APPENDIX F

Hydrologic Analysis of Validation Sites

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APPENDIX F
HYDROLOGIC ANALYSIS OF VALIDATION SITES

F.1 VALIDATION SITES

The purpose of this appendix is to describe the hydrologic analyses that were completed at thirteen validation sites in order to develop recommendations on the North Coast Instream Flow Policy.

F.1.1 Validation Site Locations

The group of I3 validation sites was developed based on criteria described in Appendix G. The thirteen validation sites are listed in Table F-1. The watershed area for each gaged location was determined using the ESRI ArcInfo 9.2 Geographic Information System (GIS) as shown in Figure F-1. Passage and/or spawning transects, longitudinal slope, and pebble counts were measured by R2 Resource Consultants, Inc (R2) and Stetson Engineers Inc. (Stetson) at the validation sites.

F.1.2 Gaged Flows

For all thirteen validation sites, gaged data were available from one of three sources: the US Geological Survey (USGS), Napa County Resource Conservation District (NCRCD), and the National Park Service (NPS).

Gage data is summarized in Table F-1. USGS provided data for 11 gages, NCRCD for two gages, and NPS for one gage. Note that both USGS and NPS have measured stream flow for Pine Creek, but for this analysis, only the NPS data were used.

Periods of record for the sites were between October 1958 and September 2005. The sites' drainage areas range from 0.25 square miles (East Fork Russian River Tributary) to 34 square miles (Lagunitas Creek).

F.1.2.1 USGS Gage Data

Stetson obtained USGS data from the National Water Information System (NWIS, 2006) and checked the gaged data for errors and missing data. Provisional data were excluded. Missing data were not filled; however, for the purpose of computing statistics, any months with missing data were not included.

F.1.2.2 NCRCD Gage Data

NCRCD data were received as raw 15-minute measurements (NCRCD, 2006). The data were processed into daily average flows. For brief periods (i.e., < 5 days) of missing measurements, data were interpolated. For longer periods of missing data, no correction was made. Generally, NCRCD made continuous measurements in the winter period, but not in the summer period when flows were low or zero. For the purpose of computing statistics, any months with missing data were not included.

Table F-1. Gage Records for Validation Sites.

Gage ID	Agency	Description	County	Drainage Area (mi^2)	Daily Stream Flow Begin Date	Daily Stream Flow End Date
11468010[1]	USGS	Albion River near Comptche	Mendocino	14.4	8/1/1961	10/13/1969
CAS[2]	NCRCD	Carneros Creek	Napa	2.75	11/30/2004	5/24/2006
11464050	USGS	Dry Creek Tributary near Hopland	Mendocino	1.19	10/1/1967	9/30/1969
11468850	USGS	Dunn Creek near Rockport	Mendocino	1.88	9/1/1961	9/30/1964
11461400	USGS	EF Russian River Tributary near Potter Valley	Mendocino	0.25	10/1/1958	9/30/1961
11463940	USGS	Franz Creek near Kellogg	Sonoma	15.7	10/1/1963	9/30/1968
HRV	NCRCD	Huichica Creek	Napa	6.11	10/1/2002	9/30/2005
11460400	USGS	Lagunitas Creek at SP Taylor State Park	Marin	34.3	12/21/1982	9/30/2005
Olema[3]	NPS	Olema Creek	Marin	12.57	10/1/1986	4/18/2005
11460170[4]	USGS NPS	Pine Creek at Bolinas	Marin	7.83	6/1/1967 10/1/1998	9/30/1970 9/30/2003
11460920	USGS	Salmon Creek at Bodega	Sonoma	15.7	8/1/1962	10/1/1975
11465800	USGS	Santa Rosa Creek near Santa Rosa	Sonoma	12.5	8/1/1959	10/13/1970
11464860	USGS	Warm Springs Creek near Asti	Sonoma	12.2	8/15/1973	9/30/1983

Notes:

1. The USGS also recorded stream flow at the Albion River gage from 1/31/2001 to 9/30/2003. These data are discontinuous with many periods of missing data and were not used in the analysis.
2. NCRCD has three gaging locations on Carneros Creek. Continuous stream flow records were obtained for gage CAS, CAH (Carneros at Henry Road, drainage area = 5.30 mi^2) and CAO (Carneros at Old Sonoma Road, drainage area = 6.69 mi^2). Field data were measured at the CAS gage and stream flow at this station was used for the hydrologic and habitat analyses.
3. Olema flow records were continuous for the period of record of 1998-2003. Only this continuous period was used for the hydrologic and habitat analyses.
4. Pine Creek data for 10/1/1998-9/30/2003 was used for the hydrologic and habitat analyses.

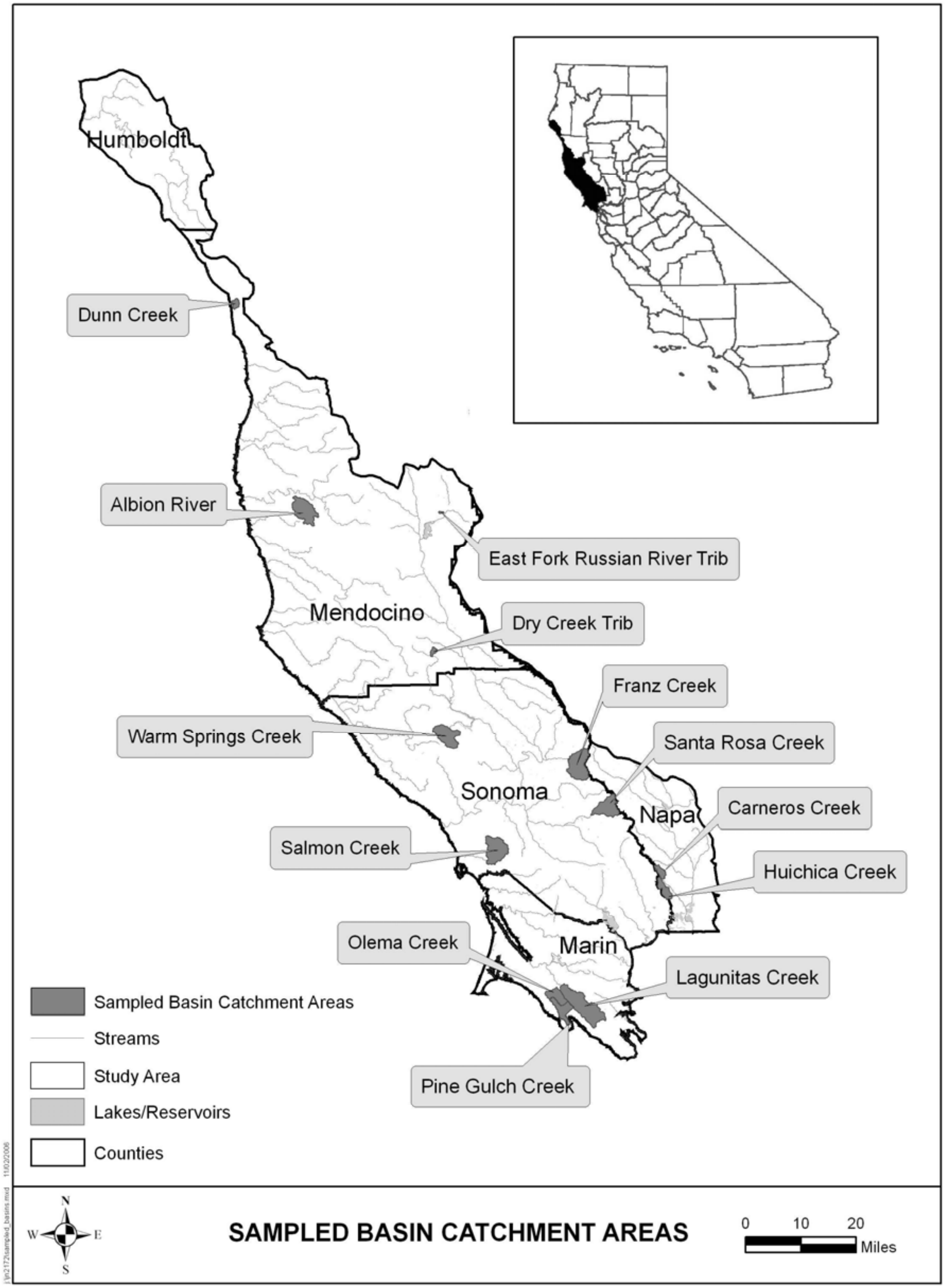

Figure F-1. Locations of validation sites.

F.1.2.3 NPS Gage Data

Stetson obtained NPS gaged data from Brannon Ketcham of Point Reyes National Seashore and Darren Fong of Golden Gate National Recreation Area. Data received were daily average flows. Gaged data were checked for errors and missing data. Missing data were not filled; however, for the purpose of computing statistics, any months with missing data were not included.

F.2 UNIMPAIRED TIME SERIES

Unimpaired flow is the natural flow in a stream without any human alterations to the hydrology; that is, the flow without any diversions or man-made storage. Two of the Policy elements, Minimum Bypass Flow (MBF) and Maximum Cumulative Diversion (MCD) rate or volume, are formulated with respect to the unimpaired flows of the stream. Accordingly, Stetson developed unimpaired flow time series and hydrologic parameters for each validation site.

For the 9 validation sites where permitted diversions and storage regulation during the gaged period of record were not significant (Albion River, Dry Creek Trib, Dunn Creek, EF Russian River Trib, Olema Creek, Pine Creek, Salmon Creek, Santa Rosa Creek, and Warm Springs Creek), gaged flows were used as an estimate of unimpaired flow. Unimpaired flow for one stream (Lagunitas Creek) was previously estimated by Marin Municipal Water District (MMWD) and was used in this study. For the remaining three streams that had significant impairment (Franz, Huichica and Carneros Creeks), Stetson used a hydrologic simulation program to estimate unimpaired flows.

After the unimpaired time series for each validation site were created, Stetson computed hydrologic parameters such as mean annual flow, peak flood magnitude, and flow-duration (exceedance) values. Development of these unimpaired time series and associated hydrologic parameters is described in the sections below.

F.2.1 Estimates of Diversions

The State Water Board stores information on all permitted and pending water rights applications in their Water Rights Information Management System (WRIMS) database.[1] Stetson used this database to determine the level of permitted diversions in the validation sites.

Each water rights application has one or more points of diversion, locations where water may be diverted for direct use or for on-stream or off-stream storage. The applications with points of diversion from the validation site watersheds were identified using the GIS. The annual maximum diversion to storage was calculated as the sum of the annual storage[2] for all water

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[1] A copy of the WRIMS database was received from the State Water Board on December 20, 2006

[2] Annual storage is calculated as the lesser of either the maximum storage [MAXIMUM_STORAGE] or the maximum annual use [MAX_USE_ANN].

rights applications in the watershed at the end of the period of flow record (Table F-1).[3] The annual direct diversion was calculated as the sum of the direct diversions less diversions to storage.[4] Where missing, the direct diversion rate was assumed to be 1000 gallons per day and the diversion season was assumed to be the entire year. Estimated maximum annual storage and direct diversion are shown in Table F-2.

F.2.2 Unimpaired Flow Estimated from Gaged Flows

Storage impairment was estimated as the annual storage divided by the annual runoff; total impairment was estimated as the maximum annual total diversions divided by the annual runoff, Table F-2. As observed flows may have already been reduced by as much as the total diversions, annual runoff was estimated as observed flows plus the total diversions.

Sites were considered to be significantly impaired when the when storage impairment was greater than 1% or the total impairment was greater than 5%. Diversions to storage have a greater impact on the hydrograph as they generally occur during a shorter time period which will reduce peak flows. Such peak flows are of importance in the calculation of maximum cumulative diversions. In addition, the full volume of permitted storage is more likely to be diverted, particularly with on-stream water storage, whereas direct diversions may not always be made to the extent of the permit.

Nine of the thirteen validation sites were determined not to have significant impairment during the gaged period of record. The gaged records were used as estimates of the unimpaired flows at these sites.

F.2.3 Lagunitas Creek Unimpaired Flows

The Marin Municipal Water District (MMWD) utilizes water from the Lagunitas Creek watershed as one of its municipal water supply sources. MMWD serves water to approximately 190,000 residents of Marin County. They operate multiple reservoirs within the Lagunitas Creek watershed, the largest of which are Kent Lake and Nicasio Lake. To assist in their facilities operations, MMWD developed a method for estimating daily unimpaired flows on Lagunitas Creek at the S.P. Taylor State Park location (USGS gage location).

Their rainfall runoff model, called ROFF, uses annual and monthly unimpaired volumes, daily rainfall, and antecedent rainfall conditions to estimate daily unimpaired flow. They compared

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[3] Water rights diversions are assumed to begin in the year given in the [YEAR_FIRST_USE] field in the WRIMS database. If this field was not provided by the applicant, diversions are assumed to start when the application was filed as stored in the [APPL_FILE_DATE] field.

[4] Annual direct diversion is calculated as the lesser of either the full direct diversion rate exercised over every day in the diversion, the maximum annual direct diversion [MAX_DD_ANN], or the maximum annual use. If an application has both direct diversion and storage, the annual direct diversion was reduced by the annual storage to represent only the diversions for direct use.

the estimated daily unimpaired flows to the records at the USGS gage and to the flow-duration curve for a nearby similar stream and determined that their model results were consistent with both. MMWD daily unimpaired flows were published for 1955 through 1991 (Roxon, 1992) and were used in this study as the unimpaired flow for Lagunitas Creek.

Table F-2. Estimated Annual Storage and Direct Diversions.

Gage / Validation Site	**Annual Storage (AF)**	**Direct Diversions[1] (cfs)**	**Total Diversions[2] (AF)**	**Annual Runoff[3] (AF)**	**Impairment[4] (% Annual Runoff)**	
					Storage	**Total Diversions**
Albion River Near Comptche	8	0.02	22	14,476	0.1%	0.2%
Carneros Creek at Sattui[6] (CAS)	*38*	*0.00*	*38*	*2,725*	*1.4%*	*1.4%*
Carneros Creek at Henry Rd[5,6] (CAH)	*648*	*0.06*	*691*	*4,757*	*13.6%*	*14.5%*
Carneros Creek at Old Sonoma Bridge[5,6] (CAO)	*1,022*	*4.30*	*4,135*	*8,922*	*11.5%*	*46.3%*
Dry Creek Tributary near Hopland	0	0.00	0	1,590	0.0%	0.0%
Dunn Creek near Rockport	0	0.00	0	1,807	0.0%	0.0%
EF Russian River Tributary near Potter Valley	0	0.00	0	94	0.0%	0.0%
Franz Creek near Kellogg[6]	*300*	*0.85*	*914*	*17,920*	*1.7%*	*5.1%*
Huichica Creek[6]	*929*	*1.51*	*2,020*	*6,724*	*13.8%*	*30.0%*
Lagunitas Creek at SP Taylor State Park[6]	*99,320*	*39.23*	*127,747*	*16,1901*	*61%*	*79%*
Olema Creek	35	0.15	143	18,211	0.2%	0.8%
Pine Creek at Bolinas	0	0.20	145	8,817	0.0%	1.6%
Salmon Creek at Bodega	60	0.66	537	18,604	0.3%	2.9%
Santa Rosa Creek near Santa Rosa	62	0.37	329	14,061	0.4%	2.3%
Warm Springs Creek near Asti	0	0.00	0	25,295	0.0%	0.0%

Notes:

1. Direct Diversions include only diversions for direct use and do not include diversions to storage (Annual Storage).
2. Total Diversions is Annual Storage plus Direct Diversions.
3. Annual Runoff is recorded mean annual flow plus Total Diversions.
4. Storage Impairment is calculated as Annual Storage divided by Annual Runoff; Total Diversions Impairment is Total Diversions divided by Annual Runoff.
5. The lower gages on Carneros Creek (CAH and CAO) were used in the calibration of the HSPF model but were not used in the habitat and spawning analysis.
6. The validation sites where flow was determined to be significantly impaired are italicized.

F.2.4 Simulated Unimpaired Flows

Three validation sites, Carneros, Huichica and Franz Creeks, were significantly impaired during the gaged periods of record. For these sites, unimpaired time series were estimated using Hydrological Simulation Program - Fortran (HSPF) version 12. Model inputs, calibration, and simulation results are described below.

