Appendix A

Draft Modeling Approaches Used to Develop Unimpaired Watershed Hydrologies

A.1 Background

The State Water Resources Control Board (State Water Board) is considering the use of unimpaired flows in its Phase II comprehensive update to the Water Quality Control Plan for the San Francisco Bay-Sacramento/San Joaquin Delta Estuary (Bay-Delta Plan) for Sacramento River mainstem and major tributary inflow and Delta eastside tributary inflow (including the Calaveras, Cosumnes and Mokelumne rivers) requirements. The State Water Board is also considering the use of unimpaired flows as part of the Phase I update to the Bay-Delta Plan for San Joaquin River inflow requirements as part of a separate process that is not addressed in this document. Unimpaired hydrology or "unimpaired flow" represents an index of the total water available to be stored and put to any beneficial use within a watershed under current physical conditions and land uses. This index represents something different than the "natural flow" that would have occurred absent human development of land and water supply.

Previous work on unimpaired flows in the Sacramento watershed has been completed by the California Department of Water Resources' (DWR's) Bay-Delta office to provide estimates throughout the Central Valley. DWR's unimpaired flow estimates are produced by "removing the impacts of most upstream alterations as they occurred over the years" (DWR 2007, DWR 2016a). Land use, levees, flood bypasses, and weirs are all assumed to exist as they do currently. DWR produces unimpaired estimates for 24 locations in the Central Valley and the Sacramento-San Joaquin Delta (Delta) for October 1920 through September 2014 on a monthly basis. These estimates are considered to be accurate higher in the watershed but are not considered to be as accurate lower in the valley floor and Delta. DWR's methods for estimating unimpaired flow in the Valley floor and Delta did not account for any stream/groundwater interaction and took a very simplified approach to estimating surface runoff from ungaged streams (DWR 2007, DWR 2016a).

In addition to the work by DWR's Bay-Delta Office, DWR's Division of Flood Management estimates "full natural flow" (FNF) on a monthly basis for 36 locations around the state and on a daily basis for 19 locations. DWR's methods for calculating FNF have not been documented, however the estimates are used by users throughout the Bay-Delta watershed to calculate indices of water availability such as water year types and the Eight River Index. In turn, these indices are used to determine water supply allocations and water quality objectives for multiple beneficial uses of water, including objectives to protect fish and wildlife. Nearly all of the FNF locations within the Sacramento Watershed estimated by the Division of Flood Management are at the rim of the Sacramento Valley. The methods used by the Division of Flood Management are similar to those utilized by the Bay-Delta Office, where the effects of diversions and storage are removed from the time series.

The methods used by both groups at DWR do not provide unimpaired estimates at the bottom of each watershed, with the exception of the Sacramento Valley Total Outflow, which includes an estimate of valley floor runoff. DWR's estimate of valley floor runoff is based on rationale that is "subjective [and] that need to be revisited and verified in future updates" (DWR 2007). To provide estimates at the bottom of the watershed, better estimates of surface runoff and stream gains and

losses to groundwater are needed. This is a challenge, however because most diversions are not gaged, most of the watersheds in the Sacramento Valley do not have gages near the mouths, and it is very difficult to estimate stream gains and losses to groundwater.

This study was undertaken to better estimate unimpaired flows at the mouths of the tributaries in the Sacramento River Watershed, at locations on the mainstem Sacramento River, and at the mouths of the Delta eastside tributaries.

The overall approach used to estimate unimpaired flows was to calculate a mass-balance in the lower reaches of each major tributary and along the mainstem Sacramento River. The inflows to the reaches are the unimpaired flows at the rim locations, surface runoff from the valley floor, and stream-groundwater gains. The only losses from the mainstem and tributaries are stream losses to groundwater and weir spills to bypasses. Groundwater levels and stream-groundwater interactions were assumed to be at the same level as is estimated for current conditions.

Unimpaired flows were estimated with the Sacramento Valley Unimpaired Flow Model (SVUFM). Inputs to the model include rim inflows that were estimated based on measured data and stream-groundwater interaction from a California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) simulation of current conditions. These model inputs are described in greater detail below.

A.2 Rim Watershed Hydrology

A.2.1 Introduction

Rim inflows are flows that come from outside of the region simulated by a hydrologic model. They are flows that enter the model domain from outside of the model domain. The SVUFM model domain includes the Delta and the valley floor of the Sacramento River, its tributaries, and eastside tributaries to the Delta, generally extending upstream to the foothills. The unimpaired rim inflows used as model input include estimates of unimpaired inflow to the locations of the large reservoirs at the edges of the Sacramento Valley such as Lake Shasta, Oroville Reservoir, and Folsom Lake (although these reservoirs are simulated as being empty in the unimpaired flow model). Unimpaired rim inflows are also used as inflow to the smaller tributaries that originate outside of the SVUFM domain.

Rim watersheds typically are characterized by complex topography, steep slopes, shallow soils, and limited aquifer systems. Precipitation percolating to groundwater quickly returns to streams as base flow. Rim watersheds are generally mountainous and highly productive in terms of runoff. The hydrology of rim watersheds at higher elevations is largely determined by the snowfall and snowmelt cycle. Streamflow records (directly gaged, extended through correlation, and adjusted for upstream regulation) are considered to be the most appropriate basis for estimating water supplies from these watersheds.

The rim inflow dataset was generated for water years 1922–2009. It represents the flows that would occur under a repeat of historical weather conditions. It is assumed that a repeat of these conditions would result in identical surface runoff and stream flows as historically observed. In many cases historical streamflow records have been extended through correlation. Rim inflows have been developed assuming stationarity over the historical period and assuming that statistical relationships between unimpaired stream flows in adjacent watersheds are constant. This

assumption of stationarity is not appropriate when there has been significant land use change in the rim watersheds. Assumptions of stationarity are not valid when climate change has occurred.

Unimpaired rim inflow estimates based on historical streamflow data were obtained for the Sacramento Valley Hydrologic Region from DWR, and for the Delta Eastside Tributary Region from the Bureau of Reclamation (Reclamation). The data are stored as monthly time series. The first row in the dataset denotes the name of the time series data used in SVUFM. Inflow names contain the prefix "I_" followed by a five or six letter string. The five-letter string is an acronym for inflows to reservoirs or lakes. The six-letter string denotes the river followed by the river mile (RM). For example, I_SHSTA represents the inflow to Lake Shasta, and I_NFY029 represents inflow to the North Fork Yuba River at RM 29.

A.2.2 Methods

A.2.2.1 Watersheds

Figure A-1, Rim Watersheds, displays the 71 primary rim watersheds that provide inflow to the Sacramento River watershed and Delta eastside tributaries. Watershed numbers are provided in the figure for cross-referencing to subsequent tables. Many of the rim watersheds in the Sierra Nevada have been extensively developed for both hydropower generation and water supply. Natural stream flows in these watersheds are significantly altered by storage regulation and interbasin water transfers. As part of the process to remove this upstream impairment, rim watersheds were divided into sub-watersheds to estimate local inflows to reservoirs or stream flows at diversion dams. Sub-watersheds are not shown in Figure A-1. Of the 71 rim watersheds shown in Figure A-1, 12 were further subdivided for analytical purposes (Table A-1). Three of the 71 rim watersheds shown in Figure A-1 do not contribute to the SVUFM model domain because they either only contribute under impaired conditions (watersheds 44 and 45, Trinity River) or are south of the model domain (watershed 60, Littlejohns Creek).

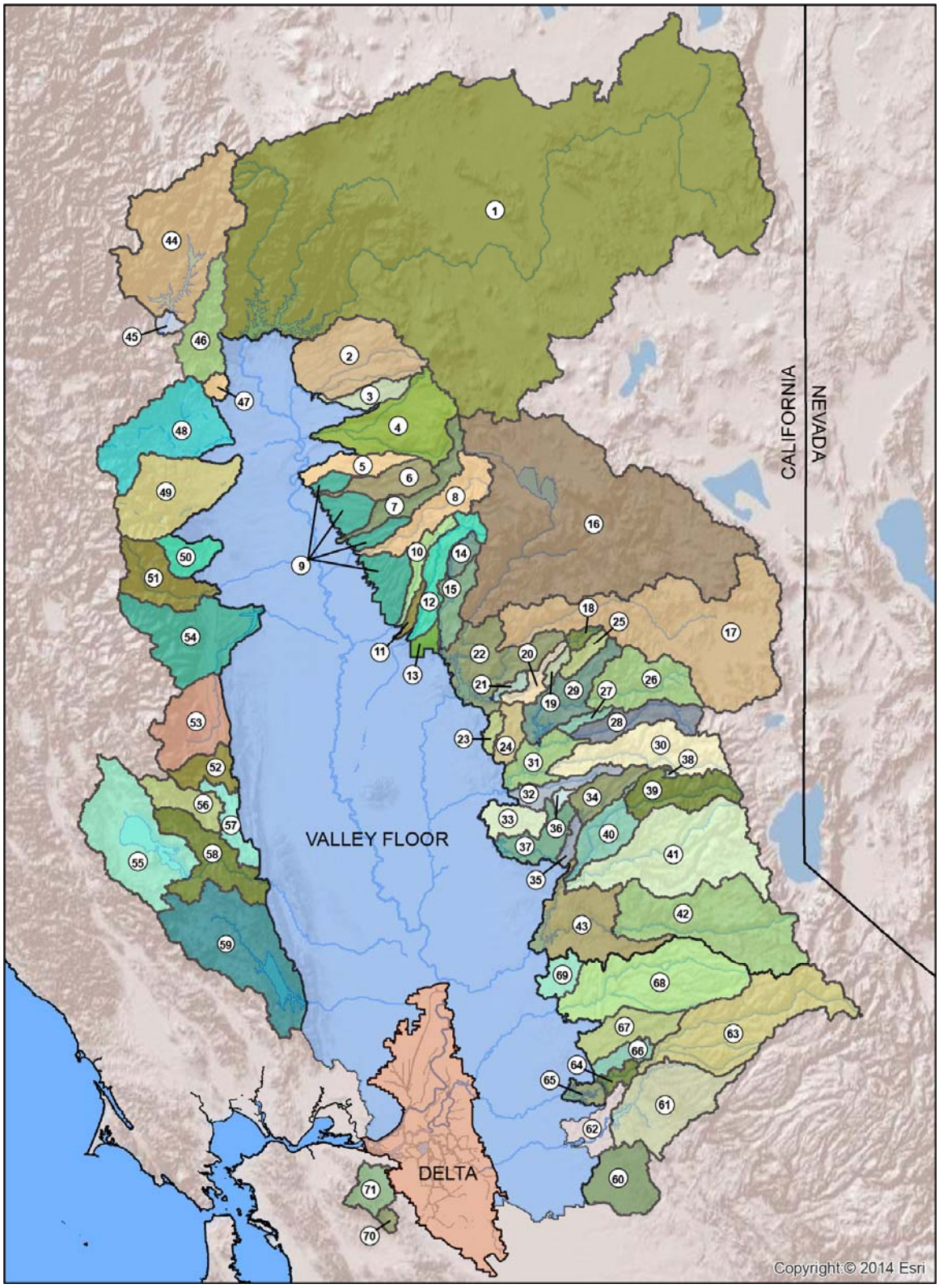

Figure A-1. Rim Watersheds that Provide Inflow to the Valley Floor of the Sacramento River Watershed and Delta Eastside Tributaries

Table A-1. Subdivision of Watersheds

Watershed	Watershed Number (as shown in Figure A-1)	Number of Sub-Watersheds
West Branch Feather River at Hendricks Diversions Dam	14	2
West Branch Feather River near Yankee Hill	15	2
North Fork Feather River at Pulga	16	7
Middle Fork Feather River near Merrimac	17	4
Middle Fork Yuba River above Our House Diversion Dam	28	2
South Fork Yuba River at Jones Bar	30	4
Deer Creek inflow at Yuba River	32	4
Camp Far West Reservoir	37	2
Middle Fork American River	41	12
South Fork American River near Placerville	42	10
Mokelumne River near Mokelumne Hill	63	6
Cosumnes River at Michigan Bar	68	4

A.2.2.2 Approaches for Estimating Rim Inflows

Only in limited cases are streamflow records available over the entire period of simulation. For the majority of streams, historical time series data have been extended using various statistical methods assuming stationarity over the historical period. Methods used to develop each inflow are summarized in Table A-2. These methods are as follows:

- Direct gage measurement: Stream gage data exist at the watershed outflow point for water years 1922 through 2009.
- Streamflow correlation: Stream gage data exist at the watershed outflow point for only a limited period between water years 1922 and 2009. Gage data are extended through linear correlation of annual flows with streamflow records from adjacent watersheds. Double mass plots of monthly flows are used to check that a constant (and linear) relationship exists between the dependent and independent variables. Annual synthetic flows are disaggregated to a monthly time step based on the cumulative fraction of annual runoff that has occurred by the end of month, while attempting to preserve the shape of the hydrograph of the dependent watershed.
- Proportionality: No gage data exist for the watershed. It is assumed that runoff is proportional to the product of drainage area and average annual precipitation depth over the watershed.[1] Outflow is determined through association of the watershed with a similar, but gaged watershed and the use of multiplicative factors representing the ratio of watershed areas and ratio of precipitation depths.

[1] Determined using PRISM data of the 30-year average annual precipitation for 1971-2000 (PRISM 2013).

- Mass balance: Typically, this method is used when watersheds have significant storage regulation. Reservoir operating records of dam releases and reservoir storage, together with estimated reservoir evaporation, are used to estimate inflows to the reservoir.

