model simulation) with an increase in median end of water storage over the Existing Conditions Operations scenario of approximately 27,780 acre-feet.

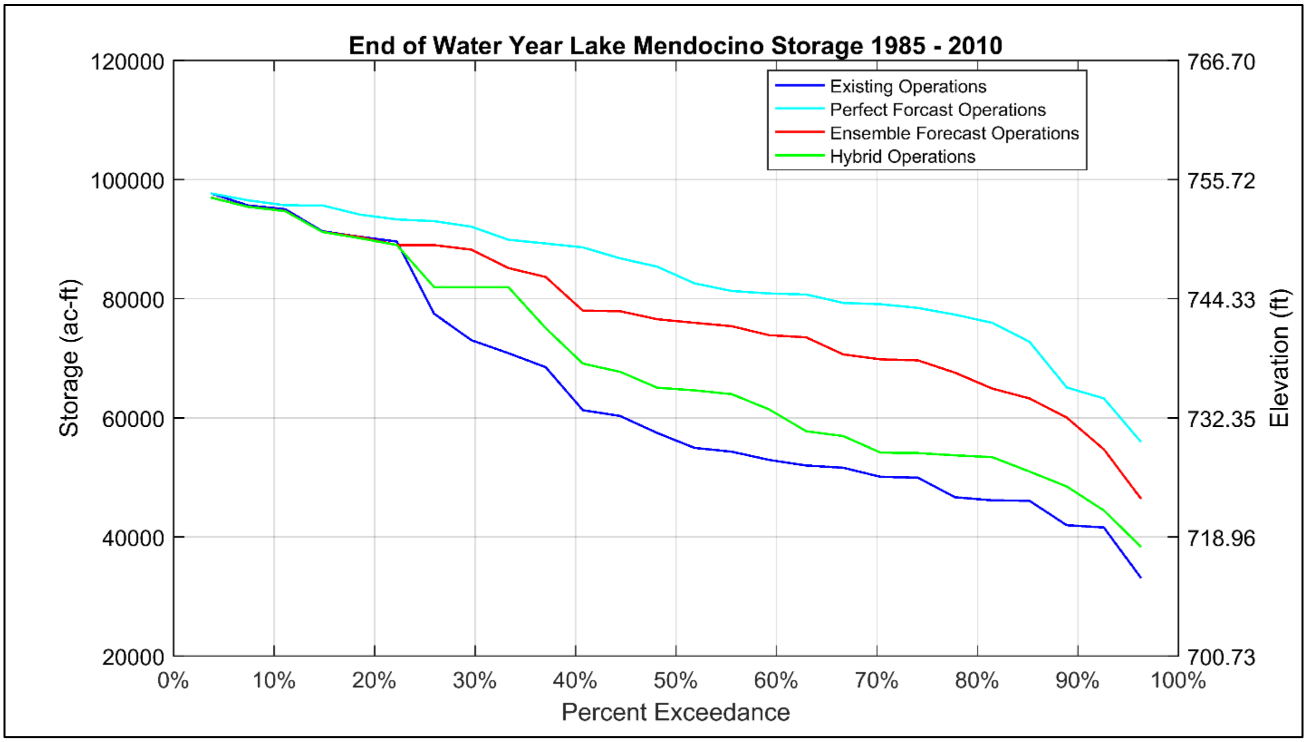


Figure 5-5. Lake Mendocino simulated end of water year storage percent exceedance of all scenarios for 1985-2010.

Model simulation results for the Ensemble Forecast Operations scenario also demonstrate significant storage gains over the Existing Conditions Operations scenario from the 22% to 96% exceedance range with an increase in median end of water year storage over the Existing Conditions Operations scenario of approximately 20,057 acre-feet.

Model simulation results for the Hybrid Operations scenario demonstrate modest storage gains over the Existing Conditions Operations scenario from the 26% to 96% exceedance range with an increase in median end of water year storage over the Existing Conditions Operations scenario of approximately 8,633 acre-feet.

The results presented in Figure 5-5 also show that all of the alternative scenarios (Perfect Forecast, Ensemble Forecast, and Hybrid Operations) result in a decrease in variability of end of water year storage over the Existing Conditions scenario. The Perfect Forecast Operations scenario demonstrates the least amount of variability in end of water year storage with the smallest difference between the 4% and the 96% exceedance storage levels. The Ensemble Forecast Operations scenario also demonstrates a significant reduction in variability of end of water year storage relative to the Existing Operations scenario. The Hybrid Operations scenario demonstrates some reduction in variability of end of water year although not as significant as the other alternatives.

5.1.5 Reservoir Release Ramping Rates

Reservoir release ramping rates were found to constrain simulated flood releases for all model scenarios. The number of instances or days in which ramping rates constrained releases for each scenario is shown in Figure 5-6. Almost all of the instances are the result of the decreasing rate of change rule of 50 cfs per day between March 15 and May 15. As shown in Figure 5-6 most of the instances occur during compliance operations. For *Normal* hydrologic conditions the minimum instream flow requirements reduce 60 cfs on May1 from 185 cfs to 125 cfs. Figure 5-6 are shows there are instances where ramping rules constrain flood releases. The Perfect Forecast Operations scenario has the least number of instances occurring during flood releases. The Ensemble Forecast Operations and Hybrid Operations scenarios both have increased instances ramping rules constraining flood releases over the Existing Operations scenario.