F.2.4.1 HSPF Description

HSPF is a software program (model) that simulates hydrologic processes in land segments and stream channels in response to meteorological conditions. HSPF is available as part of the Better Assessment Science Integrating point and Nonpoint Sources (BASINS) software system, available via free download from the US Environmental Protection Agency (EPA, 2006).

The HSPF simulation was run on a daily time step over a continuous period. Model inputs were daily precipitation and evaporation time series and land segment and reach parameters. Model outputs were daily time series of soil moisture and flow. The model setup was calibrated by adjusting parameters for each of the three watersheds to provide the most accurate estimate of natural stream flow (unimpaired flow) when compared to the available gaged stream flow records.

F.2.4.2 Input Data

F.2.4.2.1 Precipitation

Stetson obtained precipitation data from the Western Regional Climate Center (WRCC). All stations used were part of the National Climatic Data Center (NCDC) station network. “Summary of the Day” files, containing daily precipitation, were obtained for all stations in the vicinity of the validation sites. The most representative precipitation station was chosen for each validation site based on proximity, elevation, period of record, and quality of the record of each station. The precipitation station selected for each modeled validation site is listed in Table F-3.

Table F-3. Precipitation Stations Used in Model.

	Precipitation Station	
Modeled Validation Site	**NCDC Station ID**	**Name**
Carneros Creek	048351	Sonoma
Franz Creek	041312	Calistoga
Huichica Creek	048351	Sonoma

Continuous daily precipitation records were generated at each of the required precipitation stations for the period of October 1, 1958 through September 30, 2005. These data were used to simulate flows at the modeled validation sites. Simulation results were only used in the hydrologic and habitat analyses for the period of gaged stream flow record.

Records at Sonoma and Calistoga were both missing approximately 2% of daily entries between October 1, 1958 and September 30, 2005. Records at nearby stations were considered to fill the missing values at each main station. For Sonoma, only one alternative station was required to fill the missing data, while Calistoga required two alternative stations. The two main stations and their alternative stations are listed in Table F-4.

Table F-4. Precipitation Stations Used to Fill Missing Data.

Main Precipitation Stations			**Alternative Stations Used to Fill Missing Data**		
Name	**ID**	**Long-Term Average Precipitation (in)**	**Name**	**ID**	**Long-Term Average Precipitation (in)**
Sonoma	048351	29.85	Napa State Hospital	046074	24.90
Calistoga	041312	38.00	Saint Helena Santa Rosa	047643 047965	35.30 30.55

Missing data were due to two types of errors:

(1) Accumulated errors: Precipitation is not available as daily data but is instead provided as the total precipitation accumulated over a period of days (accumulation period). The Sonoma record contained 12 instances of accumulated errors, while Calistoga contained 8.

The missing period was filled by distributing the accumulated amount over each day in the accumulation period according to the rainfall during the concurrent period at a nearby gage. Table F-5 illustrates how accumulated errors were corrected.

Table F-5. Example of Accumulated Precipitation Error Correction.

Date	**Main Station Precipitation, Raw (in)**	**Alternative Station Precipitation, Raw (in)**	**Main Station Precipitation, Filled (in)**
04/24/63	0	0	0
04/25/63	A	0.40	0.30
04/26/63	0.34	0.05	0.04
04/27/63	0	0	0
04/28/63	0	0	0

From the example raw data in Table F-5, the accumulated period was April 25 and April 26, 1963. On April 25, no precipitation value was reported; on April 26, the value reported was the total accumulated amount that fell on both April 25 and 26. The total accumulated precipitation at the main station is 0.34 inches, while the total for the same period at the alternative station is 0.45 inches. The 0.34 inches at the main station were distributed over the accumulation period according to the daily precipitation distribution at the alternative station: 89% (0.4 in/0.45 in) of the rainfall occurred on 4/25/63, and 11% (0.05 in/0.45 in) occurred on 4/26/63. Accordingly, the estimated daily precipitation at the main station were be 0.30 (89% of 0.34 in) and 0.04 inches (11% of 0.34 in).

In the event that none of the alternative stations had daily precipitation records available or that none of the stations observed rainfall during the accumulation period, the accumulated amount at the main station was distributed equally over the period.

(2) Missing daily values: Daily precipitation values were not reported.

Missing daily values were estimated from the precipitation records at a nearby station. The rainfall amount at the main station was determined using the ratio of the long-term average rainfall at the main station to the long-term average rainfall at the alternative station:

$$P_{main} = P_{alt} \frac{LTA_{main}}{LTA_{alt}}$$

where P_{main} = daily precipitation amount at the main station
P_{alt} = daily precipitation amount at the alternative station
LTA_{main} = long-term average precipitation at the main station
LTA_{alt} = long-term average precipitation at the alternative station

Long-term average precipitation for each station was obtained from the WRCC Climatological Data Summaries for the period of record up to December 31, 2005 (WRCC, 2006), as listed in Table F-4.

After correcting the Sonoma and Calistoga records for accumulated and missing errors, the resulting continuous records for the period October 1, 1958 to September 30, 2005 records were loaded in the HSPF model as inputs.

F.2.4.2.2 Evaporation

Stetson obtained evaporation data from the WRCC (2006) and from the California Irrigation Management Information System (CIMIS) (CIMIS, 2006) and created a continuous daily evaporation record from January 1, 1958 through September 30, 2005 for two stations, Carneros and Windsor. Table F-6 lists the validation sites and their assigned evaporation station. Evaporation stations were assigned to each validation site based on proximity and evapotranspiration zone. Validation site watersheds and evaporation stations were plotted on a map defining 18 different zones of reference evapotranspiration for the state of California (Jones et al, 1999). Land within a zone, for example the “Coastal Plains Heavy Fog Belt” zone, experiences similar levels of evaporation.

Table F-6. Potential Evapotranspiration (PET) Used in Model.

Validation Site	Evaporation Station	ID	Network	Station PET (in)
Carneros Creek	Carneros	109	CIMIS	45.77
Franz Creek	Windsor	103	CIMIS	44.21
Huichica Creek	Carneros	109	CIMIS	45.77

Data obtained from the WRCC were collected from stations in the National Climatic Data Center (NCDC) station network. NCDC evaporation data for some stations in the North Coast region extend back prior to 1958. The earliest CIMIS data were collected in the mid-1980s. Significant gaps in the data were identified at nearly all stations. Records at Carneros and Windsor were missing 89% and 71% of daily entries between October 1, 1958 and September 30, 2005, respectively. The station with the most complete record, Dutton’s Landing, was still missing 60% of daily entries between 1958 and 2005. Because of data gaps, eight or nine alternative stations were required to fill in all the missing data at the main evaporation stations. Alternative stations were assigned to each validation site based on proximity and evaporation zone.

Data errors in the Carneros and Windsor records were due to missing daily values. Unlike the precipitation records, no accumulated errors were reported.

Missing daily values were estimated from the evaporation records at an alternate station. In some cases daily evaporation was available at only one of the eight or nine alternate stations. The evaporation amount at the main station was determined using the ratio of the long-term average evaporation for the month at the main station to the long-term average evaporation for the month at an alternate station:

$$E_{main} = E_{alt} \frac{LTA_{main}}{LTA_{alt}}$$

where E_{main} = daily precipitation amount at the main station
E_{alt} = daily precipitation amount at the alternative station
LTA_{main} = long-term average evaporation at the main station for the month
LTA_{alt} = long-term average evaporation at the alternative station for the month

Long-term average evaporation for each station was obtained from the WRCC Climatological Data Summaries for the period of record up to December 31, 2005 (WRCC, 2006) and from monthly averages reported by CIMIS (CIMIS, 2006).

After filling the Carneros and Windsor records for accumulated and missing errors, the resulting continuous records for the period October 1, 1958 to September 30, 2005 records were loaded in the HSPF model as inputs.

Table F-7. Evaporation Stations Used to Fill Missing Data in Validation Site Evaporation Records.

Main Evaporation Stations			**Alternative Evaporation Stations Used to Fill Missing Data**		
Name	**ID**	**Network**	**Name**	**ID**	**Network**
Carneros	109	CIMIS	Duttons Landing	042580	NOAA/NCDC
			Novato	63	CIMIS
			Point San Pedro	157	CIMIS
			Petaluma East	144	CIMIS
			Grizzly Island Refuge	43650	NOAA/NCDC
			Santa Rosa	83	CIMIS
			Monticello Dam	45818	NOAA/NCDC
			Markley Cove	45360	NOAA/NCDC
			Berryessa Lake	40705	NOAA/NCDC
Windsor	103	CIMIS	Healdsburg	51	CIMIS
			Santa Rosa	83	CIMIS
			Bennett Valley	158	CIMIS
			Warm Springs Dam	049440	NOAA/NCDC
			Oakville	77	CIMIS
			Monticello Dam	045818	NOAA/NCDC
			Markley Cove	045360	NOAA/NCDC
			Berryessa Lake	040705	NOAA/NCDC

F.2.4.2.3 Land Segment and Reach Parameters

In addition to precipitation and evaporation inputs, HSPF requires a description of the watershed. The watershed area is represented as land segments; the stream channels are represented as reaches. Precipitation and evaporation occur on the surface of the land segments, changing the soil moisture conditions on and within the land. The changing soil moisture conditions may result in water leaving the land and entering the reaches (runoff). This runoff moves through the reaches to the watershed outlet.

The stream channels were divided into reaches at each confluence and gaged location. The watershed areas were divided into land segments based on the 1961-1990 mean annual precipitation isohyets (Oregon Climate Service, 1998). A land segment was defined in the GIS at every two-inch precipitation increase. HSPF reaches and land segments are shown in Figure F-2 and Figure F-3. The area of each land segment contributing to each reach was measured in the GIS.

HSPF parameters which describe the land segment are listed in Table F-8; HSPF parameters which describe the reaches are listed in Table F-9. The slope of the land surface, length of reach, and change in elevation over the reach were measured in the GIS. Values noted as 'calibrated' were adjusted during the calibration process until simulated stream flow best matched the gaged records. This is discussed further in the next section.

Each reach also requires input of an FTABLE which gives the reach area, volume and outflow over a range of water depths. The FTABLEs were generated by WinHSPF, a user interface which is provided in the BASINS package. The tables were calculated assuming a trapezoidal cross section and using the reach length, change in elevation, and drainage area (used to estimate mean channel width and mean channel width) measured in the GIS with the default slopes and Manning's *n* provided by WinHSPF.

F.2.4.3 Calibration and Results

During calibration, Stetson adjusted HSPF watershed input parameters to obtain the best possible match between simulated and observed flow. As observed flows were known to be impaired, the total simulated water volume was compared to the observed water volume plus the maximum annual storage and diversion volumes. Simulated and observed hydrograph shapes were compared during seasons when there was likely to be fewer diversions.

The following parameters were varied to calibrate the model:

precipitation multiplier
evaporation multiplier
INFILT
UZSN
LZSN
INTFW
IRC
AGRWC

The USGS has developed a software program, Expert System for Calibration of HSPF (HSPexp), which helps calibrate the watershed parameters. This program compares simulated and observed hydrographs for selected storage and provides expert advice on which parameters should be increased or decreased to improve the calibration. Stetson used the HSPexp program during calibration.

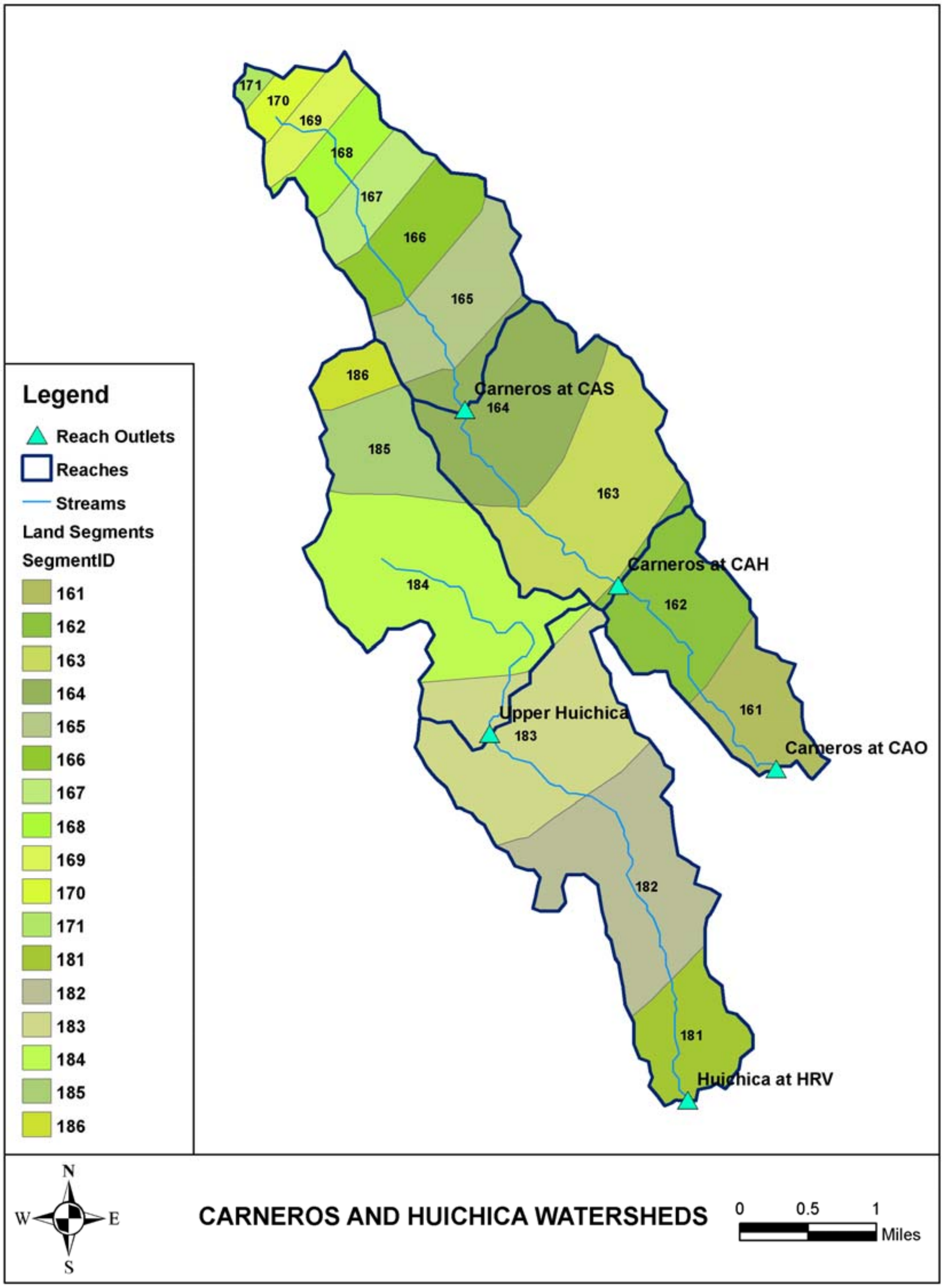

Figure F-2. HSPF reaches and land segments, Carneros and Huichica Watersheds.