Table A-2. Data Sources and Calculation Methods for Upper Watershed Inflows

Inflow Label	Watershed Number	Observed Period	Agency	Gage ID	Flow Correlation	Propor-tionality	Mass Balance
I_ALD001	42	10/22 - 09/81	USGS	11440000	●		
I_ALMMW	16	10/21 - present	USGS	11399500			●
I_AMADR	66	–	–	–		●	
I_ANT011	6	10/40 - 09/82	USGS	11379000	●		
I_ANTLP	16	10/30 - 09/93	USGS	11401500	●		●
I_BCC014	10	10/21 - 09/86	USGS	11384000	●		●
I_BCN010	3	10/59 - 09/67	USGS	11374100	●		
I_BKILD	41	11/90 - present	USGS	11428400	●		●
I_BLKBT	54	01/53 - present	USACE	Report of Operations	●		●
I_BOWMN	30	02/27 - present	USGS	11416500	●		
I_BRC003	57	10/98 - present	USGS	11451715	●	●	
I_BRR023	37	–	–	–	●	●	●
I_BRYSA	59	01/57 - present	Reclamation	Report of Operations	●		●
I_BTC048	12	10/30 - present	USGS	11390000			●
I_BTL006	4	10/40 - 09/61, 10/61 - present	USGS, USGS	11376500, 11376550	●		
I_BTVLY	16	10/36 - present	USGS	11400500	●	●	
I_BUKSL	16	10/80 - present	USGS	11403530	●		●
I_CAPLS	42	10/22 - 09/92	USGS	11437000	●		●
I_CCH053	58	10/60 - present	USGS	11451760	●	●	●
I_CLR011	47	10/40 - present	USGS	11372000	●		●
I_CLR025	46	10/64 - present	Reclamation	Report of Operations	●	●	
I_CLRLK	55	10/44 - present	USGS	11451000			●
I_CLV026	62	–	–	–		●	
I_CMBIE	35	–	–	–	●	●	●
I_CMCHE	65	–	–	–		●	
I_CMP001	68	10/56 - 09/04	USGS	11333000	●		
I_CMP012	68	10/49 - 09/54	USGS	11331500	●	●	

Inflow Label	Watershed Number	Observed Period	Agency	Gage ID	Flow Correlation	Propor-tionality	Mass Balance
I_CMPFW	37	–	–	–	●	●	●
I_COW014	2	10/49 - present	USGS	11374000	●	●	
I_CSM035	68	10/21 - present	USGS	11335000			●
I_CWD018	48	09/71 - 09/86	USGS	11375810	●		
I_DAVIS	17	10/25 - 09/80, 12/67 - present	USGS, DWR	11391500, Report of Operations	●	●	
I_DCC007	41	09/60 - present	USGS	11427700	●		●
I_DEE023	69	10/60 - 09/77	USGS	11335700	●	●	
I_DER001	32	10/35 - present	USGS	1418500			
I_DER004	32	–	–	–		●	
I_DHC001	33	–	–	–		●	
I_DRC012	8	10/21 - present	USGS	11383500	Data for all years		
I_DSC035	67	10/61 - 09/70, 10/35 - 09/41	USGS, USGS	11326300, 11327000	●	●	
I_ELD027	50	10/48 - present	USGS	11379500	●		
I_ENF001	16	10/50 - 09/60	USGS	11403000	●		●
I_ENGLB	31	10/21 - 09/41, 10/41 - present	USGS, USGS	11418000, 11419000	●		●
I_EPARK	52	10/21 - present	Reclamation	Report of Operations			●
I_FOLSM	43	10/21 - present, 02/55 - present	USGS, Reclamation	USGS Report of Operations			●
I_FRDYC	30	07/66 - present	USGS	11414100	●		●
I_FRMAN	17	10/65 - present	DWR	Report of Operations	●		●
I_FRMDW	41	10/64 - present	USGS	11427500	●		●
I_GRZLY	16	10/85 - present	USGS	11404300	●		●
I_HHOLE	41	10/85 - present	USGS	11428800	●		●
I_HON021	23	10/50 - 09/86	USGS	11407500	●		
I_ICEHS	42	10/1923 - present	USGS	11441500	●		●
I_INDVL	56	10/74 - present	USGS	11451300	●		●

Inflow Label	Watershed Number	Observed Period	Agency	Gage ID	Flow Correlation	Propor-tionality	Mass Balance
I_JKSMD	28	10/26 - present	USGS	11407900	●		●
I_JNKSN	68	10/46 - 09/54	USGS	11332500	●		
I_LBEAR	63	–	–	–		●	
I_LCC038	11	02/59 – present, 02/59 - 09/93	DWR, DWR	A04910, A04280	●		●
I_LDC029	13	–	–	–		●	
I_LGRSV	18	10/63 - present	USGS	11395030	●		●
I_LJC022[a]	60	10/51 - 09/95	USACE	multiple data sources	●		●
I_LKVLY	38	–	–	–		●	
I_LNG000	41	10/66 - 09/92	USGS	11433100	●	●	●
I_LOONL	41	10/62 - present	USGS	11429500	●		●
I_LOSVQ	70	10/97 - present	CCWD		●		
I_LST007	19	10/73 - present	USGS	11396000	●		●
I_LWSTN[a]	45	10/21 - present	USGS	11525500	●		●
I_MERLC	24	10/63 -present	BVID	Report of Operations	●		●
I_MFA001	41	10/21 - 09/85	USGS	11433500	●		●
I_MFA036	41	10/65 - present	USGS	11427770	●		●
I_MFF019	17	10/51 - 09/86	USGS	11394500	●		
I_MFF073	17	10/68 - 09/80	USGS	11329100	●		●
I_MFM010	63	10/21 - present	USGS	11317000			
I_MFY013	28	10/68 - present	USGS	11408870			●
I_MLC006	7	10/28 - present	USGS	11381500	●		
I_MNS000	9	–	–	–		●	
I_MOK079	63	10/27 - present	USGS	11319500			●
I_MSH015	71	04/53 - 09/83	USGS	11337500			
I_NBLDB	29	10/66 - 09/40	USGS	11413520	●		●
I_NFA022	40	10/21 - 09/41, 10/41 - present	USGS, USGS	11426500, 11427000		●	●
I_NFA054	39	10/21 - 09/41, 10/41 - present	USGS, USGS	11426500, 11427000		●	●

Inflow Label	Watershed Number	Observed Period	Agency	Gage ID	Flow Correlation	Propor-tionality	Mass Balance
I_NFF027	16	10/21 - present	USGS	11404500	●		●
I_NFM006	63	09/84 - present	USGS	11316700	●		●
I_NFY029	26	10/30 - present	USGS	11413000	●	●	
I_NHGAN	61	10/63 - present	USACE	Report of Operations	●		●
I_OGN005	27	10/21 – 09/69, 09/68 - present	USGS, USGS	11409500	●	●	●
I_OROVL	22	10/21 - present, 10/67 - present	USGS, DWR	11407000, Report of Operations			●
I_PARDE	64	–	–	–	●	●	●
I_PLM001	42	10/22 - 09/39	USGS	11440500	●		
I_PYN001	5	10/49 - 09/66	USGS	11377500	●	●	
I_RBCON	41	10/91 - present	USGS	11427960	●		●
I_RLLNS	34	04/50 - present	USGS	11422500	●	●	●
I_RUB001	41	10/58 – 09/84	USGS	11433200	●		●
I_RVPHB	14	–	–	–	●	●	●
I_SCOTF	32	–	–	–		●	●
I_SCW008	49	12/76 - 09/86	USGS	11375870	●		
I_SFA021	42	10/64 - present	USGS	11444500	●		●
I_SFA035	42	10/22 - present	USGS	11443500	●		●
I_SFA056	42	10/22 - present	USGS	11439500	●		●
I_SFD003	32	–	–	–		●	
I_SFF008	21	10/21 - 09/66	USGS	11397000	●		●
I_SFF011	20	10/21 - 09/66	USGS	11397000	●		●
I_SFM006	63	10/21 - present	USGS	11317000	●		
I_SFR005	41	10/62 - present	USGS	11430000	●		●
I_SFY007	30	10/40 - present	USGS	11417500	●		
I_SGRGE	53	11/28 - present	Reclamation	Report of Operations			●
I_SHSTA	1	10/25 - 09/42 01/44 - present	USGS, Reclamation	11369500, Report of Operations		●	●

Inflow Label	Watershed Number	Observed Period	Agency	Gage ID	Flow Correlation	Propor-tionality	Mass Balance
I_SILVR	42	10/22 - present	USGS	11436000	●		●
I_SLT009	25	10/60 - present	USGS	11413300	●		●
I_SLTSP	63	10/27 - present	USGS	11314500	●		●
I_SPLDG	30	12/65 - present	USGS	11414250	●		●
I_STMPY	41	04/46 - 09/60	USGS	11432500	●		
I_THM028	51	10/21 - 09/96	USGS	11382000	●		
I_TRNTY[a]	44	10/21 - present, 10/61 - present	USGS, Reclamation	11525500, Report of Operations	●		●
I_UNVLY	42	10/61 - present	USGS	11441002			
I_WBF006	15	10/30 - 09/63	USGS	11406500	●	●	●
I_WBF015	15	10/30 - 09/63	USGS	11406500	●	●	●
I_WBF030	14	10/30 - 09/63	USGS	11406500	●	●	●
I_WLF013	36	–	–	–	●	●	●

Key:

cfs = cubic feet per second; DWR = California Department of Water Resources; PG&E = Pacific Gas and Electric; USGS = U.S. Geological Survey; WBA = Water Budget Area

[a] Littlejohns Creek, Trinity Reservoir, and Lewiston Lake are not part of the Sacramento Valley watershed, as such, their inflows do not contribute to SVUFM.

A.2.3 Results

Total average annual unimpaired rim inflow to the Sacramento and Delta Valley floor (the SVUFM model domain) is approximately 21,500 thousand acre-feet per year (TAF/yr)(Table A-3). This includes all significant rim watersheds that provide inflow to the Delta except for the San Joaquin River watershed. Year-to-year variation in unimpaired rim inflow is high, with a standard deviation of approximately 10,000 TAF/yr.

The largest rim inflow to the Sacramento and Delta Valley floor comes from the watershed upstream of Shasta Dam, which includes the Sacramento, Pit, and McCloud River watersheds. The average annual inflow from this watershed is 26% of the total. This watershed combined with the rim inflows from the Feather, Yuba, and American Rivers generally provides 70% of the total unimpaired rim inflow to the Sacramento and Delta Valley floor (Table A-3). The Sacramento River rim watershed provides much more inflow (93%) to the valley floor than the Delta tributaries (7%).

Table A-3. Average Annual Rim Inflow to the Sacramento and Delta Valley Floor

Label	Watershed Number	Description	Type	Average Annual Flow (TAF)	Standard Deviation of Annual Flow (TAF)	Average as Percent of Total Rim Inflow
Lake Shasta Inflow			**Total**	**5,667**		**26.4%**
I_SHSTA	1	Shasta Lake	Reservoir inflow	5,667	2,030	26.4%
Sacramento River Eastside Tributaries North of the Feather River Watershed			**Total**	**2,066**		**9.6%**
I_COW014	2	Cow Creek near Millville	Stream inflow	420	231	2.0%
I_BCN010	3	Bear Creek (North) near Millville	Stream inflow	60	26	0.3%
I_BTL006	4	Battle Creek near Cottonwood	Stream inflow	351	120	1.6%
I_PYN001	5	Paynes Creek and Sevenmile Creek	Stream inflow	53	31	0.2%
I_ANT011	6	Antelope Creek near Red Bluff	Stream inflow	101	52	0.5%
I_MLC006	7	Mill Creek near Los Molinos	Stream inflow	217	86	1.0%
I_DRC012	8	Deer Creek near Vina	Stream inflow	231	114	1.1%
I_MNS000	9	Minor northeast streams	Stream inflow	237	123	1.1%
I_BCC014	10	Big Chico Creek near Chico	Stream inflow	101	58	0.5%
I_LCC038	11	Little Chico Creek near Chico	Stream inflow	22	15	0.1%

Label	Watershed Number	Description	Type	Average Annual Flow (TAF)	Standard Deviation of Annual Flow (TAF)	Average as Percent of Total Rim Inflow
I_BTC048	12	Butte Creek	Stream inflow	245	126	1.1%
I_LDC029	13	Little Dry Creek	Stream inflow	26	17	0.1%
Feather River Watershed			**Total**	**4,382**		**20.4%**
I_WBF030	14	West Branch Feather River at Hendricks Diversion Dam	Stream accretion	96	45	0.4%
I_RVPHB	14	Round Valley and Philbrook lakes	Reservoir inflow	20	10	0.1%
I_WBF006	15	West Branch Feather River near Yankee Hill	Stream accretion	69	33	0.3%
I_WBF015	15	West Branch Feather River at Miocene Diversion Dam	Stream accretion	148	70	0.7%
I_ALMMW	16	Lake Almanor and Mountain Meadows Reservoir	Reservoir inflow	728	231	3.4%
I_BTVLY	16	Butt Valley Reservoir	Reservoir inflow	75	31	0.3%
I_ANTLP	16	Antelope Reservoir	Reservoir inflow	33	23	0.2%
I_BUKSL	16	Bucks Lake	Reservoir inflow	85	40	0.4%
I_GRZLY	16	Grizzly Creek	Stream inflow	52	21	0.2%
I_ENF001	16	East Branch of North Fork Feather River near Rich Bar	Stream accretion	621	398	2.9%
I_NFF027	16	North Fork Feather River at Pulga	Stream accretion	754	286	3.5%
I_DAVIS	17	Lake Davis	Reservoir inflow	26	21	0.1%
I_FRMAN	17	Lake Frenchman	Reservoir inflow	23	18	0.1%
I_MFF073	17	Middle Fork Feather River near Portola	Stream accretion	115	64	0.5%
I_MFF019	17	Middle Fork Feather River near Merrimac	Stream accretion	962	540	4.5%
I_LGRSV	18	Little Grass Valley Reservoir	Reservoir inflow	78	36	0.4%
I_LST007	19	Sly Creek Reservoir	Reservoir inflow	75	36	0.3%

Label	Watershed Number	Description	Type	Average Annual Flow (TAF)	Standard Deviation of Annual Flow (TAF)	Average as Percent of Total Rim Inflow
I_SFF011	20	South Fork Feather River at Ponderosa Dam	Stream accretion	94	56	0.4%
I_SFF008	21	South Fork Feather at Enterprise	Stream accretion	21	13	0.1%
I_OROVL	22	Lake Oroville	Local reservoir inflow	282	243	1.3%
I_HON021	23	South Fork Honcut Creek near Bangor	Stream inflow	24	16	0.1%
Yuba River Watershed			**Total**	**2,354**		**10.9%**
I_MERLC	24	Merle Collins Reservoir	Reservoir inflow	48	33	0.2%
I_SLT009	25	Slate Creek at Slate Creek Diversion Dam	Stream inflow	141	67	0.7%
I_NFY029	26	North Fork Yuba River below Goodyears Bar	Stream inflow	539	245	2.5%
I_OGN005	27	Oregon Creek at Log Cabin Diversion Dam	Stream inflow	53	30	0.2%
I_JKSMD	28	Jackson Meadows Reservoir	Reservoir inflow	76	34	0.4%
I_MFY013	28	Middle Fork Yuba River above Our House Diversion Dam	Stream accretion	152	86	0.7%
I_NBLDB	29	New Bullards Bar Reservoir	Local reservoir inflow	402	221	1.9%
I_BOWMN	30	Bowman Lake	Reservoir inflow	93	36	0.4%
I_FRDYC	30	Fordyce Lake	Reservoir inflow	87	38	0.4%
I_SPLDG	30	Lake Spaulding	Local reservoir inflow	306	112	1.4%
I_SFY007	30	South Fork Yuba River at Jones Bar	Stream accretion	207	110	1.0%
I_ENGLB	31	Englebright Reservoir	Stream inflow	147	85	0.7%
I_SCOTF	32	Scotts Flat Reservoir	Local reservoir inflow	33	18	0.2%
I_DER004	32	Deer Creek at Wildwood Dam	Stream accretion	33	18	0.2%
I_DER001	32	Deer Creek near Smartville	Stream accretion	29	16	0.1%