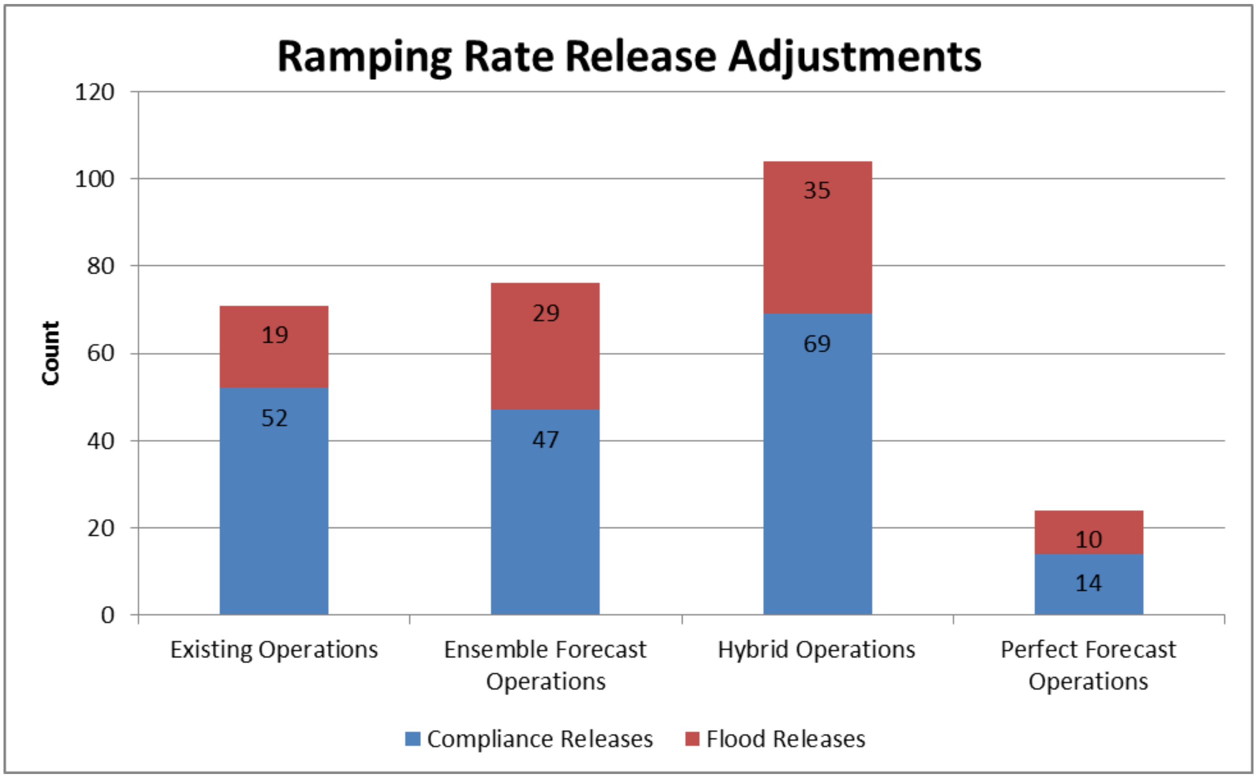


Figure 5-6. Number of instances of ramping rate rules constraining compliance releases and flood control releases.

5.2 Downstream Flow Conditions

Downstream flows for the Perfect Forecast, Ensemble Forecast and Hybrid Operations scenarios match closely to the Existing Conditions scenario. Charts of percent exceedance of daily flows for the Hopland, Cloverdale and Healdsburg model junctions have been provided as Figure 5-7, Figure 5-8 and Figure 5-9 respectively. Of note is that flows for the Perfect Forecast, Ensemble Forecast and Hybrid Operations scenarios are above the Existing Operations scenario from the 75% to the 93% exceedance range (dry season conditions) for all of the downstream junctions. This increase is due to higher compliance releases to maintain higher minimum instream flow as a result of more water available in Lake Mendocino for these scenarios. This indicates an improvement over the Existing Conditions scenario through maintaining higher flows for fishery needs and other beneficial uses.

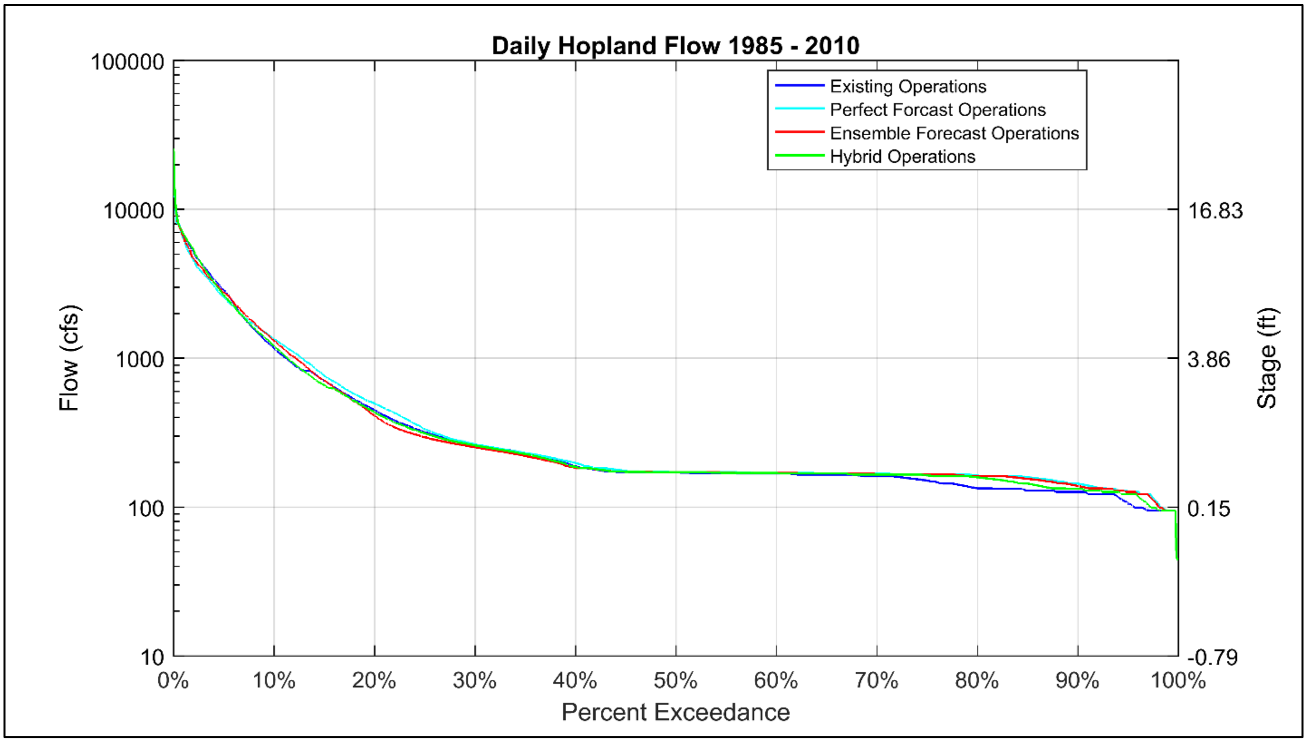


Figure 5-7. Hopland simulated flows percent exceedance of all scenarios for 1985-2010.