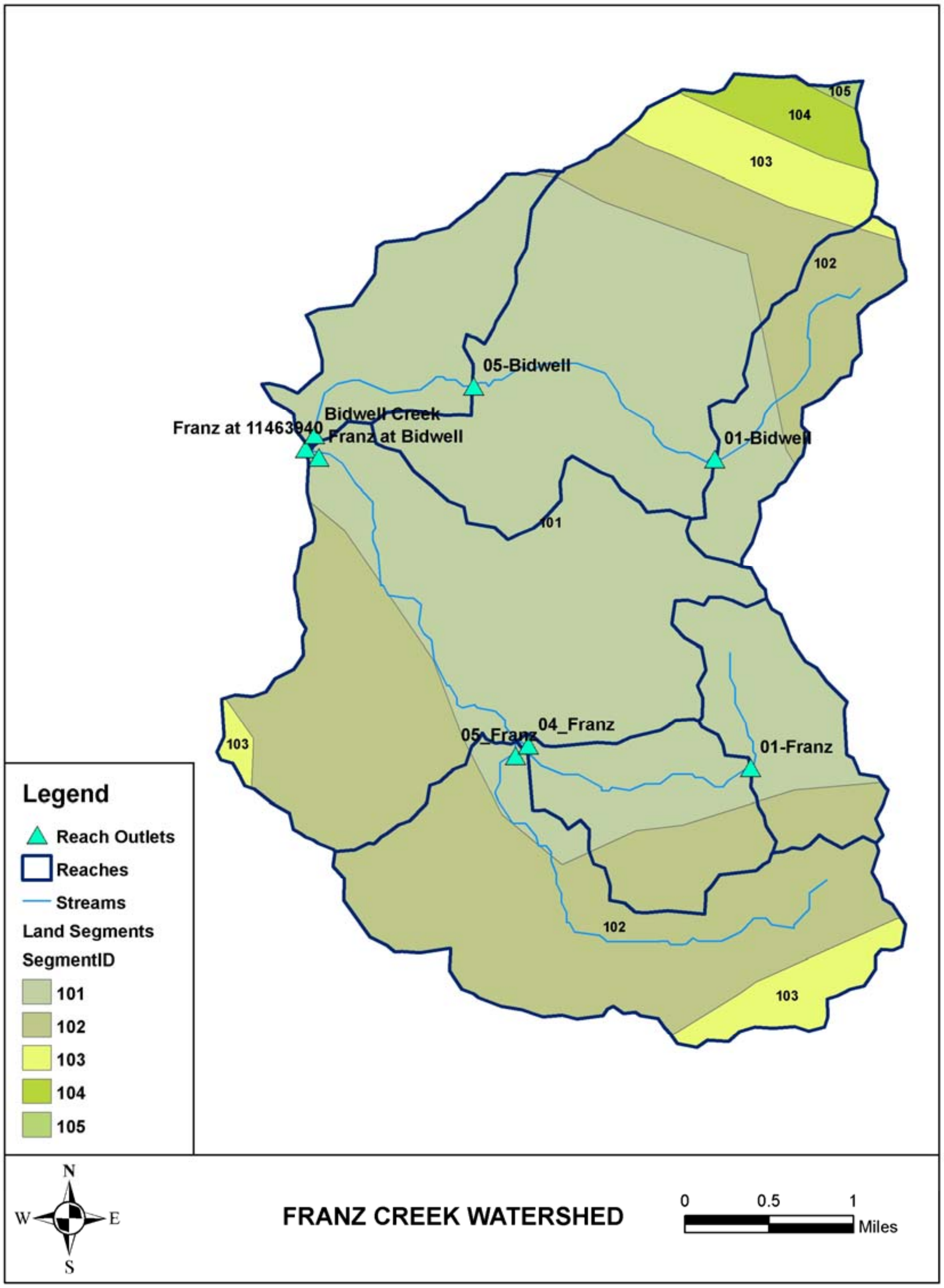

Figure F-3. HSPF reaches and land segments, Franz Creek Watershed.

Table F-8. Land Segment Parameters.

Parameter	Description	Value
AGWETP	fraction of remaining PET which can be satisfied from active groundwater	0
AGWRC	active groundwater recession constant (ratio of active groundwater outflow today to active groundwater outflow yesterday)	calibrated
BASETP	Fraction of remaining PET which can be satisfied from base flow	0
CEPSC	interception storage capacity	0.2 in
DEEPFR	Fraction of groundwater inflow which will enter deep (inactive) groundwater	0
INFEXP	infiltration equation exponent	1.5
INFILD	ratio between the maximum and mean infiltration capacity	2
INFILT	index to the infiltration rate capacity	calibrated
INTFW	interflow inflow parameter	calibrated
IRC	interflow recession parameter (ratio of interflow outflow today to interflow outflow yesterday)	calibrated
KVARY	variability of groundwater recession flow	0
LSUR	length of the assumed overland flow plane	250 ft
LZETP	lower zone evapotranspiration	0.3
LZSN	lower zone nominal storage	calibrated
NSUR	manning's n for the overland flow plane	0.4
PETMAX	temperature below which potential evapotranspiration (PET) is reduced	40 deg F
PETMIN	minimum temperature when PET occurs, PET is reduced from the input value at PETMAX to 0 at PETMIN	30 deg F
SLSUR	slope of the overland flow plane	GIS
UZSN	upper zone nominal storage	calibrated

Table F-9. Reach Parameters.

Parameter	Description	Value
DB50	Median diameter of the bed sediment	0.01
DELTH	change in water elevation over the length of the reach	GIS
KS	weighting factor for hydraulic routing	0.5
LEN	length of reach	GIS
STCOR	stage correction to calculate stage from depth	0 ft

The first step of calibration was to adjust parameters to get the correct water balance, i.e., until the simulated runoff volume is approximately equal to the observed runoff volume plus the estimated diverted volume. The average precipitation for each land segment was calculated in the GIS as the spatial average of the 1961 – 1990 mean annual precipitation (Oregon Climate Service, 1998). Precipitation inputs to each land segment were multiplied by the ratio of estimated precipitation value on the land segment divided by the long term average at the gage. Land segment evaporation was initially assumed to be the same as the evaporation at the gage. These initial precipitation and evaporation multipliers were adjusted by calibration.

The next step of calibration was to adjust storm volumes and then the hydrograph shape. Storm volumes are affected by the INFILT, UZSN and LZSN which determine how much water enters and is held in the land segments as soil moisture. Hydrograph shape is affected by the INTFW, IRC and AGRWC which determine how quickly water leaves each of the soil moisture storages.

As the observed flows are impaired, the values of the parameters suggested by HSPexp were manually adjusted further to get the best possible fit.

Franz Creek was calibrated to match flows at the USGS gage (11463940). Annual runoff volumes and simulated differences are listed in Table F-10; simulated and observed flows are plotted in Figure F-4.

There were only short periods of observed data at the Carneros Creek at Sattui (CAS) and the Huichica gage and the gage was reported by the NCRCD as being inaccurate at low flows. Simulated and observed flows at the Carneros Creek at Henry Road (CAH) and Old Sonoma Bridge (CAO) were compared to calibrate the watershed parameters. The resulting calibrated parameters were used for both the Carneros and Huichica Creek watersheds.

Annual runoff volumes and simulated differences for Carneros Creek and Huichica Creek are listed in Table F-11; simulated and observed flows are plotted in Figure F-5 and Figure F-6. Simulated flows were higher than observed flows at the beginning of the flow period; this represents the most likely time of diversions to storage.

Table F-10. Comparison of Franz Creek Simulated and Observed Flows

Annual Runoff Volume	**Water Year**					
Water Year	**1964**	**1965**	**1966**	**1967**	**1968**	**Average**
Observed (AF)	5,932	22,445	15,788	27,225	13,616	17,001
Storage (AF)	300	300	300	300	300	300
Direct Diversion (AF)	615	615	615	615	615	615
Minimum Unimpaired[1] (AF)	6,232	22,745	16,088	27,525	13,916	17,301
Maximum Unimpaired[2] (AF)	6,847	23,361	16,704	28,140	14,532	17,917
Simulated (AF)	7,275	23,414	13,272	27,815	15,476	17,451
Minimum Error[3]	**17%**	**3%**	**-18%**	**1%**	**11%**	**1%**
Maximum Error[4]	**6%**	**0%**	**-21%**	**-1%**	**6%**	**-3%**

Notes:

1. Minimum Unimpaired runoff is estimated as the observed runoff volume plus the water rights annual storage.
2. Maximum Unimpaired runoff is estimated as the observed runoff volume plus the water rights annual storage and direct diversions (Table F-2).
3. Minimum error is calculated as the difference between simulated and minimum unimpaired flows divided by the minimum unimpaired flows.
4. Maximum error is calculated as the difference between simulated and maximum unimpaired flows divided by the minimum unimpaired flows.

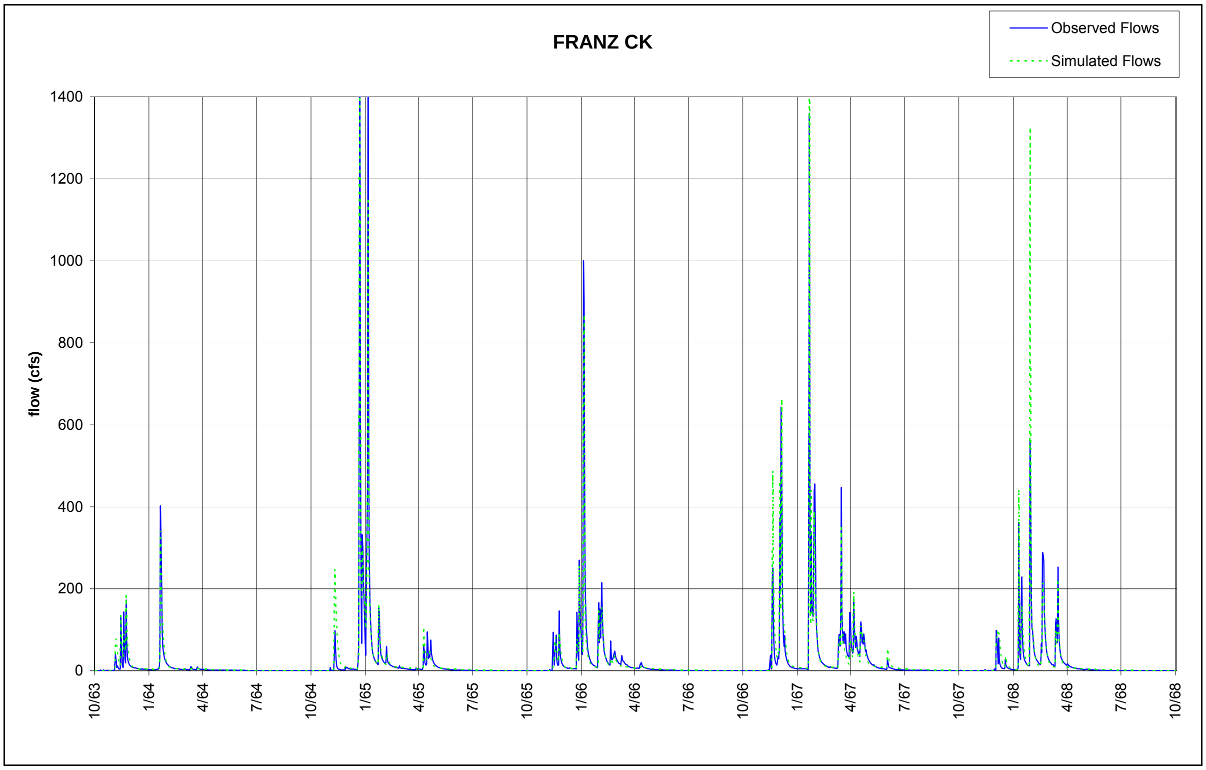

Figure F-4. Franz Creek simulated and observed flows

Table F-11. Comparison of Carneros and Huichica Creeks Simulated and Observed Flows.

Station	**Annual Runoff Volume**	**Water Year**			
		2002	**2003**	**2004**	**2005**
Carneros at Sattui (CAS)	Observed (AF)	n/a	n/a	n/a	2682
	Simulated (AF)				3062
	Differences (% Unimpaired[1])				**13%**
Carneros at Henry Rd (CAH)	Observed	n/a	n/a	n/a	4060
	Simulated				5842
	Differences (% Unimpaired[1])				**23 to 24%**
Carneros at Old Sonoma Bridge (CAO)[2]	Observed	4027	5179	3374	6043
	Simulated	7530	6171	5034	8028
	Differences (% Unimpaired[1])	**-8% to 49%**	**-34% to 0%**	**-33% to 15%**	**-21% to 14%**
Huichica Creek (HRV)	Observed	4330	2575	n/a	n/a
	Simulated	5979	4840		
	Differences (% Unimpaired[1])	**-6% to 14%**	**5% to 38%**		

Notes:

1. Unimpaired runoff is estimated to range from a minimum of the observed runoff volume plus the water rights annual storage to a maximum of the observed runoff volume plus the water rights annual storage and direct diversions (Table F-2). Percent error is calculated as the difference between simulated and unimpaired flows divided by the unimpaired flows.
2. Carneros and Huichica watershed parameters were calibrated at the CAO gage. Precipitation and evaporation multipliers for land segments in the Huichica watershed were adjusted separately to match simulated to estimated unimpaired annual water volumes at the HRV gage.

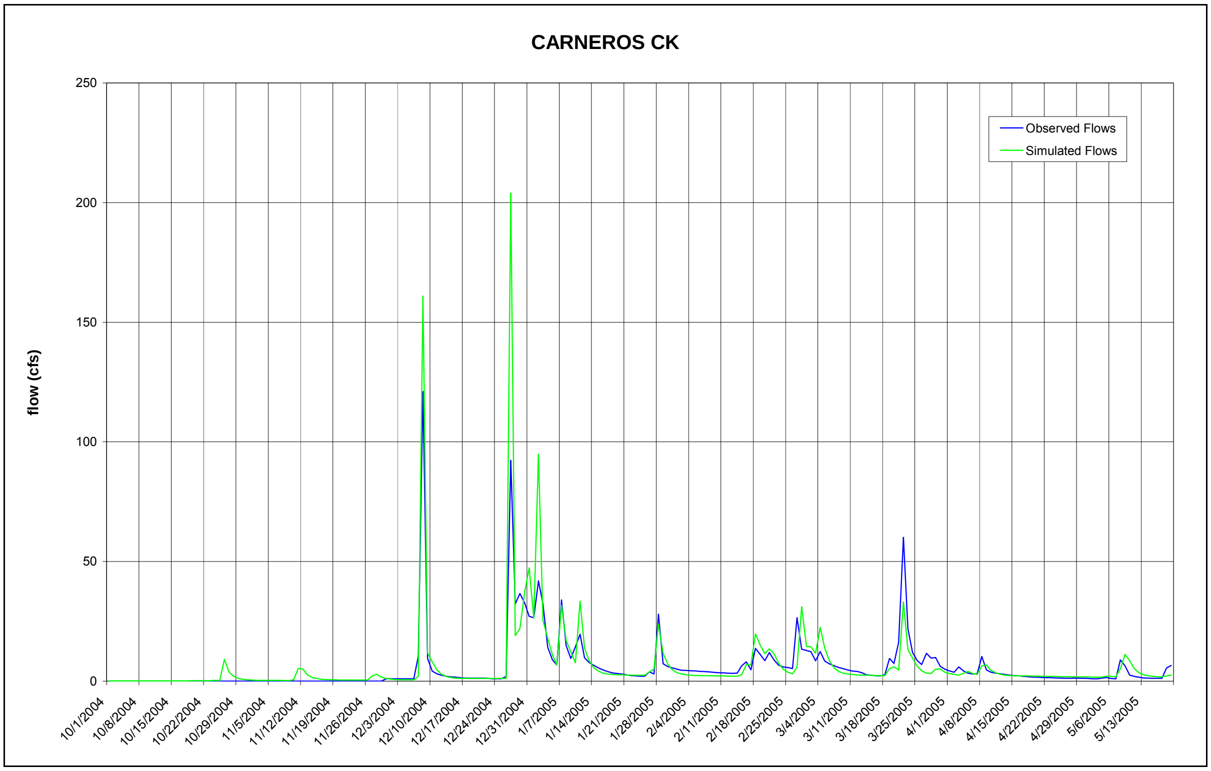

Figure F-5. Carneros Creek (CAS) simulated and observed flows.