Label	Watershed Number	Description	Type	Average Annual Flow (TAF)	Standard Deviation of Annual Flow (TAF)	Average as Percent of Total Rim Inflow
I_SFD003	32	South Fork Deer Creek at Wildwood Dam	Stream inflow	8	5	0.0%
Bear River Watershed			**Total**	**372**		**1.7%**
I_DHC001	33	Dry Creek and Hutchinson Creek	Stream inflow	54	36	0.2%
I_RLLNS	34	Rollins Reservoir natural inflow	Local reservoir inflow	160	102	0.7%
I_CMBIE	35	Combie Reservoir	Local reservoir inflow	31	16	0.1%
I_WLF013	36	Wolf Creek at Tarr Ditch Diversion Dam	Stream inflow	19	10	0.1%
I_CMPFW	37	Camp Far West Reservoir	Local reservoir inflow	16	8	0.1%
I_BRR023	37	Camp Far West Reservoir	Local reservoir inflow	93	49	0.4%
American River Watershed			**Total**	**2,705**		**12.6%**
I_LKVLY	38	Lake Valley Reservoir	Reservoir inflow	9	5	0.0%
I_NFA054	39	North Fork American River	Stream inflow	353	187	1.6%
I_NFA022	40	North Fork American River at North Fork Dam local inflow	Stream accretion	219	116	1.0%
I_FRMDW	41	French Meadows Reservoir	Reservoir inflow	114	54	0.5%
I_RBCON	41	Rubicon Lake	Reservoir Inflow	75	29	0.4%
I_DCC007	41	Duncan Canyon Creek	Stream inflow	28	13	0.1%
I_BKILD	41	Bucks Island Lake	Stream inflow	20	6	0.1%
I_RUB001	41	Local Inflows to Rubicon River	Stream accretion	100	64	0.5%
I_HHOLE	41	Hell Hole Reservoir	Local reservoir inflow	207	94	1.0%
I_LOONL	41	Loon Lake	Reservoir inflow	22	9	0.1%
I_SFR005	41	South Fork Rubicon River Inflow	Stream inflow	80	38	0.4%

Label	Watershed Number	Description	Type	Average Annual Flow (TAF)	Standard Deviation of Annual Flow (TAF)	Average as Percent of Total Rim Inflow
I_STMPY	41	Stumpy Meadows Reservoir	Reservoir inflow	22	13	0.1%
I_LNG000	41	Long Creek Canyon at mouth	Stream inflow	74	46	0.3%
I_MFA036	41	Middle Fork American River at Interbay Diversion Dam	Stream accretion	51	26	0.2%
I_MFA001	41	Middle Fork American River near Auburn local inflow	Stream accretion	245	152	1.1%
I_UNVLY	42	Union Valley Reservoir	Reservoir inflow	168	85	0.8%
I_ICEHS	42	Ice House Reservoir	Reservoir inflow	56	25	0.3%
I_CAPLS	42	Caples Lake	Reservoir inflow	27	11	0.1%
I_SILVR	42	Silver Lake	Reservoir inflow	26	12	0.1%
I_SFA056	42	South Fork American River at Kyburz	Stream inflow	247	121	1.1%
I_ALD001	42	Alder Creek near Whitehall	Stream inflow	28	17	0.1%
I_PLM001	42	Plum Creek Inflow	Stream inflow	7	4	0.0%
I_SFA035	42	South Fork American River near Camino	Stream accretion	171	107	0.8%
I_SFA021	42	South Fork American River near Placerville	Stream accretion	107	75	0.5%
I_FOLSM	43	Folsom Lake	Local reservoir inflow	249	309	1.2%
Sacramento River Westside Tributaries			**Total**	**1,529**		**7.1%**
I_CLR025	46	Whiskeytown Lake	Reservoir inflow	285	173	1.3%
I_CLR011	47	Clear Creek near Igo	Stream accretion	46	28	0.2%
I_CWD018	48	North Fork and Middle Fork Cottonwood Creek near Olinda	Stream inflow	298	215	1.4%
I_SCW008	49	South Fork Cottonwood Creek near Olinda	Stream inflow	178	137	0.8%
I_ELD027	50	Elder Creek near Paskenta	Stream inflow	68	49	0.3%

Label	Watershed Number	Description	Type	Average Annual Flow (TAF)	Standard Deviation of Annual Flow (TAF)	Average as Percent of Total Rim Inflow
I_THM028	51	Thomes Creek at Paskenta	Stream inflow	217	128	1.0%
I_EPARK	52	East Park Reservoir inflow	Reservoir inflow	66	37	0.3%
I_SGRGE	53	Stony Gorge Reservoir	Local reservoir inflow	165	120	0.8%
I_BLKBT	54	Black Butte Lake	Local reservoir inflow	205	170	1.0%
Yolo Bypass Tributaries			**Total**	**998**		**4.6%**
I_CLRLK	55	Clear Lake	Reservoir inflow	436	248	2.0%
I_INDVL	56	Indian Valley Reservoir	Reservoir inflow	111	78	0.5%
I_BRC003	57	Bear Creek above Holsten Chimney	Stream inflow	34	28	0.2%
I_CCH053	58	Cache Creek above Rumsey	Stream accretion	55	48	0.3%
I_BRYSA	59	Lake Berryessa	Reservoir inflow	362	263	1.7%
Calaveras River Watershed			**Total**	**162**		**0.8%**
I_NHGAN	61	New Hogan Reservoir	Reservoir inflow	154	119	0.7%
I_CLV026	62	Calaveras River at Bellota	Stream inflow	8	7	0.0%
Mokelumne River Watershed			**Total**	**848**		**3.9%**
I_LBEAR	63	Lower Bear Reservoir	Reservoir inflow	73	31	0.3%
I_MFM010	63	Middle Fork Mokelumne near West Point	Stream inflow	47	32	0.2%
I_NFM006	63	North Fork Mokelumne below Tiger Creek Reservoir	Stream accretion	153	81	0.7%
I_SFM006	63	South Fork Mokelumne near West Point	Stream inflow	56	39	0.3%
I_SLTSP	63	Salt Springs Reservoir	Reservoir Inflow	332	142	1.5%
I_MOK079	63	Mokelumne River at Mokelumne Hill	Stream accretion	70	46	0.3%
I_PARDE	64	Pardee Reservoir	Local reservoir inflow	11	10	0.1%

Label	Watershed Number	Description	Type	Average Annual Flow (TAF)	Standard Deviation of Annual Flow (TAF)	Average as Percent of Total Rim Inflow
I_CMCHE	65	Camanche Reservoir	Local reservoir inflow	11	8	0.1%
I_AMADR	66	Amador Reservoir	Reservoir inflow	29	21	0.1%
I_DSC035	67	Dry and Sutter creeks	Stream inflow	65	51	0.3%
Cosumnes River Watershed			**Total**	**399**		**1.9%**
I_JNKSN	68	Jenkinson Lake	Reservoir inflow	17	12	0.1%
I_CMP001	68	Camp Creek at mouth	Stream inflow	12	7	0.1%
I_CMP012	68	Camp Creek at Camp Creek Diversion Tunnel	Stream inflow	32	19	0.1%
I_CSM035	68	Cosumnes River at Michigan Bar	Stream accretion	305	217	1.4%
I_DEE023	69	Deer Creek	Stream inflow	33	26	0.2%
Delta Tributaries			**Total**	**16**		**0.1%**
I_LOSVQ	70	Los Vaqueros Reservoir	Reservoir inflow	1	2	0.0%
I_MSH015	71	Marsh Creek	Stream inflow	14	16	0.1%
Total				**21,498**	**10,080**	

A.3 C2VSim Current Conditions Simulation for Estimating Stream-Groundwater Interaction

Estimating stream-groundwater interaction throughout the Sacramento Valley under current conditions with 82 years of historical hydrology presents a challenge. Historical simulations that assume changing land use, regulations, and hydrology using C2VSim show a trend of declining groundwater elevations over the 82-year study with the steepest declines over the last decade of simulation (DWR 2016b). Long-term trends in groundwater elevation result in trends of declining stream gains and increasing stream losses to groundwater. In contrast, the purpose of this report is to estimate unimpaired flows that would occur under current groundwater storage conditions given the range of variability in hydrology during the 82-year record. This requires a method for holding the relationship between stream flow and gain or loss to groundwater constant over the duration of the simulation. This was accomplished in the C2VSim model by repeatedly re-setting groundwater storage levels to recent (2009) conditions instead of allowing groundwater levels to trend downward through the 82-year simulation period. This approach allowed for a better estimate of

stream-groundwater interaction under current conditions over the 82-year simulation period for use in estimating unimpaired flows, and is discussed in more detail below in Section A.3.1, *Methods*.

A.3.1 Methods

C2VSim is a monthly finite element model that simulates linked groundwater and surface water flow throughout California's Central Valley (DWR 2016b). C2VSim requires initial conditions, land use, urban demands, inflows, and diversion information as model inputs. Each of these inputs was developed from previous contract amounts, C2VSim studies, or CalSim II baseline studies. Monthly land use and urban demands were set equal to their respective monthly levels in water year 2005 from version R374 of the C2VSim coarse-grid (C2VSim-CG) historical simulation developed by DWR (DWR 2016b). Land use and urban demands were assumed to be constant throughout the simulation period. Major inflows and diversions used in the current condition C2VSim simulation came from the 2015 Delivery Capability Report studies and smaller inflows and diversions came from the C2VSim historical run (Table A-4 and Table A-5).

To remove long-term trends in groundwater elevation and better simulate current stream-groundwater interaction over the 82-year simulation period, an ensemble approach was taken. The ensemble runs were created by running multiple 3-year simulations, with an individual ensemble run beginning in each year of the 82-year C2VSim simulation period, and each with the initial condition equal to the October 2009 groundwater storages. The results for the first 2 years of each ensemble run were treated as a warm-up period to allow each ensemble run to stabilize, and were discarded. The results for year 3 of each ensemble run were then stitched together to create a new 82-year time series that represents the stream gains and losses to groundwater with the variability in hydrology provided in the 82-year data set, while maintaining the current range of groundwater storages.

Table A-4. C2VSim Inflow Information Sources for the Current Conditions Model Run

Inflow Number	Stream Node	C2VSim Stream Name	Source of Inflow to C2VSim
1	205	Sacramento River	CalSim II (C5)
2	211	Cow Creek	CalSim II (C10801)
3	220	Battle Creek	CalSim II (C10803)
4	218	Cottonwood Creek	CalSim II (C10802)
5	225	Paynes and Sevenmile Creek	CalSim II (C11001)
6	233	Antelope Creek Group	CalSim II (C11307)
7	243	Mill Creek	CalSim II (C11308)
8	237	Elder Creek	C2VSim Historical
9	248	Thomes Creek	CalSim II (C11304)
10	256	Deer Creek Group	CalSim II (C11309)
11	263	Stony Creek	CalSim II (C42 + D42)
12	269	Big Chico Creek	CalSim II (C11501)
13	283	Butte and Chico Creek	CalSim II (I217)
14	341	Feather River	CalSim II (C203)
15	349	Yuba River	CalSim II (I230)
16	357	Bear River	CalSim II (I285)

Inflow Number	Stream Node	C2VSim Stream Name	Source of Inflow to C2VSim
17	390	Cache Creek	C2VSim 2000–2009 Matching[a]
18	374	American River	CalSim II (C8)
19	400	Putah Creek	C2VSim 2000–2009 Matching
20	188	Cosumnes River	CalSim II (C501)
21	182	Dry Creek	C2VSim Historical
22	173	Mokelumne River	CalSim II (I504) + C2VSim Diversion 84
23	161	Calaveras River	CalSim II (C92)
24	146	Stanislaus River	CalSim II (C520)
25	135	Tuolumne River	CalSim II (C540)
26	128	Oristimba Creek	C2VSim Historical
27	116	Merced River	CalSim II (C20)
28	105	Bear Creek Group	C2VSim Historical
29	93	Deadman's Creek	C2VSim Historical
30	80	Chowchilla River	CalSim II (C53)
31	69	Fresno River	CalSim II (C52)
32	54	San Joaquin River	CalSim II (C18)
33	23	Kings River	C2VSim 2000–2009 Matching
34	420	Kaweah River	C2VSim 2000–2009 Matching
35	10	Tule River	C2VSim 2000–2009 Matching
36	1	Kern River	C2VSim 2000–2009 Matching
37	24	FKC Wasteway Deliveries to Kings River	C2VSim 2000–2009 Matching
38	11	FKC Wasteway Deliveries to Tule River	C2VSim 2000–2009 Matching
39	421	FKC Wasteway Deliveries to Kaweah River	C2VSim 2000–2009 Matching
40	4	Cross-Valley Canal deliveries to Kern River	C2VSim 2000–2009 Matching
41	4	Friant-Kern Canal deliveries to Kern River	C2VSim 2000–2009 Matching

Notes: CalSim II data are from the 2015 Delivery Capability Report CalSim II study. Model node is listed in parentheses. C2VSim historical data are from version R374 of the C2VSim-CG model.

[a] "C2VSim 2000–2009 Matching" indicates that the values for 1992–1999 were chosen from the most similar year from 2000 to 2009 based on the Sacramento Valley index.