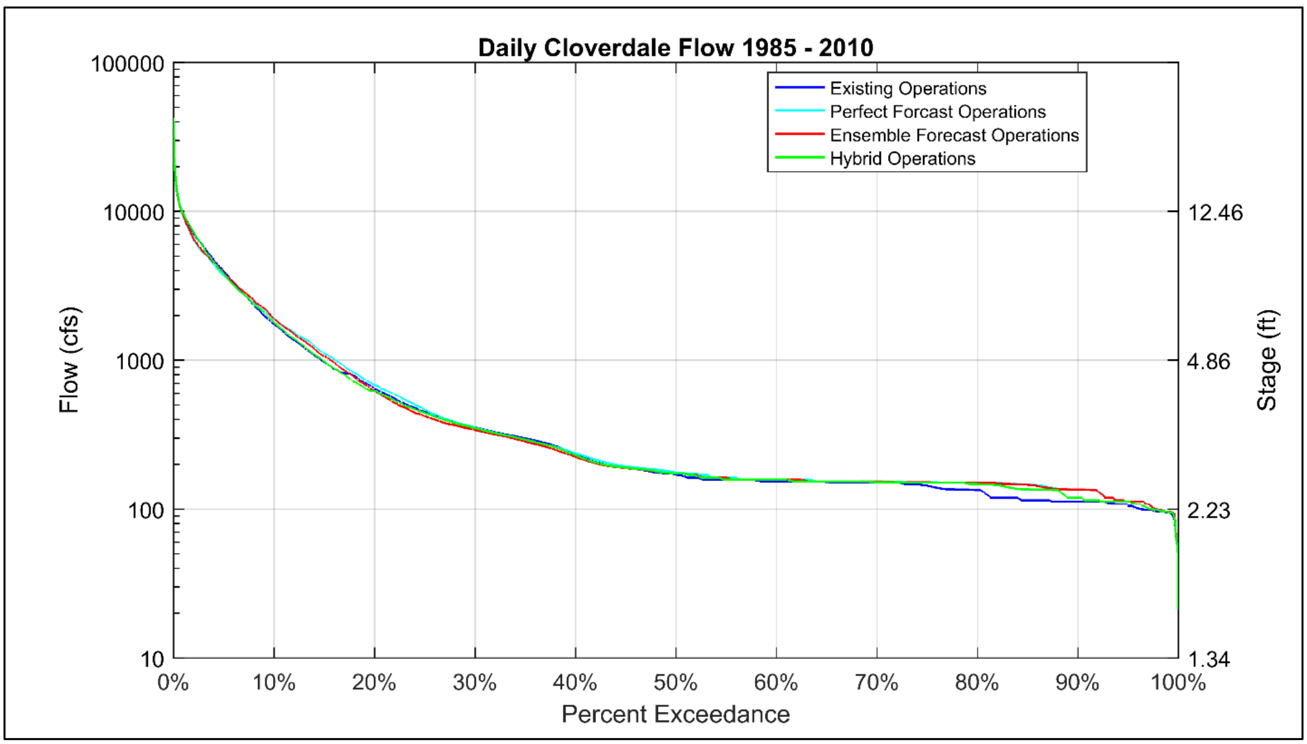


Figure 5-8. Cloverdale simulated flows percent exceedance of all scenarios for 1985-2010.

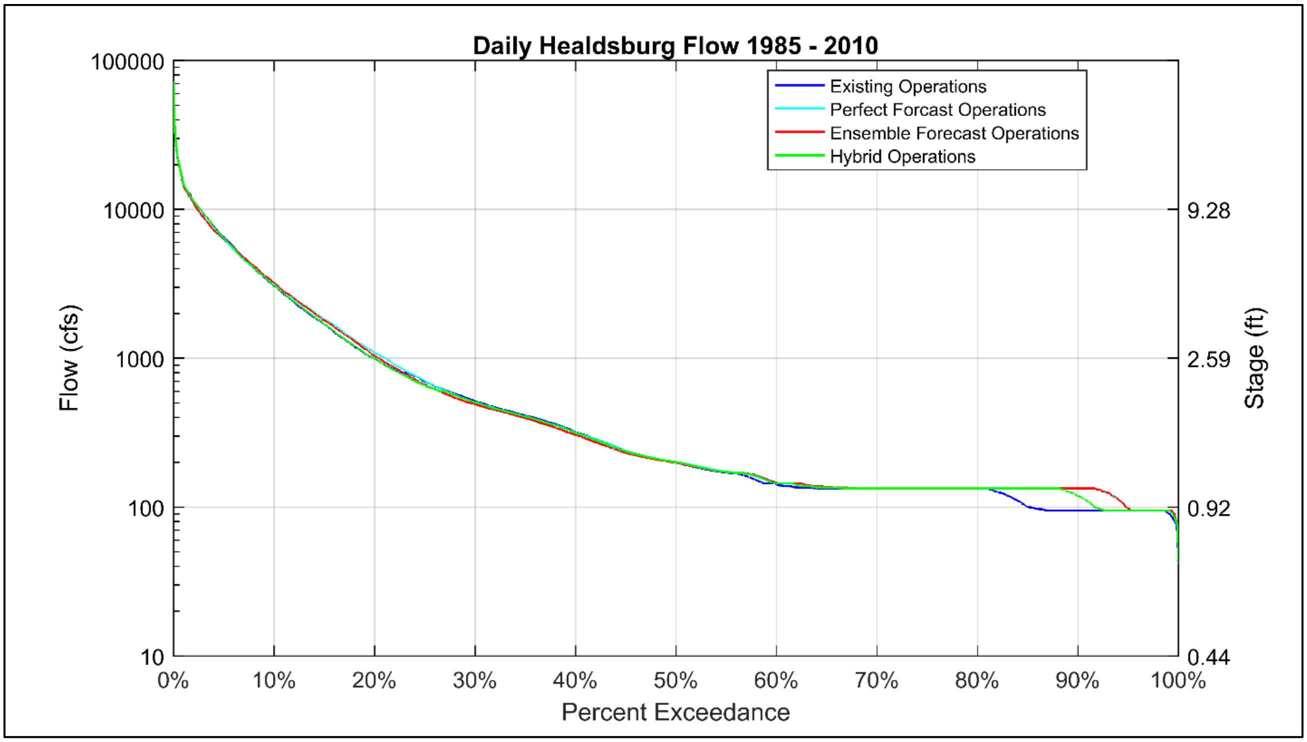


Figure 5-9. Healdsburg simulated flows percent exceedance of all scenarios for 1985-2010.

5.3 High Flow Conditions

An analysis of simulated flows was completed for the Perfect Forecast, Ensemble Forecast and Hybrid Operations scenarios to assess whether the modified operations of these alternatives created instances where flows were increased during high flow periods for the Hopland and Healdsburg model junctions.

5.3.1 Hopland Model Junction

Simulated Hopland junction flows were analyzed for each scenario for days that flows exceeded 8,000 cfs. As discussed in Section 2.4.2, 8,000 cfs is the level of flow at the Hopland Gage above which the Highway 175 Bridge is anticipated to flood.

To analyze the change in flow conditions for the Perfect Forecast Operations scenario, simulated Hopland junction flows were filtered to include only periods that either the Perfect Forecast or the Existing Operations scenario exceed 8,000 cfs. Results of this filtered dataset are provided in Figure 5-10 as a scatter plot of Hopland junction flows for the Perfect Forecast Operations scenario versus the Existing Operations scenario. A blue dashed line indicates the 8,000 cfs flow level for both the x and y axis. The blue “o” tick marks show that simulated Hopland junction flows closely match (within 0.5%) for the Perfect Forecast and Existing Operations scenarios above approximately 10,000 cfs. The green “x” tick marks show instances where the Perfect Forecast Operations scenario decreases flows greater than 0.5% below the Existing Operations scenario. The Perfect Forecast Operations scenario has 21 instances that flows were reduced which is 45% of the total sample. Results further indicate that the Perfect Forecast Operations scenario does not create any additional instances of flows above 8,000 cfs at the Hopland model junction.

The scatter plot in Figure 5-10 also includes lines indicating the flow level for monitor stage (11,300 cfs) and flood stage (15,000 cfs) at the Hopland Gage. The Perfect Forecast Operations scenario does not show any instances of increasing flows above monitor stage or flood stage at the Hopland junction.