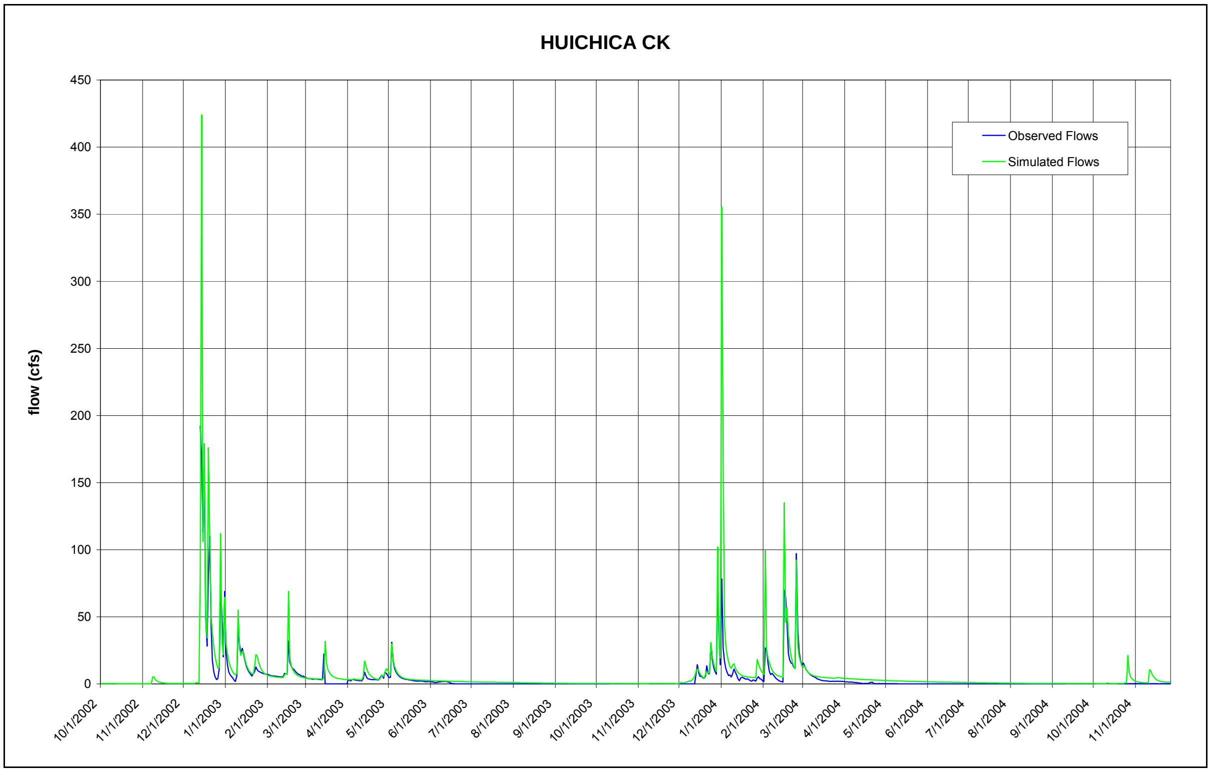

Figure F-6. Huichica Creek simulated and observed flows.

F.2.5 Unimpaired Mean Annual Flow

Unimpaired mean annual flow (Q_m) is one of the parameters used to compute Policy element alternatives for mean bypass flow (MBF3 and MBF4). Stetson computed mean annual unimpaired flow from the unimpaired time series. First, average daily flows in cubic feet per second (cfs) were converted to volumes in acre-feet (AF). Daily flow volumes for each month were then summed together. This summation was only done if the month contained a complete record; that is, any incomplete months were discarded from the unimpaired mean annual flow calculation. In general, USGS data were of high quality and very few months were excluded from statistical calculations. For all USGS gages, there were no gaps in the middle of the periods of record; the only months with missing data occurred at the beginning or end of a period of record when a gage went into or out of service. NPS data were generally of poorer quality than USGS and had months with missing measurements in the middle of continuous records. Simulated flows had no data gaps, so no months were excluded from the statistical analyses.

Annual volumes were computed by summing the monthly volumes for the water year (October through September). An annual total was only computed if all months of the record were complete. Finally, water year annual volumes for complete years only were averaged to obtain an average annual flow volume for the period of record. This quantity was then converted from a volume acre-feet per year to an average flow rate (cfs), resulting in the unimpaired mean annual flow, listed in Table F-12 for each validation site.

Table F-12. Unimpaired Mean Annual Flow for Validation Sites.

Gage / Validation Site	Complete Water Years used to Compute Q_m	Unimpaired Mean Annual Flow, Q_m (cfs)
Albion River near Comptche	8	20
Carneros Creek	4	3.8
Dry Creek Tributary near Hopland	2	2.2
Dunn Creek near Rockport	3	2.5
EF Russian River Tributary near Potter Valley	3	0.13
Franz Creek near Kellogg	5	24
Huichica Creek	4	8.9
Lagunitas Creek at SP Taylor State Park	37	72
Olema Creek	10	25
Pine Creek at Bolinas	4	12
Salmon Creek at Bodega	13	25
Santa Rosa Creek near Santa Rosa	11	19
Warm Springs Creek near Asti	10	35

F.2.6 Unimpaired Instantaneous Flood Frequency

Stetson computed instantaneous peak flood frequency for this study. Instantaneous peak flows are representative of the actual maximum flow rate that would be measured at a single point in time in a stream during a high flow event.

One of the Policy element alternatives for maximum cumulative alternative (MCD2) is formulated with respect to the instantaneous annual peak unimpaired flow with a return period of 1.5 years. Return period is the inverse of the flood probability: an event with a return period of 1.5 years has a 67% chance of occurring in any one year. The instantaneous 1.5-year peak annual unimpaired flow was estimated for the thirteen validation sites based on available observed data[5].

Stetson gathered unimpaired instantaneous flows from existing gage measurements. For USGS gages, instantaneous peak measurements were obtained from the NWIS system (USGS, 2006). For NCRCD gages, 15-minute stream flow measurements were used as estimates of instantaneous measurements. Neither instantaneous nor 15-minute data measurements were available for Lagunitas Creek and Olema Creek.

Note that for some USGS gages, the period of record for instantaneous peaks was longer than the period of record for continuous daily stream flow. In these cases, all of the instantaneous peaks were used in the analysis, since having more years increases the accuracy of the flood frequency calculations.

When more than ten years of instantaneous measurements were available, Stetson used methods described in USGS Bulletin 17B (IACWD, 1982) to compute the unimpaired 1.5-year instantaneous peak annual flow. When fewer than ten years were available, Stetson used an alternative method known as the “peaks-over-threshold” method (IACWD, 2002). For many gages, the USGS records all instantaneous peaks above a given threshold each year. The threshold is selected so that approximately three peaks will be recorded in an average year. These are the data used in the peaks-over-threshold method. The computed unimpaired instantaneous 1.5-year peak flows for each validation site are listed in Table F-13.

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[5] Observed peak flow data were used to determine the unimpaired instantaneous 1.5-year peak flood. At Carneros, Franz and Huichica Creeks, the recorded instantaneous peaks are most likely lower than the peaks that would occur in the absence of diversions.

Table F-13. Unimpaired Instantaneous 1.5-Year Peak Flood at Validation Sites.

Gage / Validation Site	Unimpaired Instantaneous 1.5-year Peak Flood (cfs)
Albion River near Comptche	740
Carneros Creek[1,3,4]	250
Dry Creek Tributary near Hopland	110
Dunn Creek near Rockport	93
EF Russian River Tributary near Potter Valley	25
Franz Creek near Kellogg[3]	1,300
Huichica Creek[3,4]	240
Lagunitas Creek at SP Taylor State Park	*n/a*[2]
Olema Creek	*n/a*[2]
Pine Creek at Bolinas[4]	740
Salmon Creek at Bodega	1,400
Santa Rosa Creek near Santa Rosa	1,200
Warm Springs Creek near Asti	860

Notes:

1. The period of record of the Carneros at Sattui (CAS) gage was not long enough to determine the 1.5-year peak flow at this location. Instead, the 1.5-year peak flow for the CAS gage was estimated by scaling the Carneros at Old Sonoma Road (CAO) gage 1.5-year peak downward to account for the smaller drainage area at CAS and the differences in precipitation and elevation between the CAO and CAS watersheds.
2. Instantaneous peak flow measurements were not available at Lagunitas and Olema Creeks.
3. Observed flows were used to determine the instantaneous 1.5-year peak flows. At Carneros, Franz and Huichica Creeks, the recorded instantaneous peaks are most likely lower than the peaks that would occur in the absence of diversions.
4. 1.5 year peak flows at Carneros, Huichica, and Pine Creeks were calculated using the peaks over threshold method

F.2.7 Unimpaired Flow Exceedances at Validation Sites

Some of the Policy element alternatives for minimum bypass flow (MBF1 and MBF2) and maximum cumulative diversion (MCD1) were based on unimpaired flow exceedances. Flow exceedances are values that represent how often a certain magnitude of flow is expected to occur. A graph of flow exceedances is also known as a flow-duration curve. In such a graph, "percent exceedance" is plotted on the *x*-axis, and corresponding flows are plotted on the y-axis. Points on the graph represent the flow that was exceeded a certain percent of the time. For example, if a graph contains a point at x = 40% and y = 12 cfs, this means that 40% of the time, the flow was greater than 12 cfs.

Flow exceedances may be computed using a variety of time series. Stream flow may be hourly, daily, monthly, etc. For this study, Stetson used unimpaired daily average flows to compute flow exceedances and create flow-duration curves for each of the thirteen validation sites. Exceedances were computed by calculating the flow at each percentile, from zero to the 99th percentile. Note that the flow at the 50th percentile is also known as the median flow.

Stetson computed daily average flow exceedances for three different time periods within the water year. First, year-round flow exceedances were computed, meaning that the percentile distribution was computed based on every daily average flow measurement from October 1 through September 30.

Flow exceedances were calculated for the winter diversion season from December 15 through March 31. The percentile distribution was computed only for daily average flows during that period (i.e., all flows between April 1 and December 14 were excluded). The 20% exceedance flow from December 15 through March 31 is used to compute the MCD rate under Flow Alternative Scenarios 1 and 3.

Finally, daily average flow exceedances were computed for the month of February only. The median (50% exceedance) flow for February is used to determine MBF1, the alternative proposed in the NMFS-DFG Draft Guidelines.

F.3 SYNTHESIZED IMPAIRED DAILY AVERAGE TIME SERIES

Impaired flow time series were calculated by first selecting one alternative for each of the Policy elements restricting flow diversions (diversion season, minimum bypass flow, and maximum cumulative diversion), then determining the maximum daily diversions that would be allowed for this combination of policy element alternatives, and finally subtracting these maximum daily diversions from the unimpaired flow time series to determine the remaining impaired flow time series.

F.3.1 Methods: Spreadsheet Computations

Selected alternatives for diversion season, minimum bypass flow, and maximum cumulative diversion were applied to the unimpaired time series to create impaired flow time series. Stetson implemented daily flow restrictions and diversion limits in spreadsheets (Microsoft Excel) to compute the maximum allowable daily diversions and the impaired daily flow time series that would remain after this water was diverted.

The Excel spreadsheets were designed such that any combination of the three Policy elements could be used to create an impaired time series. The application of the three Policy elements to compute impaired time series is discussed below. The logic implemented on a daily basis in the spreadsheets is illustrated in Figure F-7.

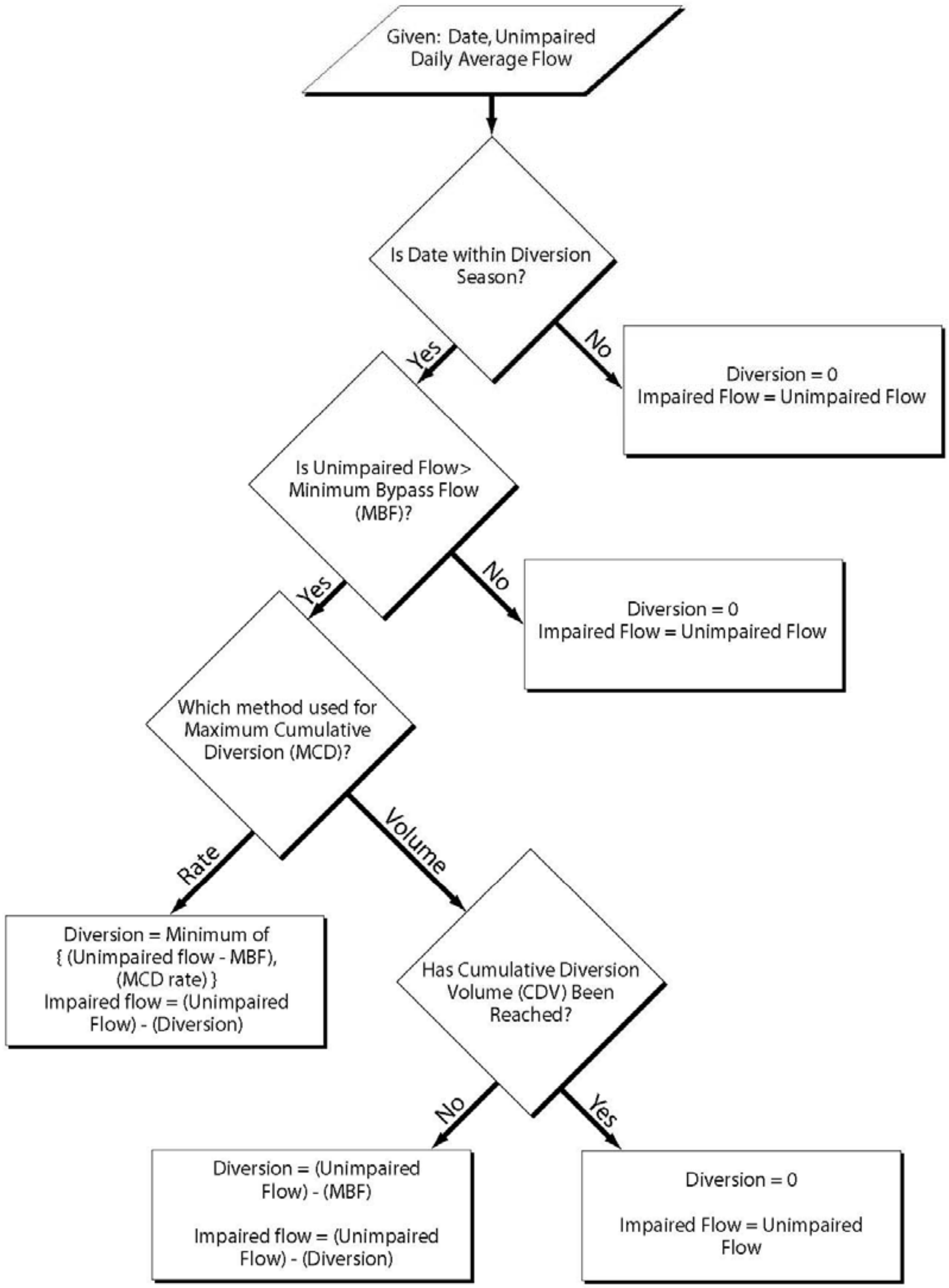

Figure F-7. Logic tree illustrating calculations in spreadsheet to determine daily diversions and impaired flow for policy element flow alternative scenarios

Any combination of the three Policy elements could be implemented to create impaired time series. For the habitat assessment, R2 analyzed impaired time series for Flow Alternative Scenarios 1 through 5 at each of the thirteen validation sites. The Policy element alternatives corresponding to each Flow Alternative Scenario are shown in Table 4-2. Additional combinations of Policy element alternatives were used to create impaired time series for the Sensitivity Scenarios discussed in Section F.4 and Table F-17 of this appendix.

Diversion Season. This is defined as the period over which diversions are allowed. Diversion season alternatives evaluated included: (DS1) December 15 through March 31 (Flow Alternative Scenarios 1, 3, and 5); (DS2) year-round (Flow Alternative Scenario 2); and (DS3) October 1 through March 31 (Flow Alternative Scenario 4 and all Sensitivity Scenarios).

In the spreadsheet, a diversion season start and end date are specified, and no diversions are allowed outside of those dates.

Minimum Bypass Flow (MBF). This is the minimum flow rate below which no diversions are allowed. MBF alternatives include: (MBF1) the February median daily flow (Flow Alternative Scenarios 1 and 5); (MBF2) the ten percent annual exceedance flow (Flow Alternative Scenario 2); (MBF3) an Upper MBF alternative which is a function of drainage area and mean annual flow (Flow Alternative Scenario 3 and all Sensitivity Scenarios); and (MBF4) a Lower MBF alternative, also a function of drainage area and mean annual flow (Flow Alternative Scenario 4). See Chapter 4, Tables 4-2 and 4-3 for a complete list of the combinations of Policy Elements alternatives used to generate each Flow Alternative Scenario used in the habitat assessment. February median flows and ten percent annual exceedance were computed as described in Section F.2.7.

On a daily basis, the spreadsheet checks whether the unimpaired daily flow exceeds the specified MBF. If it does, diversions are allowed up to a maximum of the difference between the unimpaired flow and the MBF. That is, even if diversions are allowed, the impaired flow cannot be less than the MBF. If the unimpaired flow is equal to or less than the MBF, no diversions are allowed.