Table A-5. C2VSim Diversion Information Sources for the Current Conditions Model Run

C2VSim ID	C2VSim Diversion	Assumed Current Conditions Diversion
1	Whiskeytown and Shasta for Ag	Contract amount, CalSim annual allocation, 2000–2009 C2VSim historical monthly pattern
2	Whiskeytown and Shasta for M&I	Contract amount, CalSim annual allocation, 2000–2009 C2VSim historical monthly pattern
3	Sacramento River to Bella Vista conduit for Ag	Contract amount, CalSim annual allocation, 2000–2009 C2VSim historical monthly pattern
4	Sacramento River to Bella Vista conduit for M&I	Contract amount, CalSim annual allocation, 2000–2009 C2VSim historical monthly pattern

C2VSim ID	C2VSim Diversion	Assumed Current Conditions Diversion
5	Sacramento River to Bella Vista conduit for export	Contract amount, CalSim annual allocation, 2000–2009 C2VSim historical monthly pattern
6	Sacramento River, Keswick Dam to Red Bluff, for Ag	Contract amount, CalSim annual allocation, 2000–2009 C2VSim historical monthly pattern
7	Sacramento River, Keswick Dam to Red Bluff, for M&I	Contract amount, CalSim annual allocation, 2000–2009 C2VSim historical monthly pattern
8	Cow Creek riparian diversions	Average 2000–2009 C2VSim historical
9	Battle Creek riparian diversions	Average 2000–2009 C2VSim historical
10	Cottonwood Creek riparian diversions	Average 2000–2009 C2VSim historical
11	Clear Creek riparian diversions	Zero
12	Sacramento River diversions to the Corning Canal	CalSim II arc D171
13	Stony Creek to North Canal	CalSim II arc D17301
14	Stony Creek to South Canal	CalSim II arc D42
15	Stony Creek to the Tehama-Colusa Canal	Zero
16	Stony Creek to the Glenn-Colusa Canal	Zero
17	Sacramento River to Subregion 2	Contract amount, CalSim annual allocation, 2000–2009 C2VSim historical monthly pattern
18	Antelope Creek riparian diversions	Average 2000–2009 C2VSim historical
19	Mill Creek riparian diversions	Average 2000–2009 C2VSim historical
20	Elder Creek riparian diversions	Average 2000–2009 C2VSim historical
21	Thomes Creek riparian diversions	Average 2000–2009 C2VSim historical
22	Deer Creek riparian diversions	Average 2000–2009 C2VSim historical
23	Sacramento River to the Tehama-Colusa Canal to Subregion 2	CalSim II arc D172
24	Sacramento River to the Tehama-Colusa Canal to Subregion 3	CalSim II arc C171 less D172
25	Sacramento River to the Glenn-Colusa Canal for Ag	CalSim II arc D114 less D143B, less 145B
26	Sacramento River to the Glenn-Colusa Canal for Refuges	Contract amount, CalSim annual allocation, 2000–2009 C2VSim historical monthly pattern
27	Sacramento River to Subregion 3	Average 2000–2009 C2VSim historical * CalSim annual allocation
28	Sacramento River to Subregion 4	Average 2000–2009 C2VSim historical * CalSim annual allocation
29	Little Chico Creek	Average 2000–2009 C2VSim historical
30	Tarr Ditch	Average 2000–2009 C2VSim historical
31	Miocine and Wilenor Canals	Average 2000–2009 C2VSim historical
32	Palermo Canal	Average 2000–2009 C2VSim historical
33	Oroville-Wyandotte ID through Forbestown Ditch	Average 2000–2009 C2VSim historical
34	Little Dry Creek	Average 2000–2009 C2VSim historical
35	Bangor Canal	Average 2000–2009 C2VSim historical

C2VSim ID	C2VSim Diversion	Assumed Current Conditions Diversion
36	Thermalito Afterbay	Average 2000–2009 C2VSim historical, except in 1924, 1931, 1934, 1977, 1988, and 1991 assume 525,000 AF/year (Jan-Dec)
37	Feather River to Subregion 5 for Ag (replaced by Thermalito Afterbay)	Zero
38	Feather River to Thermalito ID	Average 2000–2009 C2VSim historical, but not more than 8,200 AF/year
39	Feather River to Subregion 5 for Ag	Average 2000–2009 C2VSim historical, except in 1924, 1931, 1934, 1977, 1988, and 1991 assume 65,895 AF/year (Jan–Dec)
40	Feather River to Yuba City	Average 2000–2009 C2VSim historical
41	Feather River to Subregion 7 for Ag	Average 2000–2009 C2VSim historical
42	Yuba River for Ag	Average 2000–2009 C2VSim historical, except in 1977 assume cut by 50%.
43	Yuba River for M&I	Zero
44	Bear River to Camp Far West ID North Side	Average 2000–2009 C2VSim historical
45	Bear River to Camp Far West ID South Side	Average 2000–2009 C2VSim historical
46	Bear River to South Sutter WD	Average 2000–2009 C2VSim historical
47	Bear River Canal to South Sutter WD	Average 2000–2009 C2VSim historical
48	Boardman Canal	Average 2000–2009 C2VSim historical
49	Combie (Gold Hill) Canal	Average 2000–2009 C2VSim historical
50	Cross Canal	Average 2000–2009 C2VSim historical excluding Shasta critical years. In Shasta critical years, average data from 1991, 1992, 1994 C2VSim historical.
51	Butte Creek at Parrott-Phelan Dam	Average 2000–2009 C2VSim historical
52	Butte Creek at Durham Mutual Dam	Average 2000–2009 C2VSim historical
53	Butte Creek at Adams & Gorrill Dams	Average 2000–2009 C2VSim historical
54	Butte Creek to RD 1004	Average 2000–2009 C2VSim historical
55	Butte Creek to Sutter and Butte Duck Clubs	Average 2000–2009 C2VSim historical
56	Butte Slough	Average 2000–2009 C2VSim historical
57	Sutter Bypass East Borrow Pit to Sutter NWR	Average 2000–2009 C2VSim historical
58	Sutter Bypass West Borrow Pit North of Tisdale Bypass	Average 2000–2009 C2VSim historical
59	Sutter Bypass East Borrow Pit to lands within Sutter Bypass	Average 2000–2009 C2VSim historical
60	Sutter Bypass East Borrow Pit from North of Wadsworth Canal to Gilsizer Slough	Average 2000–2009 C2VSim historical
61	Sutter Bypass East Borrow Pit South of Gilsizer Slough	Average 2000–2009 C2VSim historical
62	Colusa Basin Drain to Subregion 3 for Ag	Average 2000–2009 C2VSim historical

C2VSim ID	C2VSim Diversion	Assumed Current Conditions Diversion
63	Colusa Basin Drain to Subregion 3 for Refuges	Average 2000–2009 C2VSim historical
64	Knights Landing Ridge Cut	Average 2000–2009 C2VSim historical
65	Sacramento River between Knights Landing and Sacramento to Subregion 6 for Ag	Average 2000–2009 C2VSim historical excluding Shasta critical years. In Shasta critical years, average data from 1991, 1992, 1994 C2VSim historical.
66	Sacramento River to City of West Sacramento	Average 2000–2009 C2VSim historical
67	Sacramento River between Knights Landing and Sacramento to Subregion 7 for Ag	Average 2000–2009 C2VSim historical excluding Shasta critical years. In Shasta critical years, average data from 1991, 1992, 1994 C2VSim historical.
68	Sacramento River to City of Sacramento	Average 2000–2009 C2VSim historical
69	Cache Creek	Average 2000–2009 C2VSim historical
70	Yolo Bypass	Average 2000–2009 C2VSim historical
71	Putah South Canal for Ag	Average 2000–2009 C2VSim historical
72	Putah South Canal for M&I	Average 2000–2009 C2VSim historical
73	Putah South Canal exports	Average 2000–2009 C2VSim historical
74	Putah Creek riparian diversions	Average 2000–2009 C2VSim historical
75	Folsom Lake for Ag	Average 2000–2009 C2VSim historical
76	Folsom Lake for M&I	Average 2000–2009 C2VSim historical
77	Folsom South Canal for Ag	Zero
78	Folsom South Canal for M&I	Contract amount, CalSim annual allocation, 2000–2009 C2VSim historical monthly pattern
79	Folsom South Canal exports	Zero
80	American River to Carmichael WD	Average 2000–2009 C2VSim historical
81	American River to City of Sacramento	Average 2000–2009 C2VSim historical
82	Cosumnes River	Average 2000–2009 C2VSim historical
83	Mokelumne River from Camanche Reservoir	Average 2000–2009 C2VSim historical
84	Mokelumne River	Average 2000–2009 C2VSim historical
85	Calaveras River	CalSim II arc D506A + D506B + D506C +D507
86	Sacramento-San Joaquin Delta for Ag	Average 2000–2009 C2VSim historical
87	Sacramento-San Joaquin Delta for M&I	Average 2000–2009 C2VSim historical
88	Sacramento-San Joaquin Delta to North Bay Aqueduct for Ag	Zero
89	Sacramento-San Joaquin Delta to North Bay Aqueduct for M&I	CalSim II arc (1/3)*D403C
90	Sacramento-San Joaquin Delta to North Bay Aqueduct export	CalSim II arc D403A + D403B + (2/3)*D403C +D403D
91	Sacramento-San Joaquin Delta to Contra Costa Canal	CalSim II arc D408_OR + D408_RS +D408_VC
92	Sacramento-San Joaquin Delta to CVP	CalSim II arc D418 + D419_CVP

C2VSim ID	C2VSim Diversion	Assumed Current Conditions Diversion
93	Sacramento-San Joaquin Delta to SWP	CalSim II arc D419_SWP

Notes: CalSim II data are from the 2015 Delivery Capability Report CalSim II study. C2VSim historical data are from version R374 of the C2VSim-CG model.
Ag = agriculture
M&I = municipal and industrial
WD = water district
ID = irrigation district
CVP = Central Valley Project
SWP = State Water Project
NWR = National Wildlife Refuge

A.3.2 Results

Table A-6 presents a summary of the stream-groundwater interactions for the C2VSim reaches that are represented in SVUFM. These reaches include the valley floor portion of the Sacramento Valley watershed, the lower sections of the Delta eastside tributaries, and the Delta (DWR 2016c). On average, this region lost an estimated 876 TAF/yr, with average annual gains or losses varying by subregion:

- The Delta eastside tributaries lost an average of 151 TAF/yr, with the greatest loss (91 TAF/yr) occurring along the Mokelumne River upstream of its confluence with the Cosumnes River.
- The Sacramento River valley floor watershed lost an average of 494 TAF/yr, with the northern portion of the watershed (north of Thomes Creek) experiencing an average gain of 126 TAF/yr and the southern portion of the watershed experiencing an average loss of 620 TAF/yr, with the biggest losses occurring along the Sacramento River north and south of the American River (reaches 65 and 67).
- The Yolo Bypass and its tributaries (Cache and Putah Creeks) lost an average of 152 TAF/yr.
- The Delta (including reaches 26, 28, 29, and 71–74) experienced relatively small change in flow associated with stream-groundwater interaction (average loss of 78 TAF/yr).

Additional information regarding the magnitude of the stream-groundwater interaction in relation to total flow and variation in stream-groundwater interaction through the year is presented in Section A.4.

Table A-6. Average Annual Stream-Groundwater Interaction Simulated by the C2VSim Current Conditions Run

C2VSim Reach Name[a]	Average Annual Gain (+)/ Loss (-) (TAF)
REACH 25 - CALAVERAS RIVER	-53
REACH 26 - SAN JOAQUIN RIVER (part of Delta)	-33
REACH 27 - MOKELUMNE RIVER	-91
REACH 28 - DRY CREEK	-3
REACH 29 - COSUMNES RIVER	-3
REACH 30 - MOKELUMNE (SOUTH) (part of Delta)	-23

C2VSim Reach Name[a]	Average Annual Gain (+)/ Loss (-) (TAF)
REACH 31 - SAN JOAQUIN RIVER (part of Delta)	-5
REACH 32 - SACRAMENTO RIVER	1
REACH 33 - COW CREEK	-11
REACH 34 - SACRAMENTO RIVER	18
REACH 35 - COTTONWOOD CREEK	-7
REACH 36 - BATTLE CREEK	10
REACH 37 - SACRAMENTO RIVER	25
REACH 38 - PAYNES CREEK	12
REACH 39 - SACRAMENTO RIVER	43
REACH 40 - ANTELOPE CREEK	14
REACH 41 - SACRAMENTO RIVER	9
REACH 42 - ELDER CREEK	2
REACH 43 - MILL CREEK	2
REACH 44 - SACRAMENTO RIVER	8
REACH 45 - THOMES CREEK	-18
REACH 46 - SACRAMENTO RIVER	4
REACH 47 - DEER CREEK	-1
REACH 48 - SACRAMENTO RIVER	0
REACH 49 - STONY CREEK	-69
REACH 50 - BIG CHICO CREEK	0
REACH 51 - SACRAMENTO RIVER	-22
REACH 52 - BUTTE CREEK	-122
REACH 53 - SACRAMENTO RIVER	-24
REACH 54 - GLENN COLUSA CANAL	0
REACH 55 - COLUSA BASIN DRAINAGE CANAL	80
REACH 56 - COLUSA BASIN DRAINAGE CANAL	63
REACH 57 - SACRAMENTO RIVER	-14
REACH 58 - SUTTER BYPASS	-44
REACH 59 - FEATHER RIVER	6
REACH 60 - YUBA RIVER	-22
REACH 61 - FEATHER RIVER	-67
REACH 62 - BEAR RIVER	-40
REACH 63 - FEATHER RIVER	31
REACH 64 - FEATHER RIVER	-26
REACH 65 - SACRAMENTO RIVER	-175
REACH 66 - AMERICAN RIVER	-56
REACH 67 - SACRAMENTO RIVER	-104
REACH 68 - CACHE CREEK	-87
REACH 69 - PUTAH CREEK	-54
REACH 70 - YOLO BYPASS - CACHE SLOUGH	-12
REACH 71 - SACRAMENTO RIVER	-17

C2VSim Reach Name[a]	Average Annual Gain (+)/ Loss (-) (TAF)
REACH 72 - SACRAMENTO-SAN JOAQUIN DELTA	-2
REACH 73 - SUISUN MARSH	80
REACH 74 - EXTEND SJR TO CARQUINEZ STRAIGHT	-79
Total	-876

[a] Reaches presented in hydrologic order with reaches 25–31 covering the Delta eastside tributaries and the southern and central Delta from south to north, and reaches 32–74 covering the Sacramento Valley and northern and western Delta from north to south.

A.4 Sacramento Valley Unimpaired Flow Model

A.4.1 Introduction

For many years DWR has been using the Water Resources Integrated Modeling System (WRIMS) to create, use, and improve the CalSim model for simulating water operations in the California Central Valley. CalSim II is the current working version of the model, but DWR is working on an improved version of this model, CalSim 3. In order to help the State Water Board assess unimpaired flow in the Sacramento Valley, DWR staff developed a SVUFM that was developed with WRIMS utilizing relevant parts of the CalSim framework.