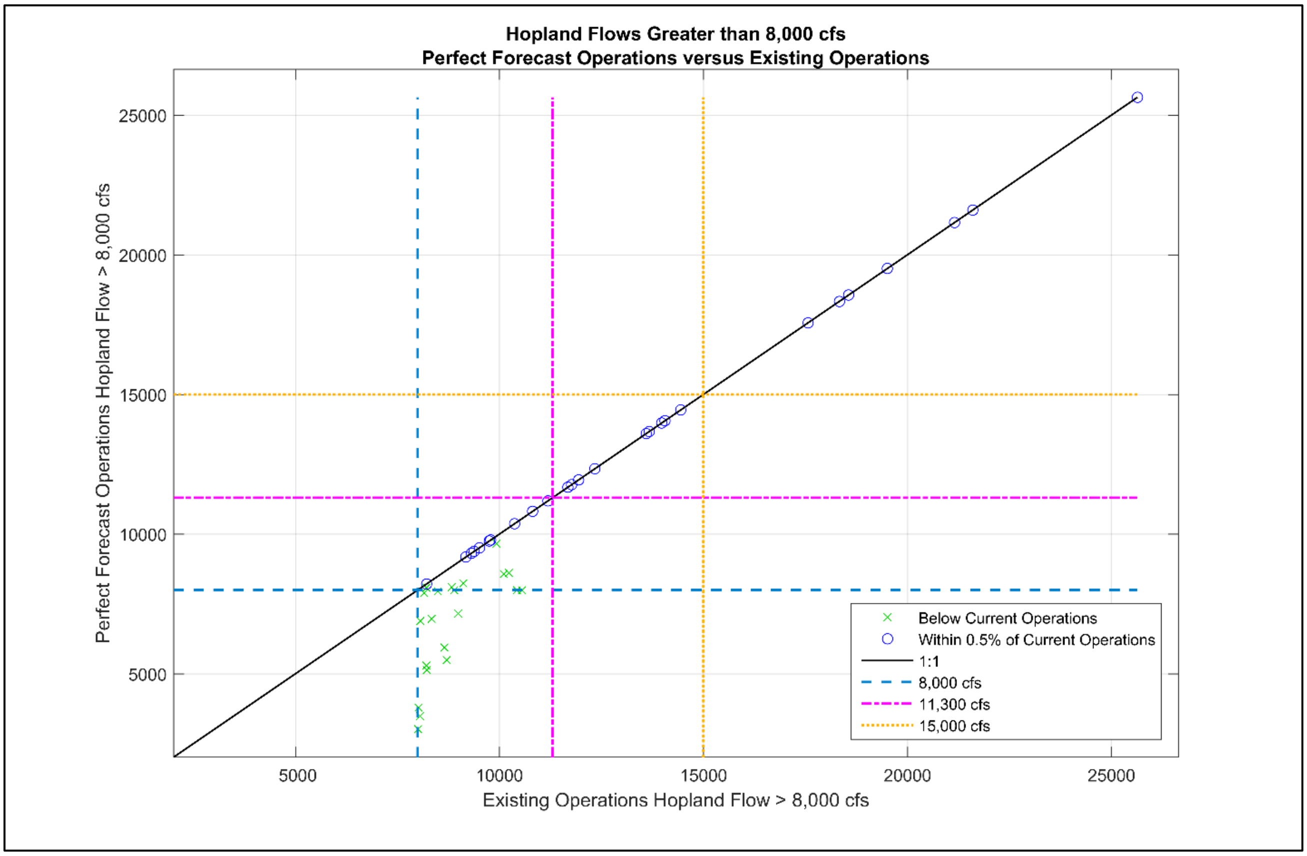


Figure 5-10. Hopland flows greater than 8,000 cfs scatter plot for Perfect forecast scenario for 1985-2010.

To analyze the change in flow conditions for the Ensemble Forecast Operations scenario, simulated Hopland junction flows were filtered to include only periods that either the Ensemble Forecast or the Existing Operations scenario exceed 8,000 cfs. Results of this filtered dataset are provided in Figure 5-11 as a scatter plot of Hopland junction flows for the Ensemble Forecast Operations scenario versus the Existing Operations scenario. The blue “o” tick marks show that simulated Hopland junction flows closely match (within 0.5%) for the Ensemble Forecast and Existing Operations scenarios above approximately 13,200 cfs. The red “+” tick marks indicate instances where the Ensemble Forecast Operations scenario increase flows above the Existing Operations scenario. The Ensemble Forecast Operations scenario shows 18 instances of increased flow over Existing Operations scenario for a flow range from 5,000 to 11,900 cfs for 32% of the total sample. As shown by the green “x” tick marks, the Ensemble Forecast Operations scenario has 20 instances of decreased flow relative to the Existing Operations scenario for a flow range from 8,000 to 10,600 cfs for 35% of the total sample. The instances where Ensemble Forecast Operations scenario increases Hopland junction flows over the Existing Operations scenario (red “+” tick marks) is somewhat balanced by instances where the Ensemble Forecast Operations scenario decreases flows (green “x” tick marks)

As shown in Figure 5-11, the Ensemble Forecast Operations scenario has two instances where flows were increased over the Existing Operations scenario above monitor stage at the Hopland junction. Of these two instances, the maximum flow increase was from a rate of approximately 11,900 cfs to 13,200 or a 1,300 cfs gain in flow for that instance. The Ensemble Forecast Operations scenario does not show any instances of increasing flow above flood stage at the Hopland junction.