Maximum Cumulative Diversion (MCD) rate or volume. This is a limit to the total (cumulative) diversions that can be made at or upstream of a point of diversion. The MCD has been implemented by restricting either the daily diversion flow rate (rate) or the total cumulative diversion volume (volume) for the diversion season. Alternatives MCD1, MCD2 and MCD4 restrict the diversion rate, while MCD3 restricts the diversion volume.

MCD rate alternatives include: (MCD1) based on winter exceedance flows (Flow Alternative Scenarios 1 and 3); (MCD2) five percent of the 1.5 year flood magnitude (Flow Alternative

Scenario 4); and (MCD4) which limits changes to the hydrograph falling limb timing (see main text, Figure 3-2, Flow Alternative Scenario 2). If the MCD rate method is used, the daily diversion quantity is restricted to that maximum rate. For example, if the unimpaired flow is 50 cfs, the MBF is 20 cfs, and the MCD rate is 12 cfs, the maximum potential diversion would be 30 cfs (unimpaired flow – MBF); however, the MCD rate restricts this daily diversion to a maximum of 12 cfs. The diversion is 12 cfs, and the impaired flow is 38 cfs (50 cfs – 12 cfs).

If the MCD volume method is used, diversions are not restricted on a daily basis, but instead on a seasonal basis. This method was employed only in MCD 3 (Flow Alternative Scenario 5) based on the draft DFG-NMFS guidelines (2002). The DFG-NMFS guidelines proposed a maximum cumulative diversion volume (CDV) equal to 10% of the estimated unimpaired runoff (EUR) for the diversion season. The ratio of the CDV divided by the EUR is referred to as the cumulative flow impairment index (CFII). There is no limit to the timing of these diversions. For this analysis, it was assumed that water diverters would take all available water until the full CDV was diverted.

In the spreadsheet, EUR was computed from the unimpaired time series, and CDV was computed for a 10% CFII. At the start of the diversion season, flow was impaired by subtracting all the water available for diversion from the unimpaired flow time series, i.e., the diversion was equal to the unimpaired flow minus the MBF. Total volume of diversions was tracked cumulatively. Once total diversions equaled the CDV, no additional diversions were taken and the unimpaired flow was equal to the impaired flow. For example, if the unimpaired flow is 50 cfs, the MBF is 20 cfs, and the CDV has not yet been reached, the allowable diversion is equal to the maximum potential diversion of 30 cfs and the impaired flow is equal to 20 cfs, which is the MBF.

F.3.2 Impaired Mean Annual Flow

After the impaired daily average time series were computed for each Flow Alternative Scenario as described above, Stetson computed mean annual impaired flow for each impaired time series using the same method described in Section F.2.5.

F.3.3 Impaired Instantaneous Flood Frequency

Stetson computed impaired instantaneous flood frequency for each Flow Alternative Scenarios for the purpose of assessing how the policy elements affect peak flows. Since continuous daily average time series were used in this study, estimates of impaired instantaneous flows had to be made separately. Due to the limited nature of instantaneous measurements (only one measurement per year, usually), the daily average time series were necessary to estimate some impaired instantaneous peaks. Thus, at each validation site, both instantaneous and continuous daily average records were required. Also, for this analysis, data with fewer than 8 years were not included since flood frequency calculations are not very accurate with only a small number of data points. After making these considerations, data were only sufficient to compute instantaneous flood frequency at four of the 13 validation sites, Albion River, Salmon Creek, Santa Rosa Creek, and Warm Springs Creek.

Stetson gathered unimpaired instantaneous measurements at the four validation sites as described in Section F.2.6. To compute the impaired instantaneous peak annual flow, Stetson used two methods, one for impairment using the MCD rate method, and one for those using the MCD volume. The process of determining the impaired instantaneous peak is diagrammed in Figure F-8.

If an MCD rate restriction was applied to impair the flow, the instantaneous peak was computed as follows: first, the date of the instantaneous peak was checked to see if it fell within the prescribed diversion season. If it was not in the diversion season, then the impaired instantaneous peak was simply equal to the unimpaired instantaneous peak. If the date did fall within the diversion season, then the impaired peak was equal to the unimpaired peak minus the MCD rate, but no less than the MBF.

If the MCD volume method was applied to impair the flow, the instantaneous peak was determined through a series of steps. First, for each water year, Stetson determined the date that the CDV was reached. This date was important because it divides the diversion season into two distinct periods: before the CDV is reached, all flows higher than the MBF are diverted [6], while after the CDV is reached, no diversions are taken.

Next, the date of the unimpaired instantaneous peak was checked for two conditions: (1) if the date was after the CDV was reached, or (2) if the date was outside of the diversion season. If either of these conditions were true, then the impaired instantaneous peak was equal to the unimpaired instantaneous peak (i.e., the diversions that season did not alter the peak flow).

If the date of the unimpaired instantaneous peak was during the diversion season and before the CDV was reached, some of the annual unimpaired instantaneous peak flow would be diverted. In this case, the impaired peak may not occur on the same date as the unimpaired peak. The impaired daily average time series was used to determine the date of the maximum impaired daily average peak flow.

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[6] The MCD volume method limits the total volume of diversions but does not prescribe the rate or timing of these withdrawals. For this analysis, it was assumed that diverters would take all available water until the full CDV was diverted.

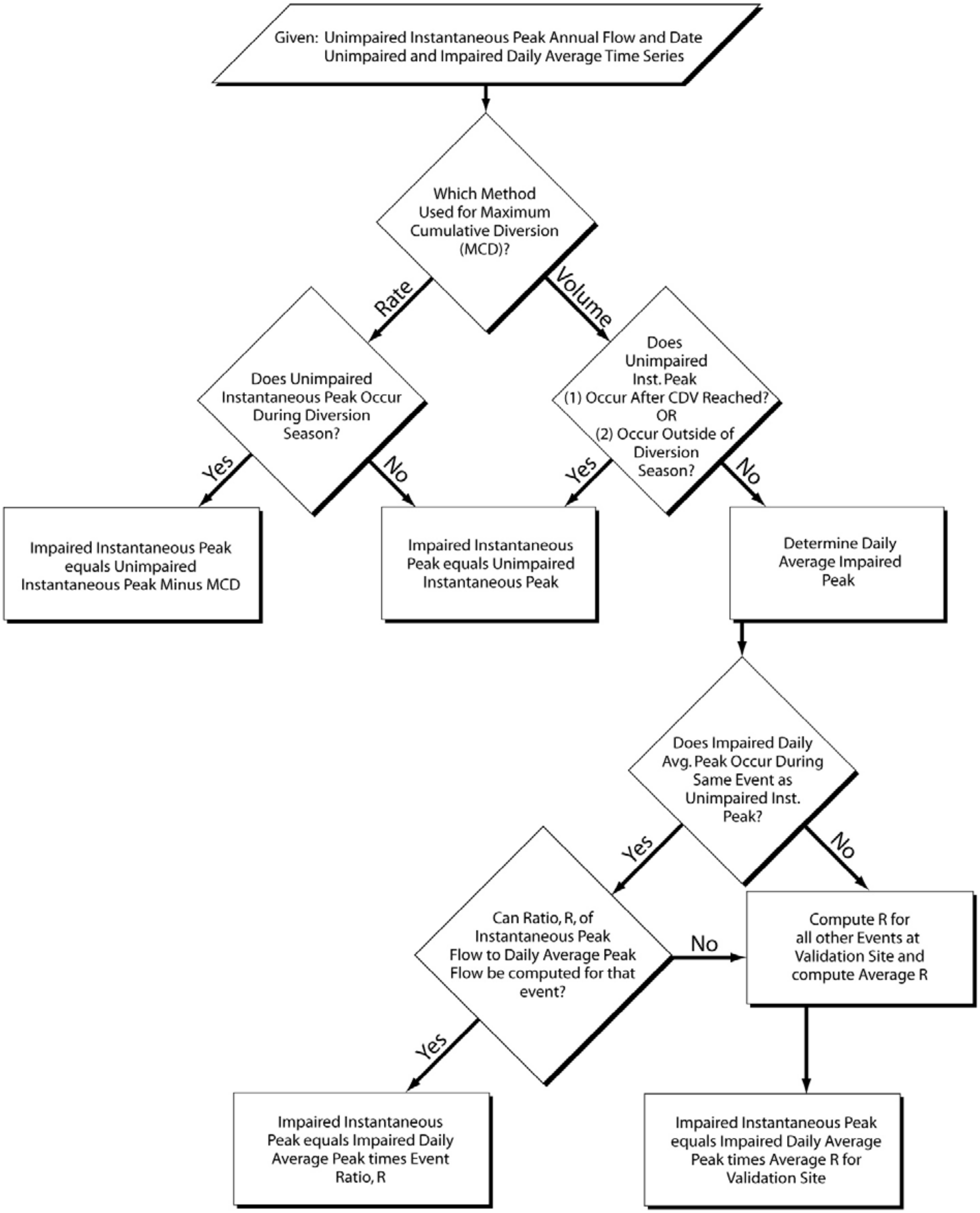

Figure F-8. Logic tree illustrating process to determine impaired instantaneous peak flows.

Due to the limited availability of instantaneous data, the impaired daily average time series was used to estimate the instantaneous peak flows. Once the daily average impaired peak was determined, the daily average flow rate was scaled up to estimate the instantaneous peak flow rate. For all four validation sites, the ratio, R, of the instantaneous unimpaired peak flow to the daily average unimpaired peak flow was computed whenever such measurements were available for the same day:

$$R = U_{p,inst} / U_{p,daily\ avg}$$

where $U_{p,inst}$ = the instantaneous unimpaired peak flow on day X
$U_{p,daily\ avg}$ = the daily average unimpaired peak flow on day X

At the four gages analyzed, there were at least five years per gage for which R could be computed. In scaling the impaired daily average peaks, two methods were used. If the daily average impaired peak occurred during the same event as the unimpaired instantaneous peak and an R value was able to be computed for that event, then that R was used to scale the impaired daily average flow as follows:

$$I_{p,inst} = I_{p,daily\ avg} * R$$

where $I_{p,inst}$ = the instantaneous impaired peak flow on day X
$I_{p,daily\ avg}$ = the daily average impaired peak flow on day X

If no R value was available for the impaired peak event, then the average R for that gage was used to scale the impaired flow:

$$I_{p,inst} = I_{p,daily\ avg} * R_{avg}$$

where R_{avg} = the average of all individual R for the validation site

Using the methods described above, Stetson determined instantaneous peak annual flows for the unimpaired flow and for the flows impaired according to each Flow Alternative Scenario. The values are listed in Table F-14.

After the instantaneous peak annual flows were estimated, a flood frequency analysis was completed. For the four validation sites, the 1.5-year instantaneous peak flows were determined to provide a relative comparison of the unimpaired flow and the flows impaired according to each Flow Alternative Scenario. In order to make comparisons most meaningful, the same period of record was used for the unimpaired flood frequency and the impaired flood frequencies. Note that for the unimpaired flows, instantaneous measurements were available for years in addition to those shown in Table F-14, but were not used in this analysis because comparable impaired peaks could not be computed.[7]

The magnitude of the 1.5-year event was computed based on methods from USGS Bulletin 17B (IACWD, 1982) as described in Section F.2.6. Generally, this method provides guidelines for excluding statistical outliers in the frequency calculation. However, for the calculation of unimpaired and impaired peak flows at these four validation sites, no outliers were excluded. This provided consistency between the unimpaired and impaired cases. For example, if the unimpaired analysis was based upon ten peak floods, the impaired frequency analysis was also based on ten events from the same ten years.

F 3.4 Analysis of Falling Limb of Impaired and Unimpaired Hydrographs

A flood hydrograph can be divided into two sections, called the rising and falling limbs. The limbs are separated by the peak stream flow runoff of the event. The rising limb is the portion of the hydrograph in which stream flow runoff (discharge) is increasing. After the peak of the event, stream flow decreases; this section of the hydrograph is referred to as the falling limb (sometimes also referred to as the receding limb or recession limb). The rising and falling limbs of an event hydrograph are illustrated in Figure F-9.

McBain and Trush and Trout Unlimited (MTTU, 2000) recommended that the maximum diversion rate of the Policy should be set based on the timing of the falling limb of peak flood events. In general, diversions in a stream will cause the impaired hydrograph for a flood event to be of shorter duration that the unimpaired hydrograph. MTTU recommended that a maximum diversion rate be imposed such that diversions would shorten the timing of the falling limb by no more than half a day.

R2 computed the MTTU MCD rate following the procedure illustrated in Figure 3-2 of the main text and described here in detail. First, events that exceeded the 1.5-yr flood were selected from the unimpaired daily flow time series. The selected events are given in Table F-15, and the 1.5-year flood magnitudes are those from Table F-13.

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[7] Note that the unimpaired flood frequency computed here differs from that computed in section F.2.6. In that analysis, all years of unimpaired instantaneous measurements were included to provide the most accurate estimate of the 1.5-year peak event. In this analysis, however, a meaningful comparison between the unimpaired and impaired peaks could be made only if the periods of record for the computed peaks were the same. For this reason, the 1.5-year peaks reported in Table F-15 may differ from those reported in Table F-13.

Table F-14. Estimated Instantaneous Peak Annual Flows for Four USGS Gages.

Validation Site	Water Year	Instantaneous Peak Annual Flow (cfs)					
		Unimpaired	**Alt. 1**	**Alt. 2**	**Alt. 3**	**Alt. 4**	**Alt. 5**
Albion River	1962	1,310	1,299	1,300	1,299	1,273	1,310
Albion River	1963	934	923	924	923	897	510
Albion River	1964	1,090	1,079	1,080	1,079	1,053	646
Albion River	1965	2,050	2,039	2,040	2,039	2,013	2,050
Albion River	1966	2,390	2,379	2,380	2,379	2,353	2,052
Albion River	1967	840	829	830	829	803	615
Albion River	1968	615	604	605	604	578	330
Albion River	1969	1,620	1,609	1,610	1,609	1,583	1,620
Salmon Creek	1963	1,430	1,418	1,417	1,418	1,360	1,430
Salmon Creek	1964	1,220	1,208	1,207	1,208	1,150	419
Salmon Creek	1965	1,540	1,528	1,527	1,528	1,470	1,540
Salmon Creek	1966	1,960	1,948	1,947	1,948	1,890	1,960
Salmon Creek	1967	1,760	1,748	1,747	1,748	1,690	1,760
Salmon Creek	1968	1,370	1,358	1,357	1,358	1,300	1,370
Salmon Creek	1969	1,650	1,638	1,637	1,638	1,580	1,650
Salmon Creek	1970	1,790	1,778	1,777	1,778	1,720	1,790
Salmon Creek	1971	1,380	1,380	1,367	1,380	1,310	1,380
Salmon Creek	1972	537	525	524	525	467	132
Salmon Creek	1973	2,260	2,248	2,247	2,248	2,190	2,260
Salmon Creek	1974	1,760	1,748	1,747	1,748	1,690	1,760
Salmon Creek	1975	1,950	1,938	1,937	1,938	1,880	1,950
Santa Rosa Creek	1960	3,200	3,192	3,193	3,192	3,140	3,200
Santa Rosa Creek	1961	550	542	543	542	490	205
Santa Rosa Creek	1962	1,140	1,132	1,133	1,132	1,080	1,010
Santa Rosa Creek	1963	1,250	1,242	1,243	1,242	1,190	1,250
Santa Rosa Creek	1964	1,040	1,032	1,033	1,032	980	173
Santa Rosa Creek	1965	2,480	2,472	2,473	2,472	2,420	2,480
Santa Rosa Creek	1966	1,590	1,582	1,583	1,582	1,530	1,590
Santa Rosa Creek	1967	1,830	1,822	1,823	1,822	1,770	1,328
Santa Rosa Creek	1968	1,040	1,032	1,033	1,032	980	547
Santa Rosa Creek	1969	1,180	1,172	1,173	1,172	1,120	1,180
Santa Rosa Creek	1970	2,150	2,142	2,143	2,142	2,090	2,150
Warm Springs Creek	1974	2,230	2,210	2,219	2,210	2,187	2,230
Warm Springs Creek	1975	908	888	897	888	865	908

Table F-14. Estimated Instantaneous Peak Annual Flows for Four USGS Gages.