A.4.2 Methods

A.4.2.1 Basic Assumptions

To simulate unimpaired flow using SVUFM, the following basic assumptions were made:

- No reservoir operations
- No diversions
- No imports or exports
- No return flows
- Existing weirs operate under current conditions
- Delta Cross Channel Gate is open all the time
- No groundwater pumping. Groundwater pumping does not connect or affect the stream network of SVUFM
- San Joaquin River unimpaired inflows are not modeled in SVUFM and are instead represented by model input as unimpaired flows estimated using methods outlined in DWR's Unimpaired Flows Report (DWR 2007).

A.4.2.2 SVUFM Modeling Approach

SVUFM is simply a data integration model with limited routing capability. It is assumed that the valley floor unimpaired flow (UF) consists of three components, as shown in Figure A-2, Unimpaired

Flow Components in SVUFM. The three components of the valley floor UF are the unimpaired rim watershed inflow (URI), the valley floor surface rainfall runoff (SR), and the stream gain from the groundwater aquifer or loss to the groundwater aquifer (SG). Three time series input datasets are used to incorporate these three flow components into the SVUFM channel network:

1. Rim watershed inflows (URIin)
2. Valley floor surface rainfall runoff (SRin)
3. Stream gain/losses (SGin)

The rim watershed inflow dataset was developed based on historical observations. Its development is described above in Section A.2, *Rim Watershed Hydrology*. The valley floor surface rainfall runoff dataset was simulated by CalSimHydro (discussed further below). The stream gain/loss dataset was simulated by a current-condition run of the C2VSim standalone model, and its development is described above in Section A.3, *C2VSim Current Conditions Simulation for Estimating Stream-Groundwater Interaction.*

In general, the unimpaired flow at the outlet of a tributary in the valley floor can be written as

$$UF_i = URI_i + SR_i + SG_i$$

Where

UFi = Unimpaired flow at the i-th tributary outlet,

URIi = Sum of unimpaired rim watershed inflows of the i-th tributary,

SRi = Sum of valley floor surface rainfall runoff along the i-th tributary, and

SGi = Sum of stream gain/losses (SG) along the i-th tributary.

In the impaired case, the full water balance would also include the sum of terms

Di = Sum of diversions (D) along the i-th tributary, and

Ri = Sum of return flows (R) along the i-th tributary,

which are taken to be zero in the unimpaired case.

The flow continuity in the SVUFM channel network is ensured by mass balance calculations at all stream nodes. In a few instances, estimated stream losses are greater than the flow in the river. Because negative flow is not physically possible, the input stream gain/loss (SGi) terms are modified internally in SVUFM to ensure that they are not greater than stream flow. This means that the SG used by SVUFM may be different from SGi. There are no other alterations to the model inputs and there is no addition of "closure terms" as is used with CalSim II modeling to compensate for differences between model results and measurements (partly because there are no direct measurements of unimpaired flow on the valley floor). The accuracy of SVUFM is mainly determined by the data quality of the three input datasets.

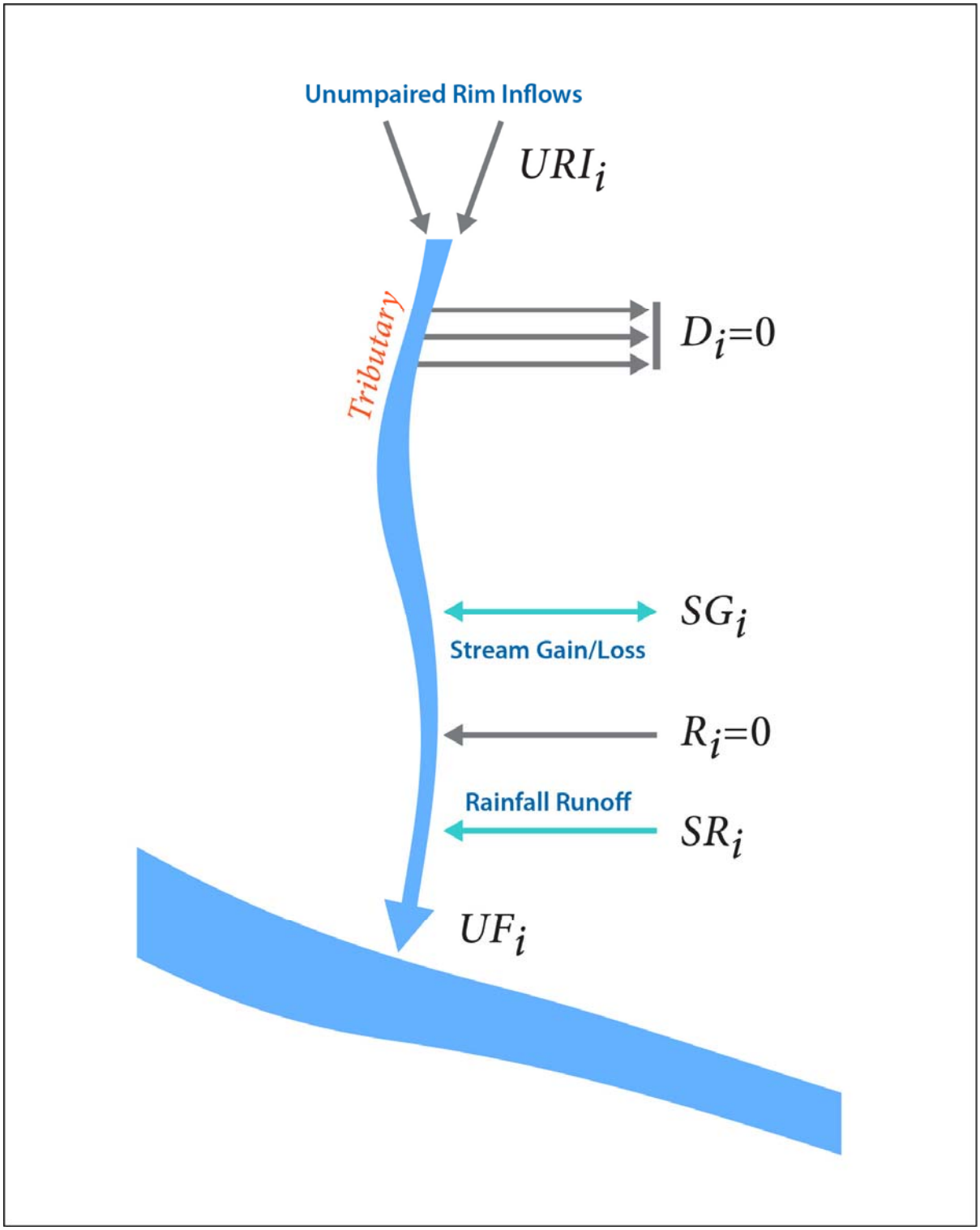

Figure A-2. Illustration of Unimpaired Flow Components in SVUFM

A.4.2.3 SVUFM Channel Network

SVUFM routes channel flows through the channel network of the Sacramento Valley, which is shown in the SVUFM schematic (Attachment A). The SVUFM network represents the water conveyance system of the Sacramento River hydrologic region and the Delta. The network is the foundation of SVUFM.

The SVUFM channel network is in the form of a node-arc network. Nodes represent specific locations, such as weirs, tributary confluences, and groundwater seepages. Flow arcs represent flows between nodes. Mass balance must be observed at each node (i.e., flows in the incoming arcs equal flows in the outgoing arcs except at nodes representing reservoirs where a change in storage may occur).

Flow arcs in SVUFM represent average monthly flows to, from, or between nodes. Arcs must connect to at least one node. Drawing conventions for arcs and nodes are shown in Figure A-3, Schematic Conventions for Flow Arcs and Nodes. Flow direction is indicated by an arrow pointing in the direction of flow. In SVUFM, arc names are generally composed of three parts: a prefix denoting the type of arc (e.g., inflow, channel, surface runoff); the arc's node of origin; and the arc's destination node. SVUFM does not include diversion or return flow arcs because diversions and returns are set to zero.

Nodes

Conveyance Nodes

The SVUFM schematic displays conveyance nodes as circles bearing a six-character "license plate" abbreviation of the conveyance name and RM or channel milepost (MP). Line types and colors are used to represent a variety of node attributes. Blue outlines represent natural conveyance channels. A gray fill color indicates a gaging station or gage location. A node with gray fill and dashed outline indicates that the gage has been discontinued.

Reservoir Nodes

Reservoir storages are not included in SVUFM. However, the reservoir nodes are shown to indicate location of the reservoirs. They have a five-character abbreviation of either the name of the dam or reservoir. For example, "SHSTA" is used to denote the location of Shasta Lake.

Flow Arcs

Channel Arcs

Channel arcs (C_*oooooo*) are used to represent flow in a stream reach or constructed channel. The destination node is omitted from the channel arc name. For example, Cottonwood Creek is abbreviated as "CWD" and the node near RM 4 of the Cottonwood Creek is shown as "CWD004". The channel arc C_CWD004 (C_*oooooo*) represents flow downstream of the stream node CWD004 near RM 4 of the Cottonwood Creek, as shown in Figure A-3.

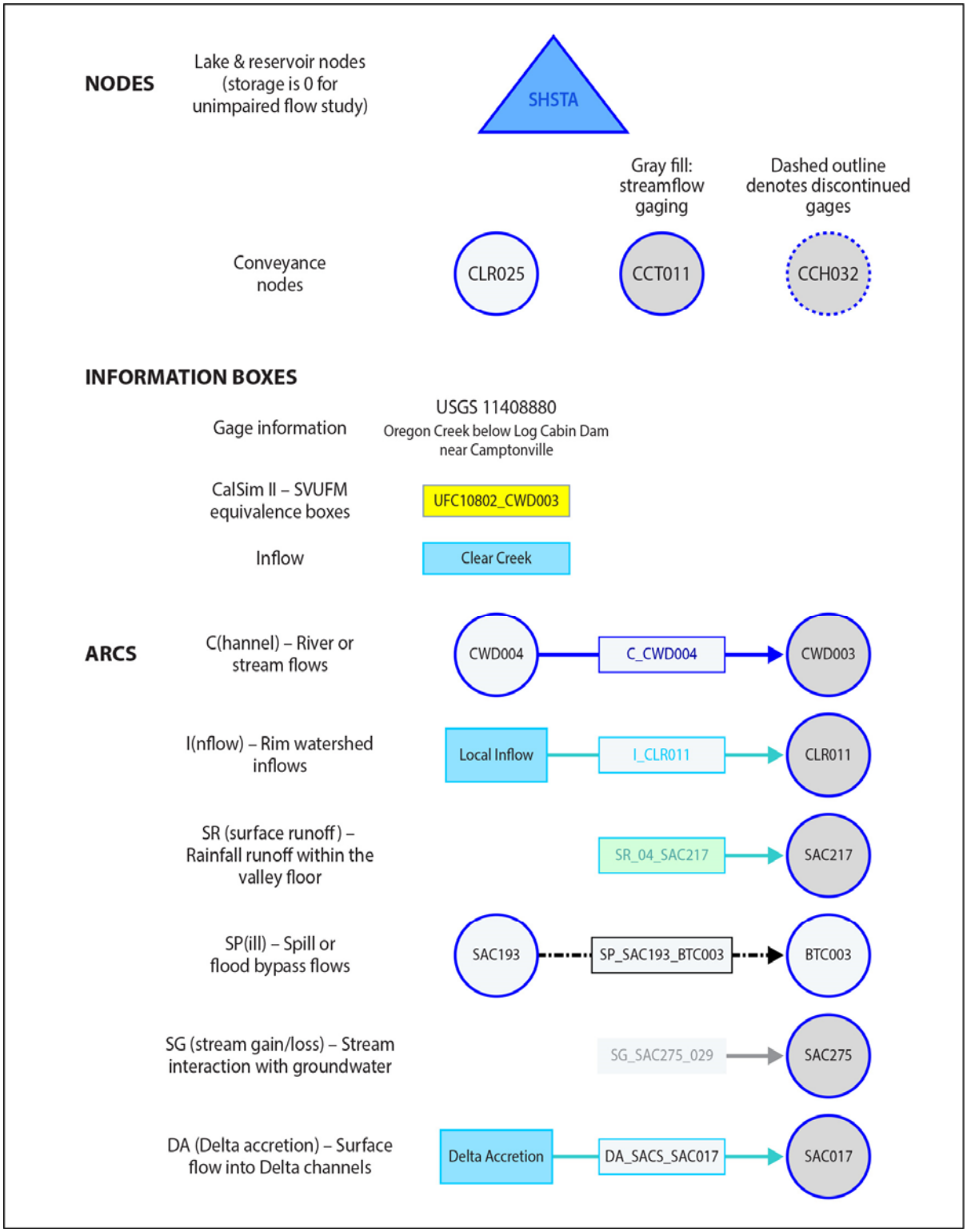

Figure A-3. Schematic Conventions for Flow Arcs and Nodes

Stream Gain/Loss Arcs

Stream gain/loss arcs are labeled with an "SG_" prefix, followed by the receiving node name and the corresponding C2VSim groundwater node. For example, the stream gain/loss arc SG_SAC259_056 represents stream gain/loss at the node SAC259 near RM 259 of the Sacramento River and "056" is used to indicate the C2VSim groundwater node. Groundwater inflow to the stream system only occurs at stream nodes with corresponding C2VSim stream nodes. On the SVUFM schematic, groundwater inflow to nodes is indicated by an incoming gray arc.

Inflow Arcs

Inflow arcs (I_*dddddd*) are used to represent rim inflow or local inflow to a node in the channel network (e.g., a reservoir node). For example, the inflow arc I_SHSTA (I_*dddddd*) represents inflow to the Shasta Lake node SHSTA. These inflows are model inputs.

Surface Runoff Arcs

Surface runoff arcs (SR_*ooo_dddddd*) are used to represent surface runoff from a water budget area (WBA) to a node in the channel network. For example, the surface runoff arc SR_04_SAC217 represents surface runoff from WBA 04 (*ooo*) to the stream node SAC217 (*dddddd*) near RM 217 of the Sacramento River. These runoff values are calculated by SVUFM based the contributing area fraction of the surface runoff from the WBA, which is from CalSimHydro as explained below.