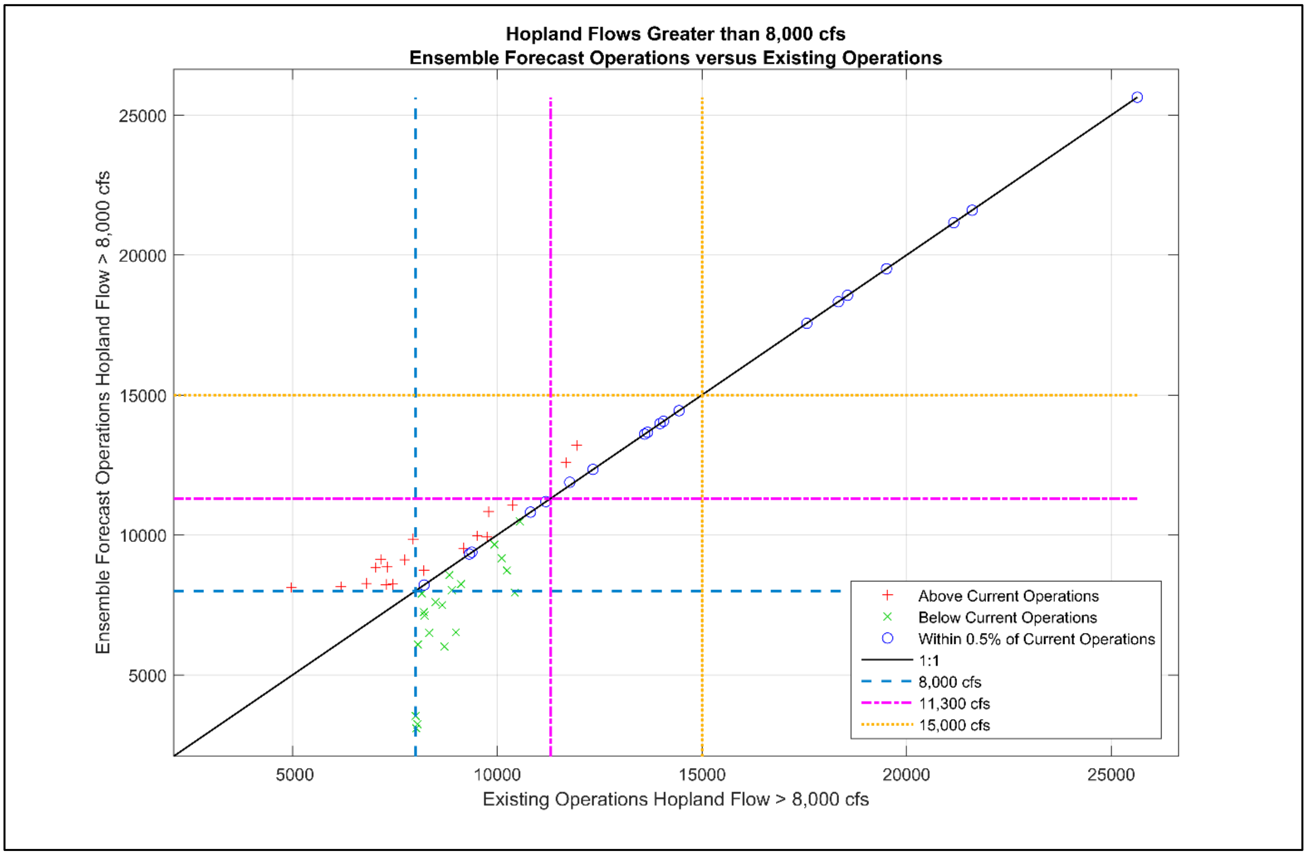


Figure 5-11. Hopland flows greater than 8,000 cfs scatter plot for Ensemble Forecast Operations scenario for 1985-2010.

To analyze the change in flow conditions for the Hybrid Operations scenario, simulated Hopland junction flows were filtered to include only periods that either the Hybrid or the Existing Operations scenario exceed 8,000 cfs. Results of this filtered dataset are provided in Figure 5-12 as a scatter plot of Hopland junction flows for the Hybrid Operations scenario versus the Existing Operations scenario. The blue “o” tick marks show that simulated Hopland junction flows closely match (within 0.5%) for the Hybrid and Existing Operations scenarios above approximately 13,200 cfs. As shown with the red “+” tick marks, the Hybrid Operations scenario shows 16 instances of increased flow over Existing Operations scenario for a flow range from 6,800 to 11,900 cfs for 29% of the total sample. As shown by the green “x” tick marks, the Hybrid Operations scenario has 13 instances of decreased flow relative to the Existing Operations scenario for a flow range from 8,000 to 10,600 cfs for 24% of the total sample. As with the Ensemble Forecast Operations scenario, the instances where Hybrid Operations scenario increases Hopland junction flows over the Existing Operations scenario (red "+" tick marks) is somewhat balanced by instances where the Hybrid Operations scenario decreases flows (green "x" tick marks)

Similar to the Ensemble Forecast Operations scenario, as shown in Figure 5-12, the Hybrid Operations scenario also has two instances where flows were increased over the Existing Operations scenario above monitor stage at the Hopland junction. Consistent with the Ensemble Forecast Operations scenario, the maximum change in flow was from approximately 11,900 cfs to 13,200 or a 1,300 cfs increase in flow for that instance. The Hybrid Operations scenario also does not show any instances of increasing flow above flood stage at the Hopland junction.

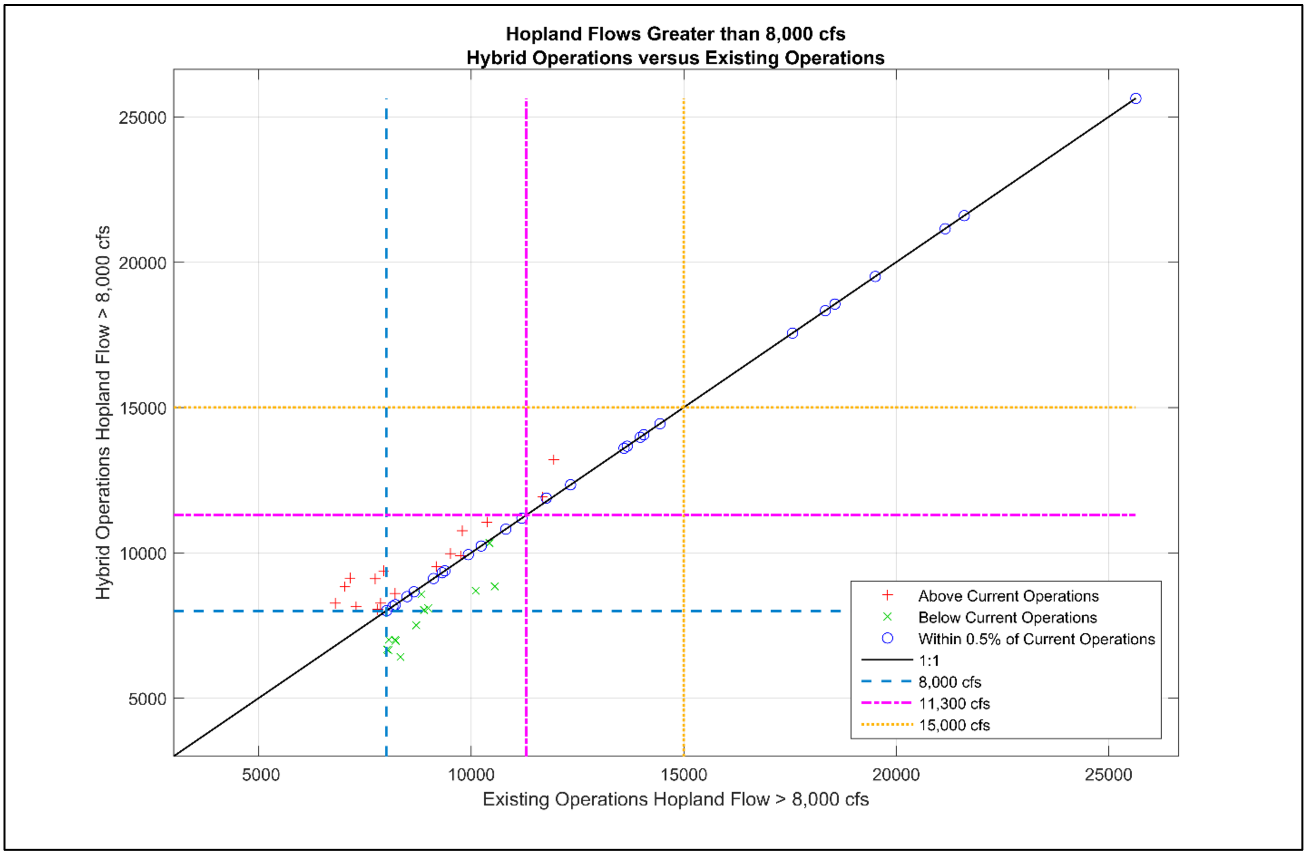


Figure 5-12. Hopland flows greater than 8,000 cfs scatter plot for Hybrid Operations scenario for 1985-2010.