Validation Site	**Water Year**	**Instantaneous Peak Annual Flow (cfs)**					
		Unimpaired	**Alt. 1**	**Alt. 2**	**Alt. 3**	**Alt. 4**	**Alt. 5**
Warm Springs Creek	1976	204	204	193	204	204	204
Warm Springs Creek	1977	57	39	57	57	30	39
Warm Springs Creek	1978	2,320	2,300	2,309	2,300	2,277	2,320
Warm Springs Creek	1979	1,030	1,010	1,019	1,010	987	613
Warm Springs Creek	1980	1,670	1,650	1,659	1,650	1,627	1,670
Warm Springs Creek	1981	1,020	1,020	1,009	1,020	977	997
Warm Springs Creek	1982	1,580	1,560	1,569	1,560	1,537	1,580
Warm Springs Creek	1983	2,660	2,640	2,649	2,640	2,617	2,660

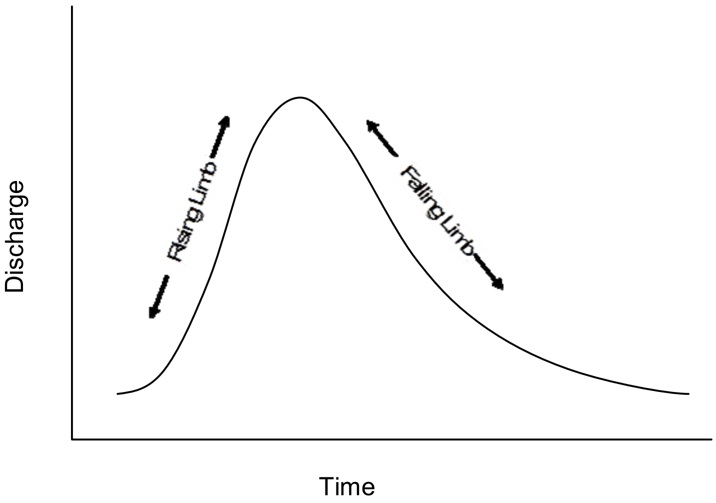

Figure F-9. Rising and falling limbs of a flood event.

The event hydrographs were plotted and a line equal to the MBF (from Table 4-3 of main text, Flow Alternative Scenario 2) was drawn parallel to the abscissa. The time that the falling limb of the unimpaired hydrograph intercepted the MBF was calculated. Next, the flow that occurred half a day earlier than that intercept was computed using linear interpolation. The difference between that flow and the MBF was the MCD rate for that event.

This procedure was repeated for all selected events at each validation site. The MCD rate for each validation site was computed by taking the average of the rates computed for each event. The computed MCD rates for the MTTU alternative (MCD4) are given in Table F-15.

Table F-15. Instantaneous 1.5-Year Peak Annual Flows for Flow Alternative Scenarios

	Instantaneous 1.5-year Peak Annual Flow (cfs)					
Validation Site	**Unimpaired**	**Flow Alternative Scenario 1**	**Flow Alternative Scenario 2**	**Flow Alternative Scenario 3**	**Flow Alternative Scenario 4**	**Flow Alternative Scenario 5**
Albion River	1,017	1,006	1,007	1,006	978	707
Salmon Creek	1,439	1,429	1,426	1,429	1,369	1,152
Santa Rosa Creek	1,170	1,161	1,162	1,161	1,107	734
Warm Springs Creek	690	666	678	683	644	614

Table F-16. Flood Events Used to Compute MCD Rate for the MTTU (2000) Element Alternative (MCD4).

	Events Evaluated		
Validation Site	**Date of Peak[1]**	**Calculated Event MCD Rate (cfs)**	**Average Validation Site MCD Rate (cfs)**
Albion River Near Comptche	12/22/64	4.4	10
	01/04/66	16	
Carneros Creek[2]	12/27/04	9.0	9.0
Dry Creek Tributary near Hopland[2]	01/31/69	3.2	3.2
Dunn Creek near Rockport[2]	04/06/63	0.10	0.10
EF Russian River Tributary near Potter Valley	02/08/60	0.10	0.10
Franz Creek near Kellogg	01/05/65	7.0	7.6
	01/29/67	7.3	
	01/29/68	8.4	
Huichica Creek[2]	12/27/04	2.2	2.2
Lagunitas Creek at SP Taylor State Park	*n/a*	*n/a*	*n/a*
Olema Creek	*n/a*	*n/a*	*n/a*
Pine Creek at Bolinas[2]	02/17/99	1.1	1.1
Salmon Creek at Bodega[2]	01/11/73	13	13
Santa Rosa Creek near Santa Rosa	02/08/60	7.2	7.2
Warm Springs Creek near Asti	01/16/74	10	11
	01/16/78	4.0	
	12/19/81	13	
	03/13/83	16	

Notes:

1. Date given is the date of the event's peak average daily flow.
2. The peak daily average event at this site was less than the 1.5-yr flood magnitude. The hydrograph of the largest event at this site was used to calculate the MCD.

F.4 SENSITIVITY ANALYSIS OF MCD RATE AND VOLUME POLICY ELEMENT ALTERNATIVE

The impacts of the diversion season and minimum bypass flow Policy elements are readily distinguishable in the impaired hydrographs for each Flow Alternative Scenario, however the extent to which the maximum cumulative diversion rate or volume limits diversions beyond the restrictions placed by the two Policy elements is not as simple to discern. To isolate the effect of the MCD alternative on the impaired hydrograph, Stetson generated and compared four MCD sensitivity analysis scenarios (termed henceforth Sensitivity Scenarios)

In each Sensitivity Scenario, the diversion season and MBF were the same, and only the selection of the MCD alternative varied. Stetson created impaired time series for eleven validation sites for each Sensitivity Scenario and computed statistics to assess the magnitude and frequency of diversions. Sensitivity Scenarios were not assessed for Lagunitas and Olema Creeks since MCD2 (Sensitivity Scenario 4) could not be computed due to lack of instantaneous peak measurements. Flood frequency was also compared for four of the validation sites.

Results of the MCD sensitivity analysis indicate that, in general, diversions occur less frequently but at much higher rates when the MCD volume method is employed. Maximum diversion rates are generally an order of magnitude higher in the MCD volume scenario. Also, the MCD volume method allows a more significant reduction of peak annual floods than the MCD rate methods.

F.4.1 Methods for Sensitivity Analysis

In each Sensitivity Scenario, the diversion season and minimum bypass flow were held constant, while the MCD was varied. The Policy element alternatives used in each Sensitivity Scenario are summarized in Table F-17.

The diversion season and minimum bypass flow for all four Sensitivity Scenarios were the same: the diversion season was October 1 through March 31 (DS3); the MBF was the Upper MBF alternative, a function of drainage area and mean annual flow (MBF3). Values used for MBF are given in Table F-18.

There are four MCD alternatives, one is analyzed in each Sensitivity Scenarios. Sensitivity Scenario 1 used MCD3, the MCD volume method specified by the DFG-NMFS draft guidelines (same method as Flow Alternative Scenario 5). The maximum volume was determined based on a CFII equal to 10%. Sensitivity Scenario 2 used MCD4, a rate computed at each validation site using the method recommended by MTTU as described in Section F.3.4 and used in Flow Alternative Scenario 2. Sensitivity Scenario 3 used MCD1, 15% of the 20% winter exceedance (used in both Flow Alternative Scenarios 1 and 3). These rates were developed based on drainage area and mean annual flow of each site. Sensitivity Scenario 4 used MCD2, a rate computed as 5% of the 1.5-year flood (Flow Alternative Scenario 4).

Table F-17. Policy Element Alternatives Used in Sensitivity Scenarios.

Policy Element	**Sensitivity Scenario 1**	**Sensitivity Scenario 2**	**Sensitivity Scenario 3**	**Sensitivity Scenario 4**
Diversion Season	**DS3** Oct 1 – Mar 31	**DS3** Oct 1 – Mar 31	**DS3** Oct 1 – Mar 31	**DS3** Oct 1 – Mar 31
Minimum Bypass Flow (MBF)	**MBF3** Function of drainage area and mean annual flow (Upper MBF)	**MBF3** Function of drainage area and mean annual flow (Upper MBF)	**MBF3** Function of drainage area and mean annual flow (Upper MBF)	**MBF3** Function of drainage area and mean annual flow (Upper MBF)
Maximum Cumulative Diversion (MCD)	**MCD3** Volume: CFII = 10% (DFG-NMFS)	**MCD4** Rate: Calculated for each site following the procedure depicted in Figure 3-2 (MTTU)	**MCD1** Rate: 15% of Winter 20% Exceedance (DFG-NMFS)	**MCD2** Rate: 5% of 1.5-year Flood (DFG-NMFS)

Table F-18. Minimum Bypass Flows for All Sensitivity Scenarios.

Validation Site	**Sensitivity Scenarios 1-4 Minimum Bypass Flow (cfs)**
Albion River	45
Carneros Creek	18
Dry Creek Trib	16
Dunn Creek	15
E. Fk. Russian River Trib	2.0
Franz Creek	52
Huichica Creek	33
Pine Gulch Creek	36
Salmon Creek	53
Santa Rosa Creek	46
Warm Springs Creek	85

MCD values for all four Sensitivity Scenarios are given in Table F-19. The range of the rate of withdrawal of the MCD volume is also given. The minimum rate of withdrawal was calculated assuming the entire cumulative diversion volume (CDV) was taken out at a constant rate over the duration of the diversion season. For example, CDV for Albion equals 1,130 acre-feet. There are approximately 182 days in the winter period, so the equivalent constant flow rate over the winter period is: (1,130 acre-feet) ÷ (182 days) ÷ (1.9835 acre-feet/cfs-day) = 3.1 cfs. The maximum rate of withdrawal listed for Sensitivity Scenario 1 in Table F-19 is the maximum daily diversion rate which would occur during the period if flow was impaired by diverting all possible water until the CDV was met, i.e., the maximum daily diversion taken from the unimpaired time series to generate the impaired time series for Sensitivity Scenario 1.

Table F-19. Maximum Cumulative Diversion (MCD) Rate and Volume for Sensitivity Scenarios.

	MCD Volume: Sensitivity Scenario 1			**MCD Rate: Sensitivity Scenarios 2-4**		
		CDV Withdrawal Rate (cfs)		**Maximum Diversion Rate (cfs)**		
Validation Site	**Cumulative Diversion Volume (CDV) for Season (acre-feet)**	**Minimum[1]**	**Maximum[2]**	**Sensitivity Scenario 2**	**Sensitivity Scenario 3**	**Sensitivity Scenario 4**
Albion River	1,130	3.1	363	10	11	37
Carneros Creek	190	0.5	96	9	1.6	13
Dry Creek Trib	150	0.4	34	3.2	1.5	5.5
Dunn Creek	87	0.2	36	0.1	0.8	4.7
E. Fk. Russian River Trib	8.6	0.0	3.4	0.1	0.1	1.3
Franz Creek	1,196	3.3	436	7.6	9.1	65
Huichica Creek	447	1.2	225	2.2	3.7	12
Pine Gulch Creek	704	2.0	252	1.1	6.2	37
Salmon Creek	1,424	3.9	451	13	12	70
Santa Rosa Creek	1,084	3.0	463	7.2	8.3	60
Warm Springs Creek	1,928	5.3	481	11	20	43

Notes:

1. Minimum rate of withdrawal was calculated as the constant rate which would result in a total diverted volume over the duration of the diversion season equal to the CDV.
2. Maximum rate of withdrawal was calculated as the maximum daily diversion rate which would occur during the period of record if flows were impaired by diverting all possible water until the CDV was met during each diversion season.

To compare the magnitudes of the various diversion rates listed in Table F-19, the diversion rates have been expressed as a percentage of the unimpaired 1.5-year peak annual flood magnitude in Table F-20. The unimpaired 1.5-year peak annual flood magnitudes are those computed in Section 2.6 (listed in Table F-13 and repeated in Table F-20). For Sensitivity Scenario 1, since only the seasonal volume is specified, the average and maximum diversion rates have been expressed in terms of the unimpaired 1.5-year peak magnitude. Clearly, Sensitivity Scenario 1 has the highest allowable maximum diversion rates, followed by Sensitivity Scenario 4 (for which maximum diversion rates were defined as being 5% of the unimpaired 1.5-year peak annual flood). Sensitivity Scenarios 2 and 3 have maximum diversion rates which are all less than 5% of the unimpaired 1.5-year peak annual flood.

Table F-20. Comparison of Sensitivity Scenarios: Diversion Rates from Table F-19 Expressed in Terms of Unimpaired 1.5-Year Peak Flood.

		Diversion rates expressed as percent of unimpaired flood magnitude				
		Sensitivity Scenario 1				
Validation Site	**Unimpaired 1.5-year Peak Annual Flood Magnitude (cfs)**	**Minimum**	**Maximum**	**Sensitivity Scenario 2**	**Sensitivity Scenario 3**	**Sensitivity Scenario 4**
Albion River	740	0.4%	49.1%	1.4%	1.5%	5%
Carneros Creek	250	0.2%	38.4%	3.6%	0.6%	5%
Dry Creek Trib	110	0.4%	30.9%	2.9%	1.4%	5%
Dunn Creek	93	0.3%	38.7%	0.1%	0.9%	5%
E. Fk. Russian River Trib	25	0.1%	13.6%	0.4%	0.4%	5%
Franz Creek	1,300	0.3%	33.5%	0.6%	0.7%	5%
Huichica Creek	240	0.5%	93.8%	0.9%	1.5%	5%
Pine Gulch Creek	740	0.3%	34.1%	0.1%	0.8%	5%
Salmon Creek	1,400	0.3%	32.2%	0.9%	0.9%	5%
Santa Rosa Creek	1,200	0.3%	38.6%	0.6%	0.7%	5%
Warm Springs Creek	860	0.6%	55.9%	1.3%	2.3%	5%

F.4.2 Results and Discussion

Figure F-10 illustrates the differences between the MCD rate and volume methods. The upper graph in the figure shows typical unimpaired and impaired hydrographs that result from limiting seasonal diversions to the MCD volume (Sensitivity Scenario 1). As shown in the figure, during early events (i.e., those around January 20 and February 9) before the CDV is reached, all of the water above the MBF is diverted[8]. The diversion rate is up to 135 cfs. In mid-February, cumulative diversions for the season reach the CDV limit and no additional diversions are taken for the remainder of the diversion season. In general, when the MCD volume method is applied, peaks early in the season are reduced to the level of the MBF, while peaks later in the season remain at unimpaired levels. Before the CDV is reached, diversions were limited only by the availability of water; any water above the MBF was diverted no matter how high the diversion rate.

The lower graph of Figure F-10 shows the unimpaired and impaired hydrographs when a MCD rate is used to restrict annual diversions (used in Sensitivity Scenarios 2, 3, and 4). Diversions are limited by a fixed flow rate (in this case 20 cfs). Contrary to the top graph, diversions never exceed 20 cfs, and they occur until the end of the diversion season whenever water is available (i.e., if flows are greater than the MBF). Note that for both of the graphs in diversion season and MBF are identical and the differences in the impaired time series are due strictly to differences in the MCD method.

F.4.2.1 Summary of Diversion Rates, Frequency, and Quantity

Statistics for the unimpaired and impaired hydrographs for each validation site for each Sensitivity Scenario were computed. Table F-21 gives the maximum diversion rate for each Sensitivity Scenario. For Sensitivity Scenarios 2 through 4, since the maximum diversion rate is fixed, the results are as expected and match the rates specified in Table F-19. For Sensitivity Scenario 1, maximum daily flow rates are not restricted, and accordingly, the rates in Table F-21 are much higher for Sensitivity Scenario 1 than for the other three scenarios. In general, Sensitivity Scenario 1 maximum diversion rates are an order of magnitude larger than the other three scenarios' MCD rates.

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[8] The MCD volume method does not specify limits to the timing or rate of withdrawal; this is left to the discretion of the water diverter and limited only by diversion capacity. This analysis assumed that water diverters would take all available water until the maximum CDV was diverted.