Delta Accretion Arcs

Delta accretion arcs (DA_*oooo_dddddd*) are used to represent local surface inflow to the Delta. For example, the Delta accretion arc DA_SACS_SAC017 represents delta accretion from the south side of the Delta near the Sacramento River (*oooo*) to stream node SAC017 (*dddddd*) near RM 17 of the Sacramento River. The six Delta accretion arcs are Sacramento North, Sacramento South, Sacramento West, San Joaquin River West, San Joaquin River East, and Mokelumne.

Weir Spill Arcs

Weir spill arcs (SP_*oooooo_dddddd*) are used to represent flood spills from the Sacramento River flood control system weirs and flood relief structures (FRS). For example, the weir spill arc SP_SAC148_BTC003 represents flood spill at the node SAC148 (*oooooo*) of the DWR Colusa Weir near RM 148 of the Sacramento River to the node BTC003 (*dddddd*) near RM 3 of Butte Creek.

CalSim II – SVUFM Equivalence Labels

To facilitate comparison with CalSim II, yellow highlighted boxes appear throughout the SVUFM schematic representing equivalent CalSim II flow arcs at selected key locations. For example, the yellow box with the label "UFC10802_CWD003" appears next to the channel arc with label "C_CWD003" to indicate that it is an unimpaired flow of the tributary Cottonwood Creek, and that the flow "C_CWD003" in SVUFM is the same arc "C10802" in CalSim II.

A.4.2.4 Operations

In general, a model of unimpaired flow does not include operations because water is allowed to flow downstream unimpeded. However, based on existing structure and channel configurations, some assumptions regarding the movement of water between channels are necessary.

Delta Cross Channel and Georgiana Slough Operation

In the SVUFM model, the Delta Cross Channel gates are assumed to be open all the time. A regression equation from CalSim II is used to compute flow through the Delta Cross Channel and Georgiana Slough (C_SAC029B) as a function of flow in the Sacramento River near the Delta Cross Channel (C_SAC041):

$$C_SAC029B = 0.1321 \times C_SAC041 + 1087.0$$

Weir Operations

To determine flood spills from existing FRSs and weirs in the Sacramento River, a piecewise linear function is used in SVUFM for each structure as its weir rating curves, as shown in the equation below,

$$Q_{spill} = \begin{cases} \alpha_0 \times Q & Q < Q_1 \\ \alpha_0 \times Q_1 + \alpha_1 \times (Q - Q_1) & Q_1 < Q \leq Q_2 \\ \alpha_0 \times Q_1 + \alpha_1 (Q_2 - Q_1) + \alpha_2 \times (Q - Q_2) & Q_2 < Q \end{cases}$$

Where Q represents the upstream inflow and Qspill represents the spill from the structure. α0, α1, α2, Q1, and Q2 are the rating curve parameters.

The SVUFM arc name and its equivalent CalSim II arc name of the FRSs and weirs in the Sacramento River are listed in Table A-7. The weir spill equation parameters are listed in Table A-8. These calculations are intended to represent existing functionality of these structures.

Table A-7. Sacramento Flood Relief Structures and Weirs

Name	SVUFM Arc	CalSim II Name
M&T Flood Relief Structure	SP_SAC193_BTC003	N/A
3Bs Flood Relief Structure	SP_SAC188_BTC003	N/A
Goose Lake Flood Relief Structure	SP_SAC178_BTC003	D117B
Moulton Weir	SP_SAC159_BTC003	D124
Colusa Weir	SP_SAC148_BTC003	D125
Tisdale Weir	SP_SAC122_SBP021	D126
Fremont Weir	SP_SAC083_YBP037	D160
Sacramento Weir	SP_SAC066_YBP020	D166A

Table A-8. Weir Spill Equation Parameters

Weir Name	α0	α1	α2	Q1	Q2
M&T Flood Relief Structure	0	0.73071	0.73071	90000	90000
3Bs Flood Relief Structure	0	0.73071	0.73071	90000	90000
Goose Lake Flood Relief Structure	0	0.73071	0.73071	90000	90000
Moulton Weir	0	0.1239	0.1621	26160	60707
Colusa Weir	0	0.4942	0.5718	16760	47178
Tisdale Weir	0	0.75177	0.75177	18000	18000

Fremont Weir	0	0.645	0.8566	36125	93308
Sacramento Weir	0	0.563	0.563	67800	67800

A.4.2.5 Input Dataset Preparation

Preparation of the three time series input datasets for SVUFM is described in the following sections.

Rim Watershed Inflows

Estimated unimpaired inflow to the SVUFM network comes from the disaggregated unimpaired rim inflows described in Section A.2, *Rim Watershed Hydrology*. There are some locations where disaggregated rim inflows need to be summed to provide unimpaired inflow to the SVUFM model network because the SVUFM schematic is not expanded as far upstream as the disaggregated rim inflows. Table A-9 shows the disaggregated rim inflows that were aggregated to create unimpaired rim inflows at the boundary locations on the SVUFM network.

Because the San Joaquin River is not part of the SVUFM model, unimpaired San Joaquin River inflow to the Delta is input to the SVUFM schematic domain in the same manner as the other rim inflows. Total San Joaquin River unimpaired inflow to the Delta is a model input that was estimated per the methods in California Central Valley Unimpaired Flow Data (DWR 2007). This inflow is named I_SJR042_SJVUF and is assigned to the channel arc C_SJR042 in SVUFM.

CalSimHydro (Valley Floor) Surface Rainfall Runoff

The surface rainfall runoff dataset used as input for SVUFM surface runoff arcs is generated by CalSimHydro as monthly time series for each WBA in the Sacramento Valley Floor from October 1921 to September 2009 in HEC DSS data format. CalSimHydro computes surface rainfall runoff for each WBA, whereas SVUFM requires these runoff values to be provided at channel node level. This difference was resolved by calculating surface runoff fractions. Using geographic information system (GIS) tools, surface runoff fractions were developed based on the WBA areas that intersect with the watershed areas adjacent to the stream. These surface runoff fractions were then used to scale down the WBA-level surface runoff to reflect the amount of surface runoff that flows into different sections of SVUFM Channel network. Locations of the SVUFM surface runoff arcs can be found in the SVUFM schematic.

Table A-9. Aggregation of Rim Inflows to Create Rim Inflows for SVUFM Schematic

Location	Rim Inflow Label in SVUFM Schematic	Disaggregated Rim Inflows Summed to Create SVUFM Rim Inflow[a]
North Fork Feather River at Pulga	I_NFF027	I_ALMMW, I_BTVLY, I_ANTLP, I_BUKSL, I_GRZLY, I_ENF001, and I_NFF027
Middle Fork Feather River near Merrimac	I_MFF019	I_DAVIS, I_FRMAN, I_MFF073, and I_MFF019
Middle Fork Yuba River above Our House diversion Dam	I_MFY013	I_JKSMD and I_MFY013
South Fork Yuba River at Jones Bar	I_SFY007	I_BOWMN, I_FRDYC, I_SPLDG, and I_SFY007
Deer Creek inflow to Yuba River	I_DER001	I_SCOTF, I_DER004, I_DER001, and I_SFD003

Middle Fork American River near Forest Hill	I_MFA023	I_FRMDW, I_RBCON, I_DCC007, I_BKILD, I_RUB001, I_HHOLE, I_LOONL, I_SFR005, I_STMPY, I_LNG000, and I_MFA036
South Fork American River near Placerville	I_SFA030	I_UNVLY, I_ICEHS, I_CAPLS, I_SILVR, I_SFA056, I_ALD001, I_PLM001, I_SFA035, and I_SFA021
Mokelumne River near Mokelumne Hill	I_MOK079	I_LBEAR, I_MFM010, I_NFM006, I_SFM006, I_SLTSP, and I_MOK079
Cosumnes River at Michigan Bar	I_CSM035	I_JNKSN, I_CMP001, I_CMP012, and I_CSM035

[a] Some of the disaggregated rim inflows have the same name as the SVUFM rim inflows, but they do not represent the same flow (typically they represent a local inflow instead of the total unimpaired flow in the river at that location).

CalSimHydro uses a daily rainfall runoff model to simulate the daily rainfall runoff for all un-ponded lands, including crops, urban areas, and native vegetation. The U.S. Soil Conservation Service (SCS) curve number method is used in the model. The SCS method is used to divide rainfall into surface runoff and associated "losses" (infiltration and evapotranspiration).The curve number used in these calculations depends on soil type, hydrologic condition (e.g., if ground cover is present to slow runoff and promote infiltration), land use, and antecedent moisture condition (estimated using an antecedent precipitation index). CalSimHydro uses land use conditions based on the ten year average of 1998-2007 DWR Division of Planning and Local Assistance (DPLA) land use survey data for agriculture and uses the 2006 data for urban area. The daily rainfall data used in CalSimHydro are spatially distributed precipitation from October 1921 to September 2009 based on historical National Climatic Data Center (NCDC) gage records and Parameter-Elevation Regressions on Independent Slopes Model (PRISM) data. Monthly surface rainfall runoff for all un-ponded lands was obtained by summing the daily rainfall runoff results.

For runoff from ponded water, CalSimHydro includes a refuge water use model to simulate monthly rainfall runoff from refuges (managed wetlands) and it includes a rice water use model to simulate monthly rainfall runoff from rice fields under ponded conditions.

Many of the smaller tributaries and the Delta do not receive surface runoff below the rim inflows in the SVUFM model. These small streams include Clear Creek, Battle Creek, Paynes Creek, Elder Creek, Thomes Creek, Stony Creek, Antelope Creek, Mill Creek, Big Chico Creek, Cosumnes River, and Calaveras River. Any local surface runoff to these creeks is expected to be relatively small and is routed to the mainstem Sacramento River, Mokelumne River, or San Joaquin River. The aggregation of surface runoff results in an underestimate of unimpaired flow at the mouth of these tributaries. Future work should include higher resolution surface runoff to better simulate unimpaired flows on all tributaries.

C2VSim Stream – Groundwater Interaction (Stream Gains and Losses)

The C2VSim model was designed to assess the groundwater aquifer and its interaction with surface water, whereas SVUFM is simply a flow routing tool. C2VSim estimates of surface water – groundwater interaction, specifically stream gain/loss to groundwater, are used within SVUFM to represent this interaction on the Valley floor. C2VSim estimates of surface water – groundwater interaction are based on a simulation of current water use conditions (described above). Current conditions were used as opposed to unimpaired flow conditions so the C2VSim model results will represent values that may be expected in the near term when modifications to the Bay-Delta Plan

may be implemented. In order to use the stream-groundwater interaction output from the current-condition run of the C2VSim model, mapping from the C2VSim stream nodes to SVUFM stream gain/loss arcs is required.

In the SVUFM schematic, the surface water-groundwater interaction is indicated by stream gain/loss arcs that reflect the direct effect of groundwater on the surface water system. A positive SG value represents a gaining stream whereas a negative value represents a losing stream that is recharging the groundwater aquifer.

Most of stream segments in C2VSim and channel arcs in SVUFM overlap each other. In general, the SVUFM streamflow network contains a node at each node location in C2VSim's streamflow network. These nodes are associated with stream-groundwater interaction, and the C2VSim estimates of stream-groundwater interaction are incorporated into SVUFM at these nodes. The SG values from C2VSim are modified by SVUFM using soft constraints to ensure the channel arc flows in SVUFM are greater or equal to zero by reducing the magnitude of the negative value of the relevant SG arcs if necessary.

The C2VSim stream network is represented by reaches. Each tributary can have one or more reaches, and the main stems of the Sacramento River and the Feather River have multiple reaches. A reach is further divided into segments. There is one node at each end of a segment. A one-segment reach has two nodes; a two-segment reach has three nodes; and so on. When two or more stream segments are from different reaches at a juncture (i.e., a confluence location or a reach connection location), C2VSim will have multiple nodes at the juncture, each of which belongs to different stream segments. In contrast, SVUFM has one node at junctures.

In general, the following mapping methods are used in order to reconcile the conceptual differences in how stream nodes in C2VSim and nodes in SVUFM are represented (Figure A-4, Assignment of C2VSim Stream-Groundwater Interaction to SVUFM Nodes).

- Stream gain or loss of a SVUFM internal node = Stream gain/loss of the C2VSim stream node at the SVUFM node, where an SVUFM internal node is defined as a node which is not at a confluence and not on a tributary immediately upstream of the confluence;
- Stream gain or loss of a SVUFM node located at a confluence = Sum of stream gains or losses at all C2VSim stream nodes that occur at the SVUFM node excluding all C2VSim tributary reach nodes at the confluence (i.e., the sum of stream gains and losses at the two C2VSim stream nodes on the main channel upstream and downstream of the confluence);
- Stream gain or loss of a SVUFM tributary node immediately upstream of a confluence = Sum of all C2VSim stream gain or loss nodes at the SVUFM node plus the C2VSim tributary reach node at the confluence. This approach allows for all stream gain or loss along a tributary to be assigned to the tributary as opposed to having some of it assigned to the SVUFM main channel node at the confluence.

The C2VSim and SVUFM schematics differ in the Lower Feather River - Sutter Bypass region (Figure A-4). C2VSim represents the Sutter Bypass as flowing into the lower Feather River above the confluence with the Sacramento River, which is what occurs when the Sutter Bypass is flooded. In contrast, the SVUFM schematic has Sutter Bypass flowing into the Sacramento River near the Fremont Weir, which is where the Sutter Bypass irrigation channel flows when the Sutter Bypass is not inundated. This may result in occasional inconsistencies in the stream-groundwater interactions in C2VSim versus SVUFM during periods when Sutter Bypass flows are high. Because stream loss is a

function of streamflow, some stream loss occurring at the downstream end of the Feather River in C2VSim would more appropriately be associated with the Sacramento River in the SVUFM schematic.