5.3.2 Healdsburg Model Junction

Simulated Healdsburg junction flows were analyzed for each scenario for days that flows exceeded monitor stage at the Healdsburg Gage, 41,200 cfs. The analysis was completed for each alternative (Perfect Forecast, Ensemble Forecast and Hybrid Operations scenarios), but because all of the alternatives yielded very similar results only the results of the Ensemble Forecast Operations alternative are discussed.

To analyze the change in flow conditions for the Ensemble Forecast Operations scenario, simulated Healdsburg junction flows were filtered to include only periods that either the Ensemble Forecast or the Existing Operations scenario exceed the monitor stage at the Healdsburg Gage, 41,200 cfs. Results of this filtered dataset are provided in Figure 5-13 as a scatter plot of Healdsburg junction flows for the Ensemble Forecast Operations scenario versus the Existing Operations scenario. Figure 5-13 includes lines to indicate the monitor stage flow level (41,200 cfs) and the flood stage flow level (53,300 cfs) for both the x and y axis. The blue "o" tick marks show that simulated Healdsburg junction flows closely match (within 0.5%) for the Ensemble Forecast and Existing Operations scenarios above approximately for all but one of instances of simulated flow exceeding 41,200 cfs. The one green "x" tick mark shows one instance that the Ensemble Forecast Operations scenario decrease flow relative to the Existing Operations scenario, although this occurrence occurs below flood stage.

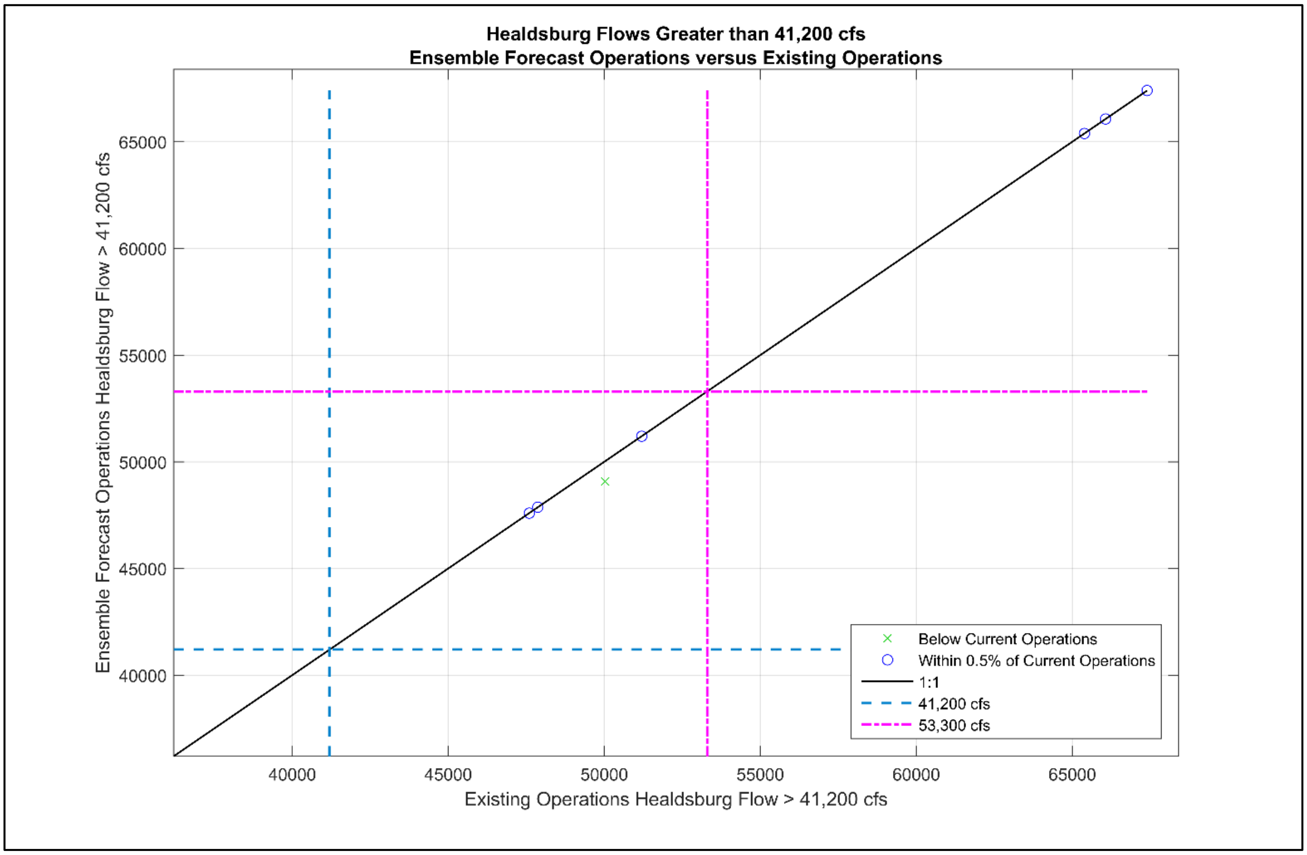


Figure 5-13. Healdsburg flows greater than 8,000 cfs scatter plot for Ensemble Forecast Operations scenario for 1985-2010.

5.4 Summary of Results

Table ___ has been prepared to provide a summary of the model results discussed in the previous sections for each of the model scenarios. The results presented in this table include: median end of water year storage (acre-feet), change in median end of water year storage over the Existing Conditions scenario (acre-feet), percent increase in median end of water year storage over the Existing Conditions scenario, total number of days Hopland junction flow is above 8,000 cfs, and number of days flood control releases are constrained by release ramping rates.

Table 5-1. Summary of modeling results.