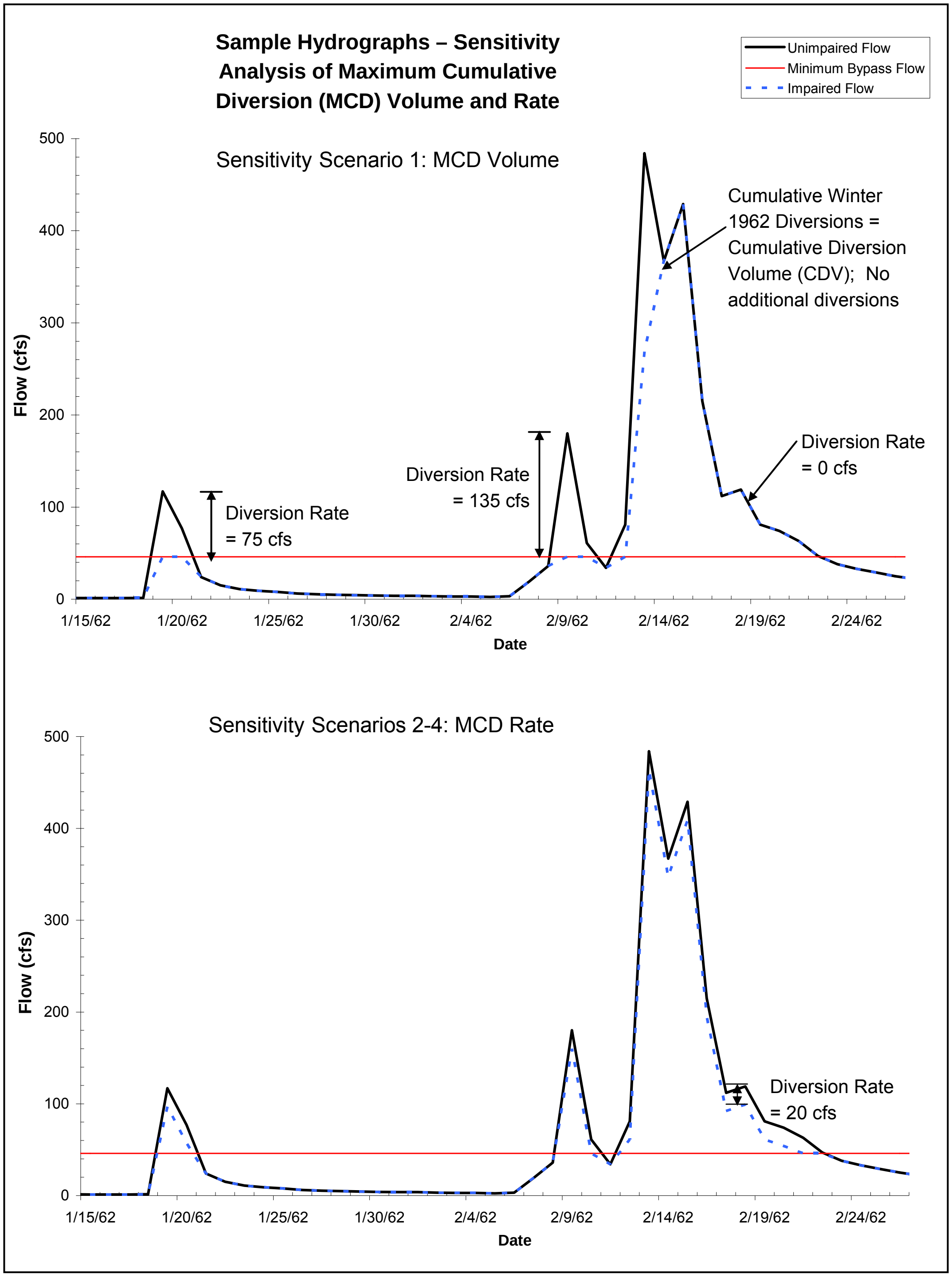

Figure F-10. Hydrographs of unimpaired and impaired flow illustrating differences between MCD volume and rate alternatives.

Table F-21. Maximum Daily Diversion Rate for Sensitivity Scenarios (based on daily average flows).

	Maximum Average Daily Diversion (cfs)			
Gage / Validation Site	**Sensitivity Scenario 1**	**Sensitivity Scenario 2**	**Sensitivity Scenario 3**	**Sensitivity Scenario 4**
Albion River near Comptche	363	10	11	37
Carneros Creek	96	9.0	1.6	13
Dry Creek Tributary near Hopland	34	3.2	1.5	5.5
Dunn Creek near Rockport	36	0.10	0.80	4.7
EF Russian River Tributary near Potter Valley	3.4	0.10	0.10	1.3
Franz Creek near Kellogg	436	7.6	9.1	65
Huichica Creek	225	2.2	3.7	12
Pine Creek at Bolinas	252	1.1	6.2	37
Salmon Creek at Bodega	451	13	12	70
Santa Rosa Creek near Santa Rosa	463	7.2	8.3	60
Warm Springs Creek near Asti	481	11	20	43

An analysis of the median diversion rates, given in Table F-22, shows that median flow rates in Sensitivity Scenario 1 are larger than the median flow rates for Sensitivity Scenarios 2 and 3. However, median diversion rates for Sensitivity Scenario 4 (which involves the 5% of the 1.5 year flood level MCD alternative) are larger for some validation sites, and smaller for other validation sites when compared to Sensitivity Scenario 1 diversion rates. Also, for Sensitivity Scenarios 2 and 3, median diversion rates are equal to maximum diversion rates in Table F-21, indicating that more than half of the time that diversions are taken, they are taken at the maximum rate. For Sensitivity Scenario 4, however, the median is less than the maximum rate, meaning that diversions occur at the maximum rate less frequently.

An important statistic to note in the sensitivity analysis is how often diversions are allowed to occur. Table F-23 shows the percent of days of the year in which diversions occurred. Note that at each validation site, the period of record for each Sensitivity Scenario was identical. Clearly, Sensitivity Scenario 1 diversions occur less frequently than Sensitivity Scenarios 2 through 4. For example, at Pine Creek, Sensitivity Scenario 1 diversions occur in 1.5% of the days in the period of record, while diversions occur in 6.5% of the days for Sensitivity Scenarios 2 through 4. This supports the assertion that the MCD volume method diverts water at higher rates over a shorter period of time, while the MCD rate method diverts water at lower, more constant rates, over a longer period of time.

Table F-22. Median Daily Diversion Rate for Sensitivity Scenarios (based on daily average flows).

Gage / Validation Site	Median Average Daily Diversion (cfs)			
	Sensitivity Scenario 1	**Sensitivity Scenario 2**	**Sensitivity Scenario 3**	**Sensitivity Scenario 4**
Albion River near Comptche	36	10	11	37
Carneros Creek	48	9.0	1.6	13
Dry Creek Tributary near Hopland	8.0	3.2	1.5	5.5
Dunn Creek near Rockport	6.0	0.10	0.80	4.7
EF Russian River Tributary near Potter Valley	0.70	0.10	0.10	0.75
Franz Creek near Kellogg	32	7.6	9.1	55.5
Huichica Creek	113	2	4	12
Pine Creek at Bolinas	34	1.1	6.2	29
Salmon Creek at Bodega	82	13	12	70
Santa Rosa Creek near Santa Rosa	44	7.2	8.3	56
Warm Springs Creek near Asti	86	11	20	43

Table F-23. Percent of Days Diversions are Allowed for Sensitivity Scenarios.

Gage / Validation Site	Percent of Days Diversion Allowed			
	Sensitivity Scenario 1	**Sensitivity Scenario 2**	**Sensitivity Scenario 3**	**Sensitivity Scenario 4**
Albion River near Comptche	2.4%	9.2%	9.2%	9.2%
Carneros Creek	0.5%	3.9%	3.9%	3.9%
Dry Creek Tributary near Hopland	1.8%	3.7%	3.7%	3.7%
Dunn Creek near Rockport	0.8%	1.1%	1.1%	1.1%
EF Russian River Tributary near Potter Valley	1.0%	1.6%	1.6%	1.6%
Franz Creek near Kellogg	2.6%	9.3%	9.3%	9.3%
Huichica Creek	0.5%	5.0%	5.0%	5.0%
Pine Creek at Bolinas	1.5%	6.5%	6.5%	6.5%
Salmon Creek at Bodega	1.7%	8.8%	8.8%	8.8%
Santa Rosa Creek near Santa Rosa	1.7%	7.4%	7.4%	7.4%
Warm Springs Creek near Asti	2.0%	9.4%	9.4%	9.4%

Finally, the total quantity of water diverted in each Sensitivity Scenario was computed. Table F-24 shows the total quantity of water diverted, expressed as a percentage of the total unimpaired flow during the entire period of record. Again, at each validation site, all four scenarios were analyzed over an identical period of record. In general, more water is diverted in Sensitivity Scenario 4 than in all other Sensitivity Scenarios. The next highest diversion quantities are in Sensitivity Scenario 1. Sensitivity Scenarios 2 and 3 have diversion quantities that are less than Sensitivity Scenarios 3 and 4, but compared to each other, diversion quantities vary depending on the validation site.

Table F-24. Percent of Total Unimpaired Flow Diverted for Sensitivity Scenarios.

	Percent of Total Unimpaired Flow Diverted			
Gage / Validation Site	**Sensitivity Scenario 1**	**Sensitivity Scenario 2**	**Sensitivity Scenario 3**	**Sensitivity Scenario 4**
Albion River near Comptche	7.8%	4.3%	4.7%	13.5%
Carneros Creek	6.9%	7.3%	1.6%	9.8%
Dry Creek Tributary near Hopland	9.6%	5.1%	2.5%	7.9%
Dunn Creek near Rockport	3.0%	0.0%	0.3%	1.9%
EF Russian River Tributary near Potter Valley	8.5%	1.3%	1.3%	10.0%
Franz Creek near Kellogg	6.9%	2.8%	3.4%	17.2%
Huichica Creek	6.9%	1.2%	1.9%	5.5%
Pine Creek at Bolinas	7.5%	0.6%	3.4%	14.4%
Salmon Creek at Bodega	7.7%	4.4%	4.1%	18.1%
Santa Rosa Creek near Santa Rosa	7.7%	2.7%	3.1%	16.1%
Warm Springs Creek near Asti	6.1%	2.9%	5.1%	10.2%

F.4.2.2 Flood Frequency of Sensitivity Scenarios

In order to assess how the MCD affects peak annual flows, Stetson computed flood frequency for the Sensitivity Scenarios. All procedures and assumptions were identical to those discussed in Section F.3.3, except that Stetson computed flood frequency for the four impaired Sensitivity Scenarios instead of the five Flow Alternative Scenarios.

The peak annual instantaneous flows were computed at four validation sites (Albion, Salmon, Santa Rosa, and Warm Springs) and are given in Table F-25. From these flows, 1.5-year peak annual instantaneous flows, listed in Table F-26, were estimated.

Table F-25. Estimated Instantaneous Peak Annual Flood Magnitudes for Four USGS Gages.

		Instantaneous Peak Annual Flood Magnitude (cfs)				
Validation Site	**Water Year**	**Unimpaired**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Albion River	1962	1,310	1,310	1,300	1,299	1,273
Albion River	1963	934	934	924	923	897
Albion River	1964	1,090	1,081	1,080	1,079	1,053
Albion River	1965	2,050	2,050	2,040	2,039	2,013
Albion River	1966	2,390	1,753	2,380	2,379	2,353
Albion River	1967	840	840	830	829	803
Albion River	1968	615	330	605	604	578
Albion River	1969	1,620	1,620	1,610	1,609	1,583
Salmon Creek	1963	1,430	1,430	1,417	1,418	1,360
Salmon Creek	1964	1,220	477	1,207	1,208	1,150
Salmon Creek	1965	1,540	1,540	1,527	1,528	1,470
Salmon Creek	1966	1,960	1,960	1,947	1,948	1,890
Salmon Creek	1967	1,760	1,760	1,747	1,748	1,690
Salmon Creek	1968	1,370	1,370	1,357	1,358	1,300
Salmon Creek	1969	1,650	1,650	1,637	1,638	1,580
Salmon Creek	1970	1,790	1,790	1,777	1,778	1,720
Salmon Creek	1971	1,380	1,380	1,367	1,368	1,310
Salmon Creek	1972	537	53	524	525	467
Salmon Creek	1973	2,260	2,260	2,247	2,248	2,190
Salmon Creek	1974	1,760	1,760	1,747	1,748	1,690
Salmon Creek	1975	1,950	1,950	1,937	1,938	1,880
Santa Rosa Creek	1960	3,200	3,179	3,193	3,192	3,140
Santa Rosa Creek	1961	550	46	543	542	490
Santa Rosa Creek	1962	1,140	1,010	1,133	1,132	1,080
Santa Rosa Creek	1963	1,250	1,250	1,243	1,242	1,190
Santa Rosa Creek	1964	1,040	46	1,033	1,032	980
Santa Rosa Creek	1965	2,480	2,480	2,473	2,472	2,420
Santa Rosa Creek	1966	1,590	1,476	1,583	1,582	1,530
Santa Rosa Creek	1967	1,830	1,830	1,823	1,822	1,770
Santa Rosa Creek	1968	1,040	497	1,033	1,032	980

Table F-25. Estimated Instantaneous Peak Annual Flood Magnitudes for Four USGS Gages.

Validation Site	Water Year	Instantaneous Peak Annual Flood Magnitude (cfs)				
		Unimpaired	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Santa Rosa Creek	1969	1,180	1,180	1,173	1,172	1,120
Santa Rosa Creek	1970	2,150	2,150	2,143	2,142	2,090
Warm Springs Creek	1974	2,230	2,230	2,219	2,210	2,187
Warm Springs Creek	1975	908	908	897	888	865
Warm Springs Creek	1976	204	85	204	204	204
Warm Springs Creek	1977	57	57	57	57	57
Warm Springs Creek	1978	2,320	2,320	2,309	2,300	2,277
Warm Springs Creek	1979	1,030	613	1,019	1,010	987
Warm Springs Creek	1980	1,670	1,670	1,659	1,650	1,627
Warm Springs Creek	1981	1,020	997	1,009	1,000	977
Warm Springs Creek	1982	1,580	1,580	1,569	1,560	1,537
Warm Springs Creek	1983	2,660	2,660	2,649	2,640	2,617

Table F-26. Instantaneous 1.5-Year Peak Annual Flows for Sensitivity Scenarios.

Validation Site	Instantaneous 1.5-year Peak Annual Flow (cfs)				
	Unimpaired	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Albion River	1,017	941	1,007	1,006	978
Salmon Creek	1,439	1,158	1,426	1,427	1,369
Santa Rosa Creek	1,170	535	1,162	1,161	1,107
Warm Springs Creek	690	544	685	681	671

The peak flows listed in Table F-26 show that Sensitivity Scenario 1, the MCD volume method, leads to the largest decrease in peak flow of any MCD element alternative. At all four validation sites, the lowest peak annual flow occurs in Sensitivity Scenario 1. The next lowest peaks are seen in Sensitivity Scenario 4. Sensitivity Scenarios 2 and 3 have smaller impacts on the peak flows than Sensitivity Scenarios 1 and 4, but vary depending on the validation site.

The MCD Sensitivity Scenarios which use the rate method (2, 3, and 4), as expected, lead to reductions in peak flows that are approximately proportional to the MCD rate for each Sensitivity

Scenario. For example, at Salmon Creek, the MCD rate for Sensitivity Scenario 2 is 13 cfs (from Table F-19). In Table F-26, the difference between the unimpaired peak flow and the Sensitivity Scenario 2 peak flow is 13 cfs. In some cases, the difference between the peaks flows is not exactly equal to the MCD rate; this is because in at least one year, the unimpaired peak flow was not during the diversion season, so the impaired peak was not reduced. This is the case for one year for the Warm Springs validation site (see Table F-25, Warm Springs WY1976). Another exception is when flows are extremely low, all impaired peaks are equal to the unimpaired peak (see Table F-25, Warm Springs WY1977).

Using the values from Table F-25, Stetson prepared graphs of the exceedance probability for each of the four validation sites (Figure F-11 through Figure F-14). The graphs were prepared based on the unimpaired peak annual instantaneous exceedance probability. The unimpaired peaks have been plotted on the graph for each year in the period of record. For comparison, the impaired peaks in each year are shown. Decreases in the annual peak caused by the different MCD element alternatives are visible. For example, in Figure F-11 (Albion River), the largest unimpaired peak occurs in 1966. For Sensitivity Scenarios 2 through 4, the annual peak that year is just slightly lower than the unimpaired peak. However, for Sensitivity Scenario 1, the annual peak is approximately 25% lower than the unimpaired peak. This demonstrates that the MCD volume method (MCD3) tested in Sensitivity Scenario 1 may cause a significant decrease in the peak flows during certain years. Such decreases are similarly evident in the graphs for Salmon Creek (i.e., 1964, 1972), Santa Rosa Creek (i.e., 1968, 1964, 1961) and Warm Springs Creek (i.e., 1981, 1976).