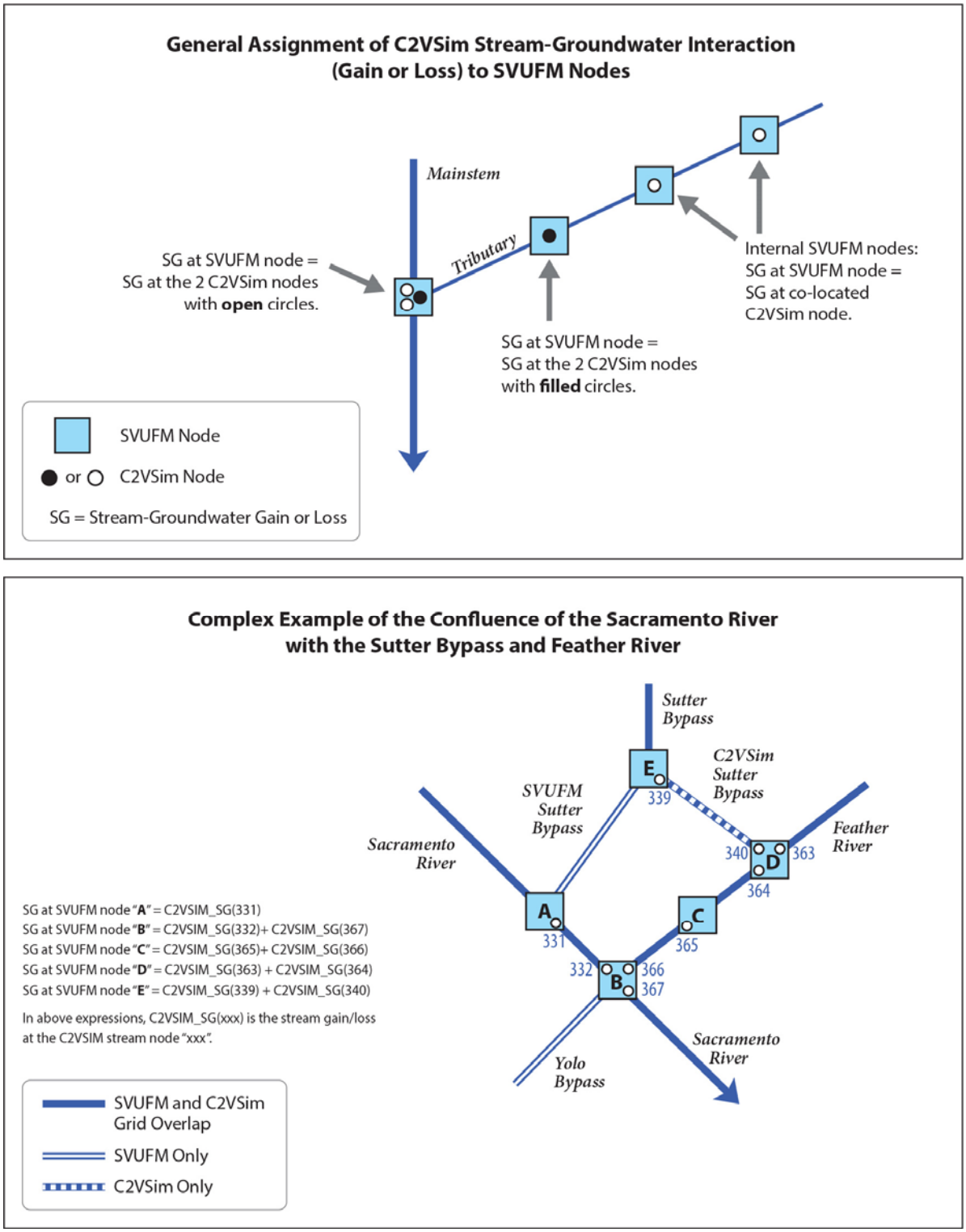

Figure A-4. Assignment of C2VSim Stream-Groundwater Interaction to SVUFM Nodes

Delta Accretions

The Delta accretion arcs represent land surface processes (as opposed to the SG arcs that represent change in flow resulting from stream-groundwater interaction). Because SVUFM represents unimpaired conditions, the SVUFM model assumes that positive net Delta depletions do not affect flow in the Delta. However, when net Delta depletions are negative, the model is indicating that precipitation (and sometimes discharge of leach water) would be contributing accretions to the Delta. Net Delta accretions are estimated on a monthly basis with a Delta consumptive use model that is similar to the evaluation used by CalSim II. When precipitation is more than sufficient to meet consumptive use, the excess is assumed to contribute to the Delta channels. Consumptive use is based on existing land use including Stone Lakes National Wildlife Refuge. If consumptive use is greater than what is provided by precipitation, SVUFM assumes the deficit would not be met with water from Delta channels (i.e., no Delta depletions).

San Joaquin Inflow

Unimpaired inflow from the San Joaquin River was assumed from DWR unimpaired flow report 4th Edition and expanded to 2009 (DWR 2007). The San Joaquin Valley unimpaired runoff estimated using these methods suffers from the similar issues discussed above in the Sacramento Valley such as not including stream gains/losses to groundwater. However, this is the best available estimate of unimpaired flows from the San Joaquin River at this time.

A.4.3 Results

The following bar charts show the monthly average SVUFM results by tributary broken up by flow component (Figures A-5 through A-30, presented in alphabetical order). The flow components include rim inflow, surface runoff, groundwater gain/loss, and outflow at tributary confluences. Table A-10 presents the annual average SVUFM results per water year type.

Two figures (Figures A-20 and A-25) provide examples of how flow components contribute to unimpaired flows on tributaries and bypasses. Tributary inflow for the Feather River shown in Figure A-20 comes from the Bear River (Figure A-8), Yuba River (Figure A-30), Honcut Creek, and Jack Slough. Tributary inflow for the Sacramento River at Freeport (Figure A-25) comes from all the upstream tributaries. “Inflows” (rim inflows) in this figure are the Lake Shasta rim inflows. The Yolo Bypass flows shown for the Sacramento River at Freeport (Figure A-25) are negative because they represent water that leaves the Sacramento River system upstream of Freeport and does not return until downstream of Freeport. The Sutter Bypass flows in Figure A-25 are small because they represent only the net change in flow that occurs within the Sutter Bypass and not water that leaves and returns to the Sacramento River via the Sutter Bypass, which would have no effect on Sacramento River flow at Freeport.

There are pattern differences between rain-fed and snow-melt fed tributaries. The monthly results show pattern differences between low altitude streams that are supplied primarily by rainfall and streams that extend higher into the mountains and receive substantial snowmelt. Snowmelt streams typically show peak flows from March to May. These include the American River (Figure A-5), the Feather River (Figure A-20), the Mokelumne River (Figure A-22), and the Yuba River (Figure 30). Most other streams show a pattern expected for streams that are fed by rainfall, with peak flows during January – March. The Sacramento River as a whole shows a pattern that is indicative of a mixture of rainfall and snowmelt runoff, with flows remaining high January – May (Figure A-25).

Almost all streams show substantially reduced unimpaired flow during July – October compared to other months. However, Battle Creek (Figure A-7) and Mill Creek (Figure A-21) show relatively high inflows during these dry months, which may indicate contribution from springs.

The valley rim inflows are by far the largest contribution to the unimpaired tributary outflows, however for some locations, surface runoff and stream gain/loss have a large influence on the unimpaired tributary outflow, such as Butte Creek (Figure A-10) and Natomas East Main Drain (Figure A-18). In the case of Natomas East Main Drain, all of its inflow comes from surface runoff.

SVUFM underestimates the unimpaired outflow from many tributaries. As described above in the SVUFM methods section, many of the small tributaries do not receive surface runoff from the valley floor in SVUFM, rather the surface runoff for these tributaries is routed directly to the mainstem Sacramento River. For the watershed as a whole, this does not affect total unimpaired runoff, and in general, rainfall runoff from the valley floor represents a relatively small percent of the total Delta inflow. Rainfall runoff to small creeks would occur during the months with highest inflow, so its inclusion would not likely cause a large percent change in total unimpaired tributary outflow, but it could be a larger percent than what is expected for rivers with large watersheds. SVUFM surface runoff results for Cottonwood Creek (Figure A-15) and Cow Creek (Figure A-16) may be indicative of what rainfall runoff could be for the small creeks that do not have surface runoff arcs.

Almost all tributaries have stream gain/loss arcs. In general, the stream gain/loss component is relatively small compared to total tributary outflow. However, for some small northern creeks, gains during the driest months (June – October) may provide most of the flow in the creek. This occurs for Elder Creek (Figure A-19), Paynes Creek (Figure A-23), and Thomes Creek (Figure A-28).

For all watersheds represented in Figures A-5 through A-30 (Sacramento Valley and Delta eastside Tributaries excluding the Delta), the total average annual rim inflow is approximately 21,500 TAF/yr, whereas the net stream-groundwater interaction (gain/loss) is an average net loss of approximately 900 TAF/yr (4% of the rim inflow), and the surface rainfall runoff from the valley floor is approximately 1,700 TAF/yr (only 8% of the rim inflow). There is very little change in unimpaired hydrology through the Delta as shown in Figure A-31. Nearly all of the unimpaired Delta outflow originates from its tributary inflows and a relatively small amount comes from Delta accretions and stream gain/loss.