Model Scenario	**Median End of Water Year Storage** (acre-feet)	**Increase over Existing Conditions** (acre-feet)	**Percent Increase** (%)	**Hopland Flows above 8,000 cfs** (number days)	**Flood Control Ramping Adjustments** (number days)
Existing Operations	56,220	-	-	47	19
Perfect Forecast Operations	84,000	27,780	49%	32	10
Ensemble Forecast Operations	76,277	20,057	36%	44	29
Hybrid Operations	64,853	8,633	15%	48	35

6 Conclusions

The modeling results presented in Section 5, indicate that implementation of FIRO for Lake Mendocino will benefit water supply. The Perfect Forecast Operations scenario represents the theoretical maximum possible gains from FIRO demonstrating a 49% increase in end of water year storage over the Existing Operations scenario. Results of the Ensemble Forecast Operations scenario represent a more realistic gain in water supply reliability, because this scenario uses a hindcast, representing current forecast skill, to set flood releases. This scenario demonstrates a significant gain in water supply reliability with a 36% increase in median end of water year storage. The Hybrid Operations scenario represents a possible initial or interim step before the full implementation of FIRO because it incorporates both a Modified Guide Curve and Ensemble Forecast Operations. By incorporating a Modified Guide Curve the Hybrid Operations can be refined to limit some of the risk of downstream flooding compared to a full implementation of FIRO. There are numerous configurations of a Modified Guide Curve. One configuration was developed for this evaluation to illustrate potential benefits. The water supply gains for this scenario show a 15% increase in median end of water year storage, which is not as significant as the Ensemble Forecast Operations, but still a significant improvement over the Existing Operations scenario.

The benefits to water supply reliability provided by the FIRO alternatives also benefit habitat conditions downstream of Lake Mendocino. Model results demonstrate that the increase in available water decreases the occurrence of *Dry* hydrologic conditions resulting in higher minimum instream flow requirements preferred by rearing salmonids. Additionally the increased storage levels in the fall season of the FIRO alternatives would retain the cold water pool in Lake Mendocino and provide lower releases temperatures relative to the Existing Operations scenario. This benefit is significant considering that releases have been observed to reach temperatures which are detrimental to salmonids when storage is drawn down to low levels in the fall during drought years.

For all the FIRO alternative scenarios simulated, Ensemble Forecast, Hybrid and Perfect Forecast Operations, modeling results show no increase in instances of flooding for points downstream relative to the Existing Conditions scenario. The Ensemble Forecast and Hybrid Operations scenarios both show instances where flows are increased at the Hopland Junction above the Existing Operations scenario between 8,000 cfs and flood stage. However, these instances are balanced by an approximate equal number of instances where flows are reduced below the Existing Operations scenario between 8,000 cfs and flood stage. The modeling completed for this study evaluated a limited historical period of which does not include the highest inflow event of record which occurred in December 1964. Additionally the daily simulation time step is likely not capturing the peak reservoir storage levels or peaks flows for downstream points.

Modeling results show that the 8,000 cfs maximum downstream flow rule constrains the ability to make pre-releases in advance of large flow events. Pre-releases for the FIRO alternatives are constrained by this rule limiting the ability to reduce reservoir storage levels in advance of large events, which can potentially cause the reservoir to reach levels that result in uncontrolled spillway releases as simulated in 1986. This rule was also shown to limit existing guide curve operations which also simulates uncontrolled spillway releases in 1986. In addition, ramping rate rules were found to constrain flood releases for all the scenarios modeled. These rules could also limit the ability of the FIRO alternatives to make pre-releases to reduce reservoir storage levels in advance of large events.

7 Recommendations for Further Study

7.1.1 Develop Synthetic Flood Events

The February 1986 flood event included in the model simulation period is a significant event for Lake Mendocino, but is only the second highest inflow event for the reservoir. The flood of record for Lake Mendocino occurred in January 1964. In order to more thoroughly evaluate Ensemble Forecast Operations alternatives it would be useful simulate other large flood events such as 1964 or even larger. Since the CNRFC cannot accurately generate ensemble flow hindcasts before 1985, the simulation of larger events would require the generation of synthetic or design hydrologic events. Synthetic events such as a 1% and 0.5% exceedance (or even lower exceedance if desired) flood events could be developed using existing events from the historical unimpaired flows and hindcasts developed by the CNRFC. Precipitation scaling factors could be developed to adjust historical flood events such as February 1986 and/or New Year's 2006 to approximately match 1% and 0.5% exceedance flood events. Adjusted or scaled observed and hindcasted precipitation would be applied to the CNRFC hydrologic model to develop synthetic hydrologic unimpaired flow and hindcasted flow data sets for the Russian River for the 1% and 0.5% exceedance flood events (Whitin, 2016). A similar approach was utilized to develop 1% and 0.5% exceedance flood events for the Folsom Reservoir on the American River.

7.1.2 Decrease the Simulation Time Step

The URR EFO Model is currently limited to simulate conditions on a daily time step, because the CNRFC historical unimpaired flow hydrology was generated at a daily time step. Lake Mendocino storage and downstream flows reach peak levels for large flow events at a sub-daily time step. Further evaluation of the Ensemble Forecast and Hybrid Operations scenarios should incorporate modeling at a sub-daily time step such as 1-hour or 6-hour to improve simulation of reservoir operations and downstream flows for large flow events. This model refinement would require close coordination with the CNRFC to estimate sub-daily unimpaired flows for the model flow junctions.

Ensemble flow forecasts for points in the Russian River watershed are generated by the CNRFC every 24 hours at noon GMT. The flow hindcasts are consistent with this current operation consisting of a daily 15 day hindcast for each day from 1985 to 2010. Review of the hindcast dataset show that flow forecasts can be very dynamic from one day to the next especially for large events such as February 1986 and December 2005. Performance of the Ensemble Forecast Operations and Hybrid Operations scenarios could improve for large events if the flow forecasts were generated by the CNRFC more frequently than once per day such as every 6 or 12 hours. With more frequent flow forecasts, pre-releases for large events may begin 6-hours or even 18-hours earlier which can make a difference in reducing reservoir storage levels in advance of large flow events.

7.1.3 Incorporate More Accurate Flow Routing

The URR EFO Model currently assumes a constant lag time for routing flows. This method of routing is adequate for the purposes of this report, to assess the preliminary viability of flood control alternatives. Further evaluation of Ensemble Forecast Operations and Hybrid Operations scenarios should incorporate a more complex flow routing methodology especially if a sub-daily time step is incorporated as discussed in Section 7.1.2. Analyses completed by HEC (HEC, 2016) indicate that the Modified Puls routing method provides reasonable results for peak-flow attenuation in the Russian River.

7.1.4 Evaluate Different Storage Thresholds

The 111,000 acre-feet storage threshold used to simulate the Ensemble Forecast Operations and Hybrid Operations scenario was used in this analysis to evaluate FIRO viability. However, lower thresholds should be evaluated to better understand how this parameter affects the performance of the Ensemble Forecast and Hybrid Operations alternatives.

7.1.5 Optimize Risk Tolerance Curve

The risk tolerance curve, as discussed in Section 4.11.3, used for simulating the Ensemble Forecast and Hybrid Operations scenarios in this study was derived through an iterative simulation approach that met the objective of improving water supply reliability while not increasing the frequency of uncontrolled spillway releases from Lake Mendocino. It is likely that the performance of the of the Ensemble Forecast and Hybrid Operations scenarios could be improved by incorporating an optimization model to optimally derive risk tolerance thresholds to meet specific project objective criteria. This optimization analysis could also be used to derive a seasonally varying risk tolerance curve that tolerates more risk in the spring, summer and fall was the risk of Atmospheric Rivers and major flow events decreases.