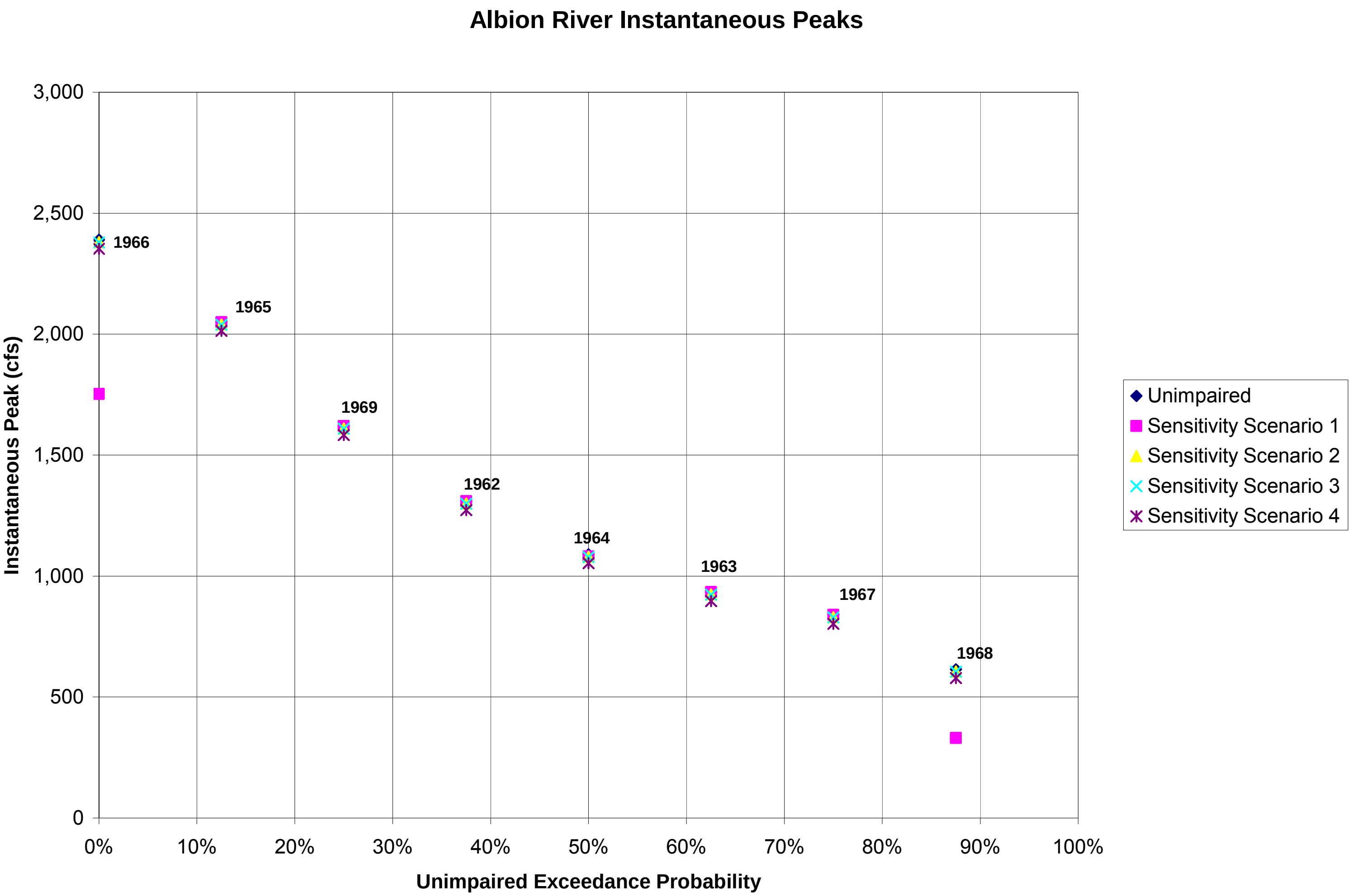

Figure F-11. Albion River instantaneous annual peak flows for Sensitivity Scenarios.

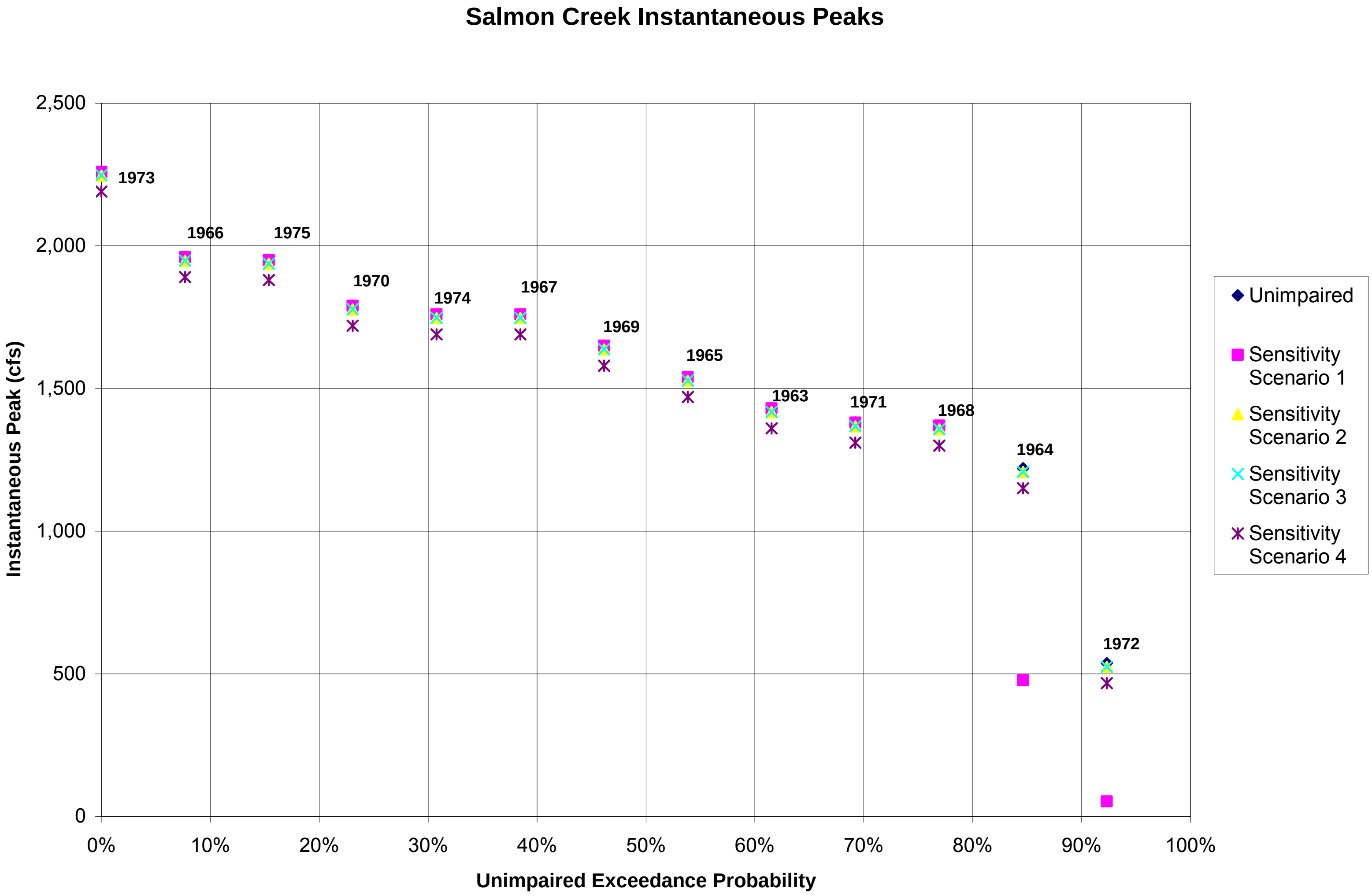

Figure F-12. Salmon Creek instantaneous annual peak flows for Sensitivity Scenarios.

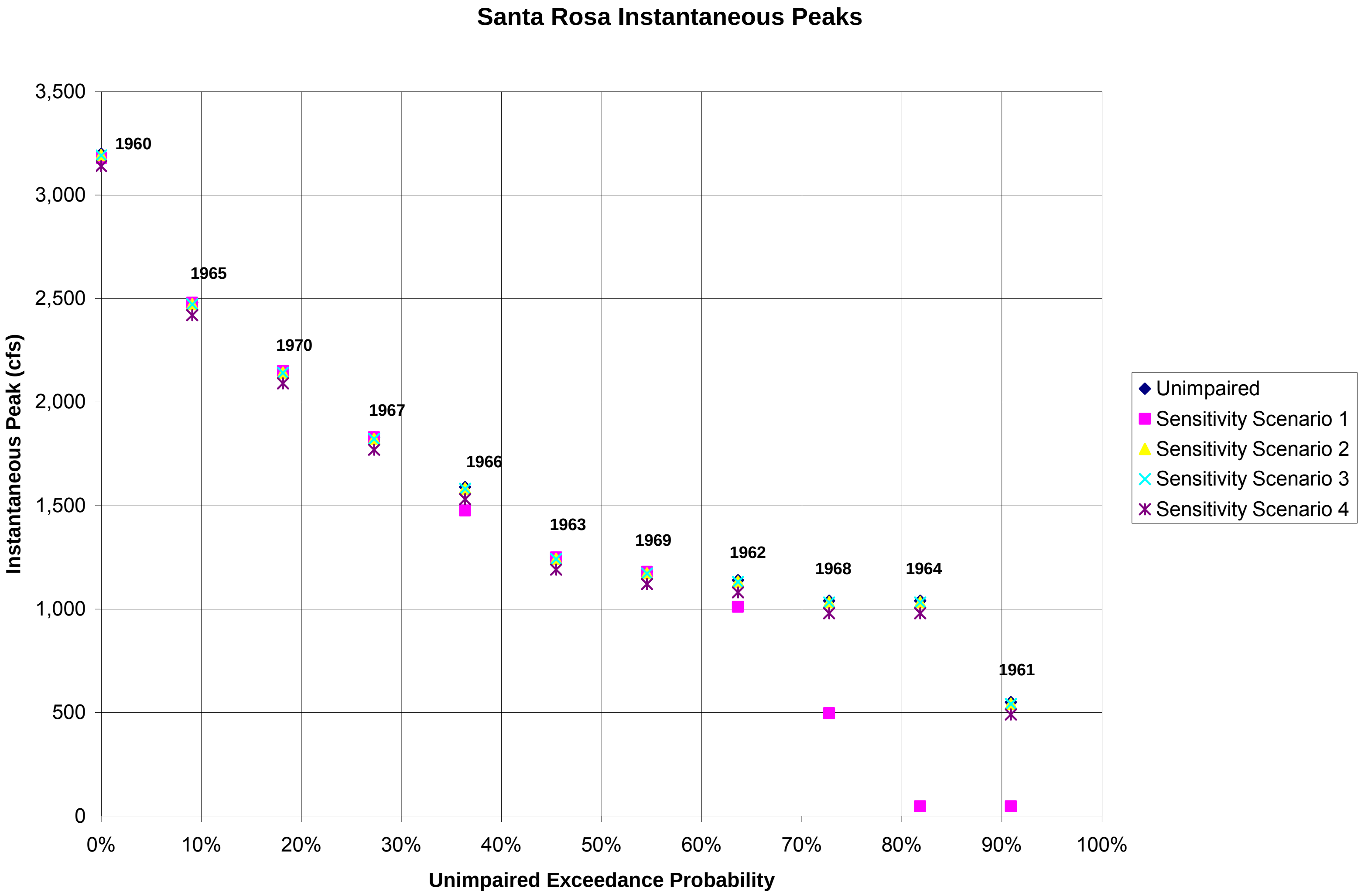

Figure F-13. Santa Rosa Creek instantaneous annual peak flows for Sensitivity Scenarios.

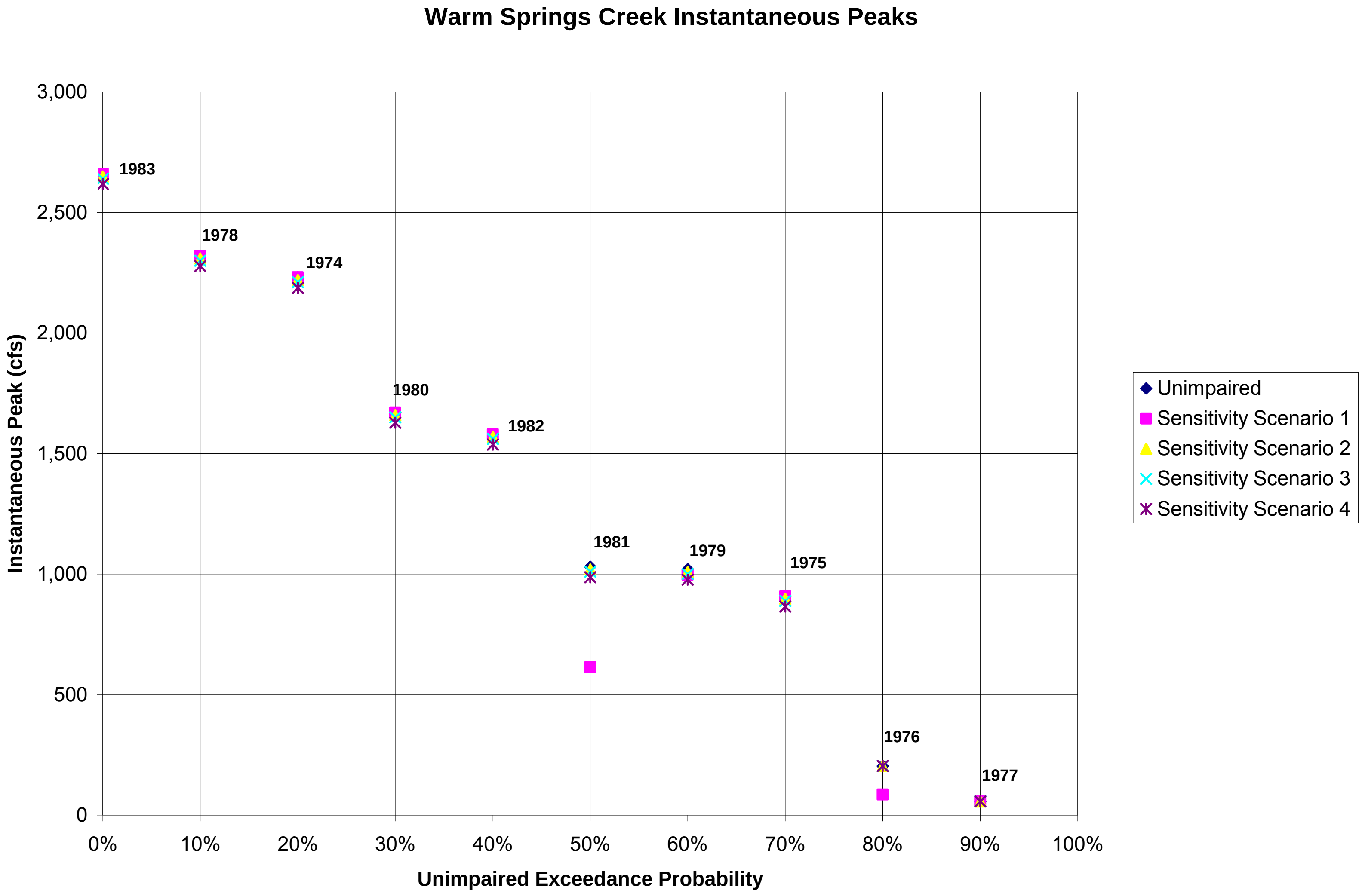

Figure F-14. Warm Springs Creek instantaneous annual peak flows for Sensitivity Scenarios.

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