7.1.6 Evaluation of Hopland Gage Maximum Flow Rule

For Lake Mendocino one constraint for the implementation of FIRO is the 8,000 cfs maximum flow at the Hopland Gage. As previously discussed in Section 2.4.1, the CVD WCM does not allow for flood control releases above 25 cfs when observed flows at the Hopland Gage exceed 8,000 cfs. As concluded in Section 6, this constraint limits effectiveness of pre-releases of FIRO alternatives. Although FIRO strategies will improve water supply conditions with this limitation, if the maximum flow at the Hopland Gage was increased, the benefits of FIRO would be even greater.

The flow rate criteria of 8,000 cfs was established based on the findings of the hydrologic and hydraulic study completed by the USACE prior to the construction of CVD (USACE, 1954). Flows above this level are believed to create flooding of the highway at the Highway 175 Bridge and force closure of the bridge. Damages to property from flooding do not occur until Hopland Gage flows exceed 15,000 cfs (NOAA, n.d.). It is likely that river morphology has changed since the construction of CVD in 1959. Accordingly, it is recommended that the rationale for the 8,000 cfs maximum Hopland Gage flow be evaluated. This evaluation would likely include review of historical and existing conditions, data collection and surveying, and potentially hydraulic modeling of the Russian River from the CVD outlet to the Highway 175 Bridge. If the current 8,000 cfs flow constraint could be raised, this would improve the performance of the Ensemble Forecast and Hybrid Operations scenarios to make pre-releases in advance of high flow events.

7.1.7 Incorporate Multiple Risk Tolerance Curves

In addition to evaluating the Hopland Gage maximum flow rule as discussed in Section 7.1.6, it is recommended that further modeling and analysis is completed to investigate the possible benefits of incorporating multiple Hopland Gage flow criteria. Ensemble Forecast and Hybrid Operations alternatives could benefit from having multiple downstream flow thresholds triggered by different risk tolerance curves. Consistent with the Ensemble Forecast and Hybrid Operations scenarios modeled in this study, a lower risk tolerance curve could use the current maximum downstream flow constraint of 8,000 cfs at Hopland (or greater if determined by the evaluation recommended in Section 7.1.6). In addition, a higher risk tolerance curve could target a higher maximum downstream flow such as monitor stage at the Hopland Gage (11,300 cfs). If there is a higher risk of exceeding the 111,000 acre-feet storage threshold in Lake Mendocino, then it may be imperative to allow for higher downstream flows and accept minor flooding such as the closure of the Highway 175 Bridge in advance of a large flood event. For very large flow events this would allow for higher pre-releases from the reservoir, which could further draw down reservoir storage levels in advance of the event to help prevent or reduce uncontrolled spillway releases and reduce downstream flood impacts. A possible example of the multiple risk curves is illustrated in Figure 7-1.

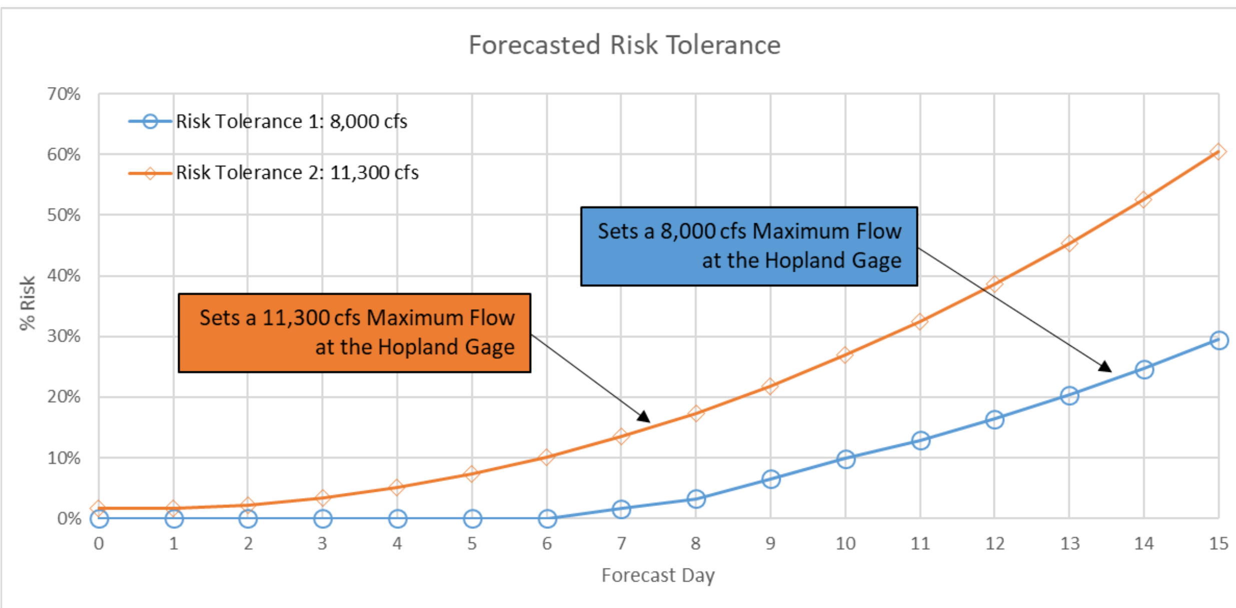


Figure 7-1. Example of multiple risk tolerance curves which can be incorporated into the Ensemble Forecast Operations scenario.

7.1.8 Refine Modified Guide Curve of the Hybrid Operations Scenario

The Modified Guide Curve used for the Hybrid Operations scenario was developed to provide an example of a possible alternate guide curve and to demonstrate how a possible Hybrid Operations approach could. It is possible that this Modified Guide Curve could be improved to provide improved water supply reliability yet not increase risk of downstream flooding. It is possible that an optimization model could be employed to develop an optimally derived guide curve.

7.1.9 Evaluate Current Release Ramping Rates

As concluded in Section 6 the existing decreasing rate of change release ramping rates can constrain flood releases which could limit pre-releases for FIRO alternatives. The primary function of the decreasing rate of change ramping rates is to prevent the rapid dewatering of fish habitat which can strand juvenile salmonids. Rate of downstream stage change is the primary parameter of concern, therefore it is recommended that an analysis to be completed that explores the possibility to refine the existing decreasing rate of change ramping rules to consider rate of change of downstream stage or flow as measure at existing gages such as the Talmage Gage or the Hopland Gage. This could limit the impact of ramping rules on FIRO alternatives during periods of high downstream flows where releases are likely to have less of an impact on stage downstream.

7.1.10 Evaluate Conditions in the Lower Russian River

Further evaluation of Ensemble Forecast Operations should include modeling additional points in the Lower Russian to evaluate if pre-releases cause any increase in flooding for this region. The Lower Russian River extends from the confluence of Dry Creek to the mouth of the Pacific Ocean. The flood prone area in the Lower Russian River is the City Guerneville. Expansion of the EFO Model would include adding Lake Sonoma, Dry Creek from Lake Sonoma to the confluence of the Russian River, and the Russian River from Dry Creek to the City of Guerneville.

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