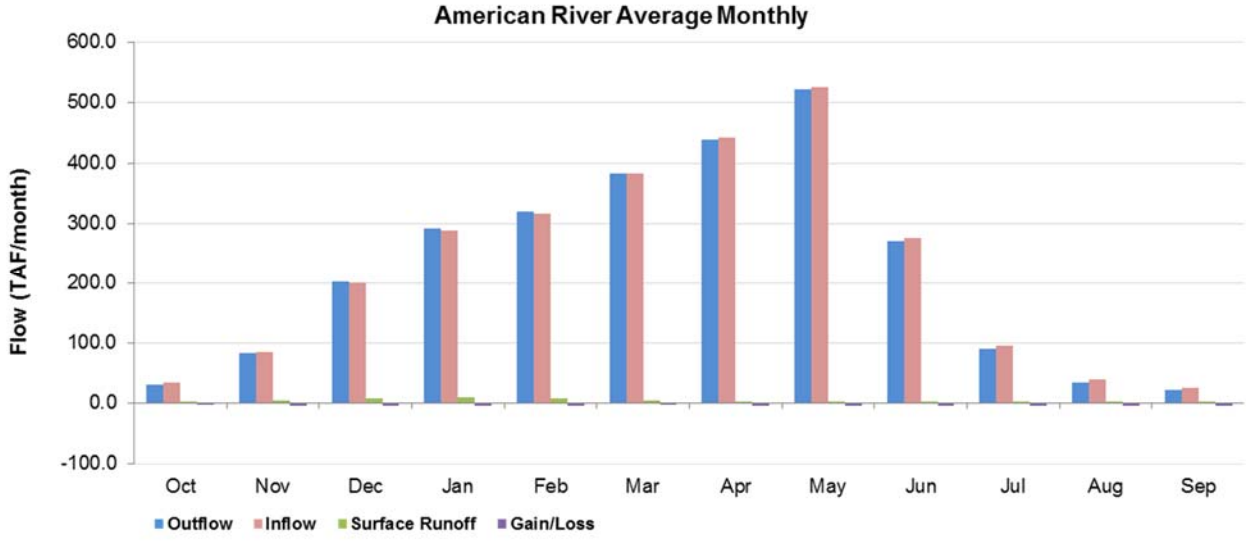

Figure A-5. Monthly Average Unimpaired Flow Components for the American River

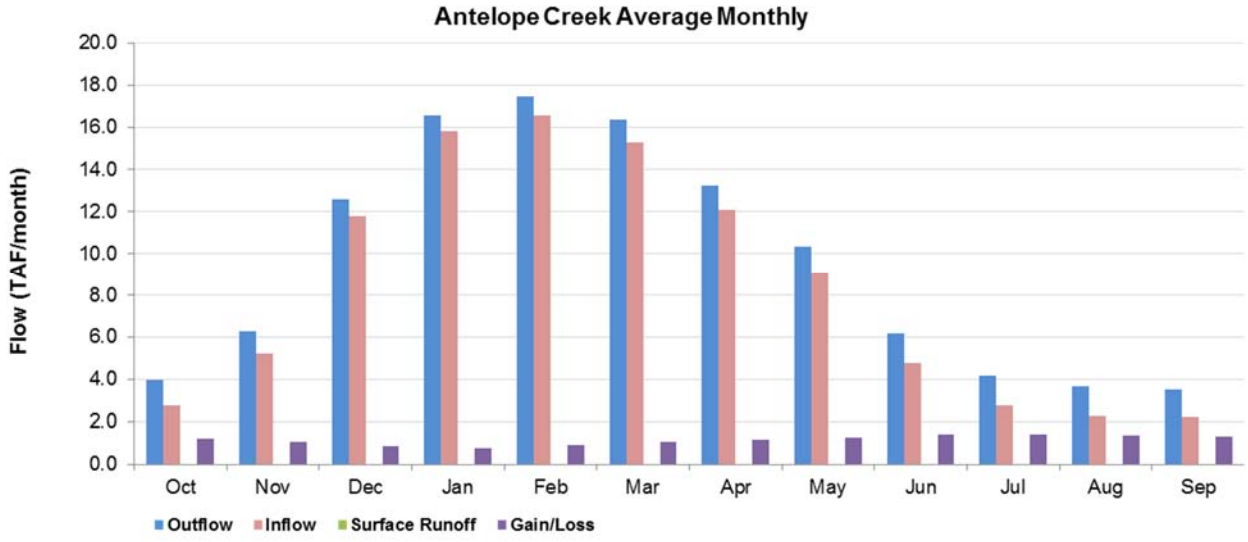

Figure A-6. Monthly Average Unimpaired Flow Components for Antelope Creek

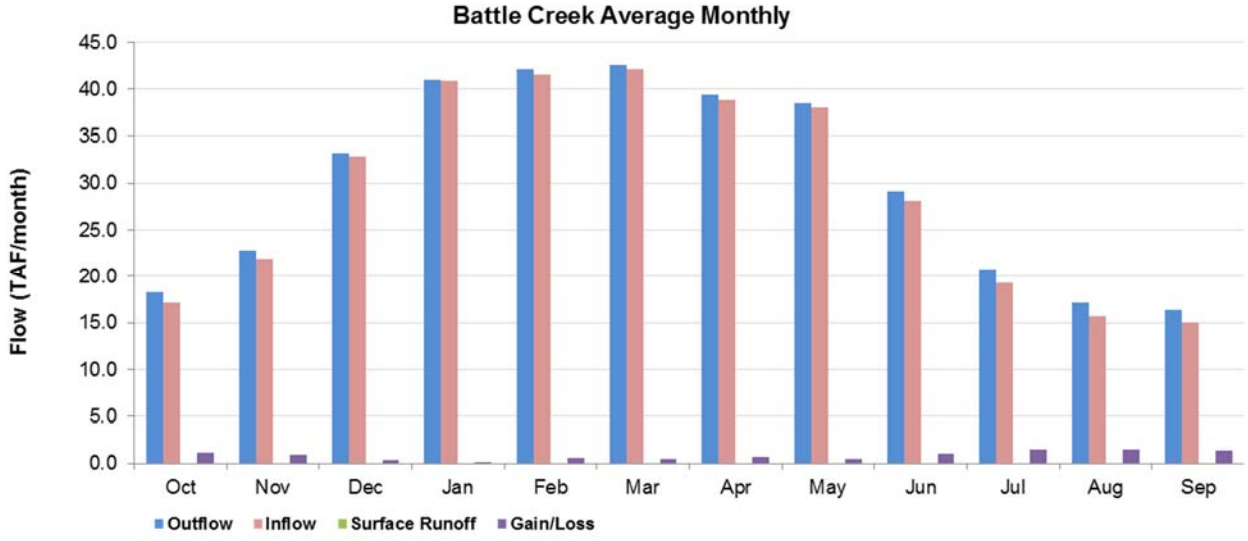

Figure A-7. Monthly Average Unimpaired Flow Components for Battle Creek

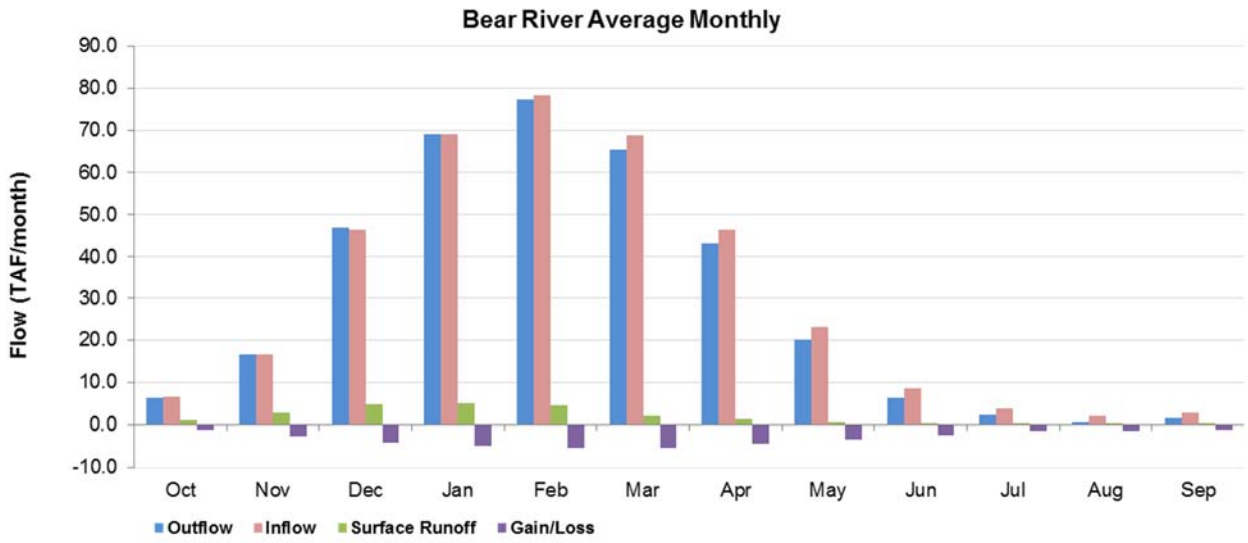

Figure A-8. Monthly Average Unimpaired Flow Components for the Bear River

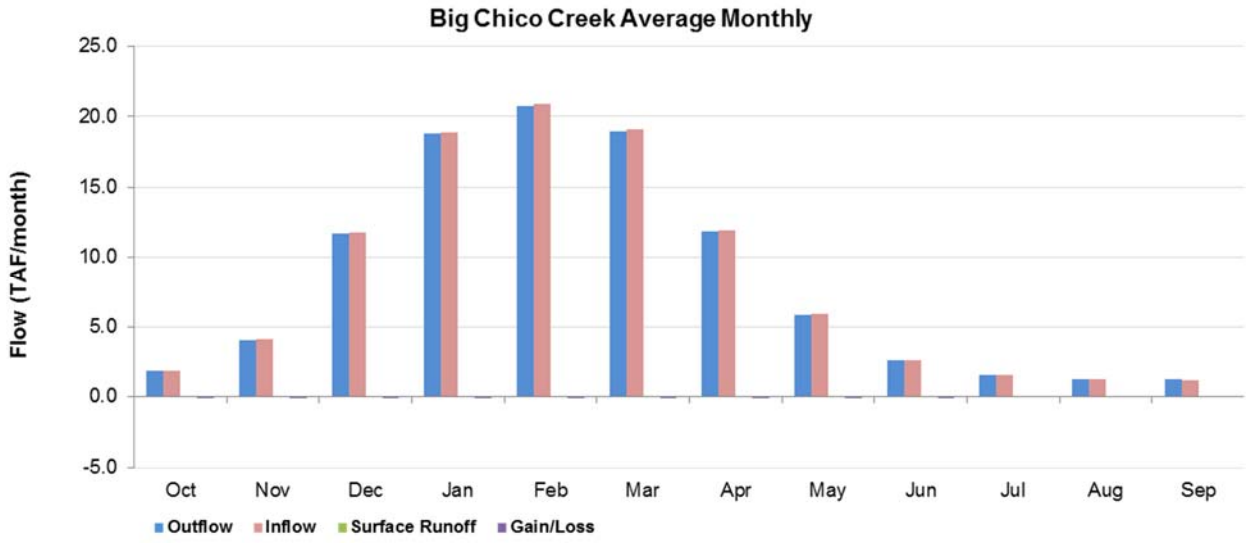

Figure A-9. Monthly Average Unimpaired Flow Components for Big Chico Creek

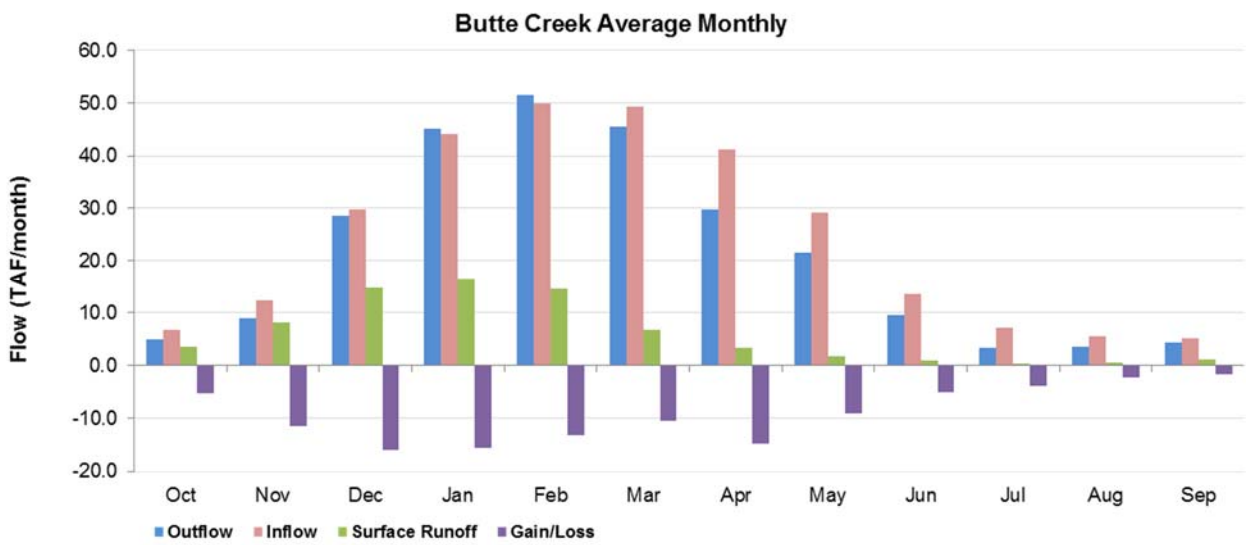

Figure A-10. Monthly Average Unimpaired Flow Components for Butte Creek

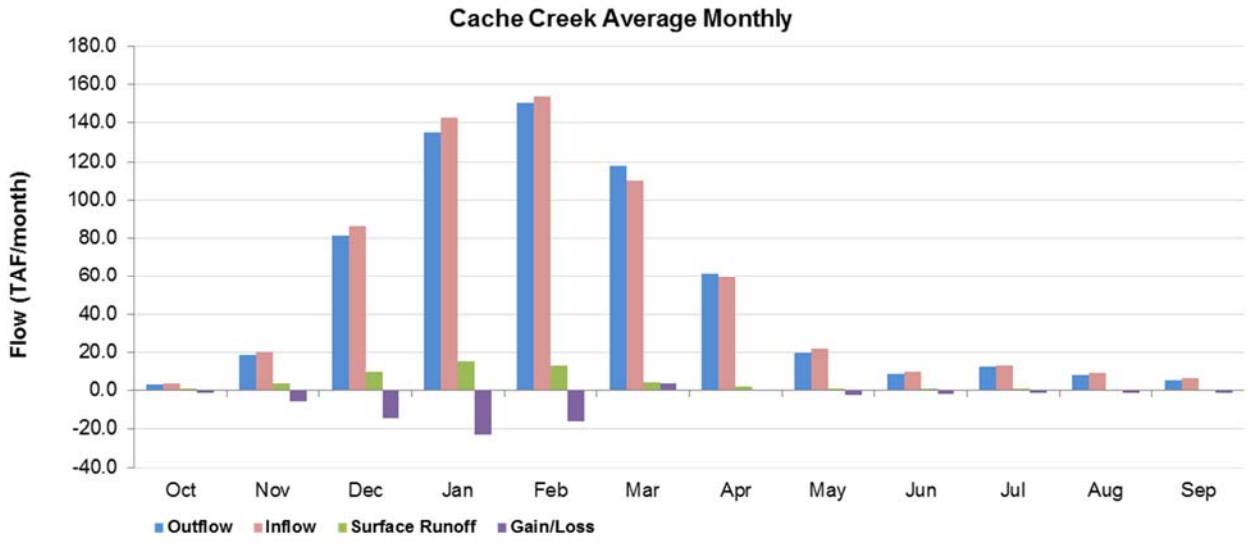

Figure A-11. Monthly Average Unimpaired Flow Components for Cache Creek

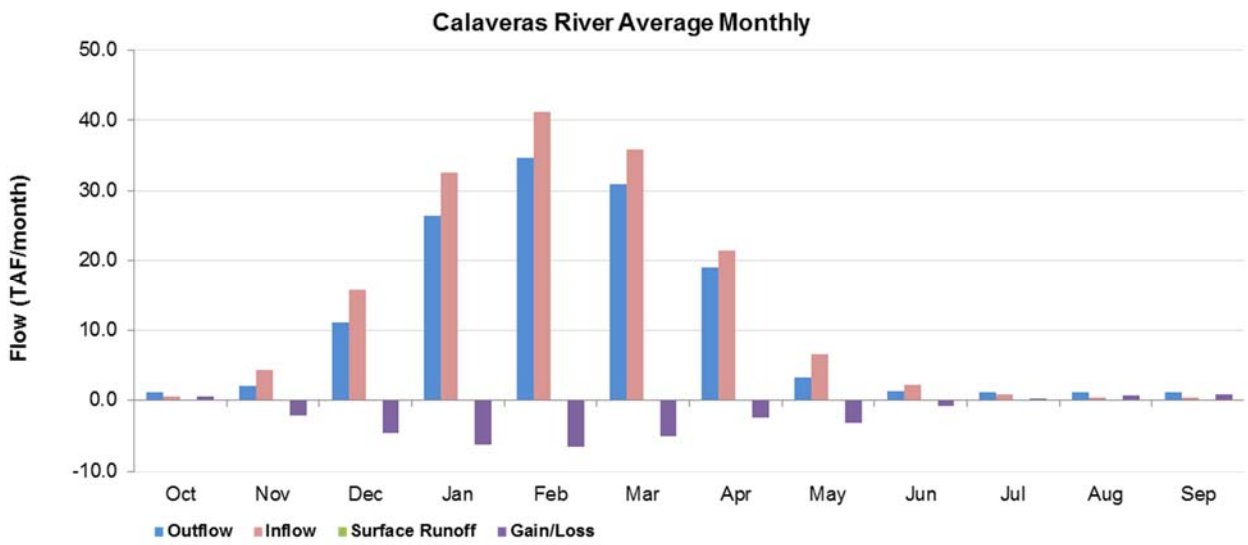

Figure A-12. Monthly Average Unimpaired Flow Components for the Calaveras River

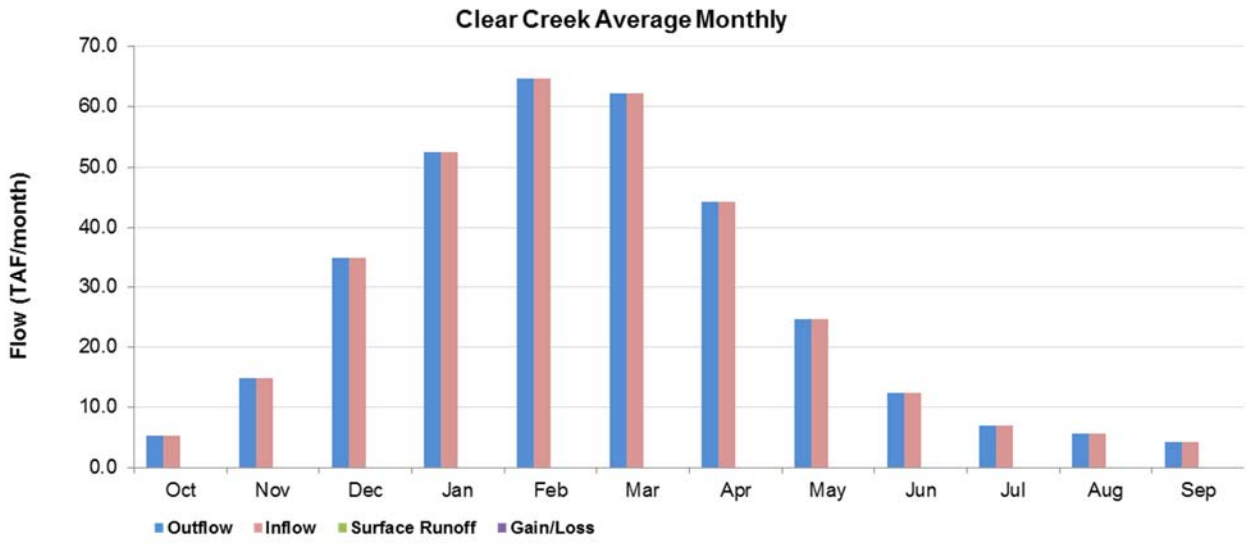

Figure A-13. Monthly Average Unimpaired Flow Components for Clear Creek

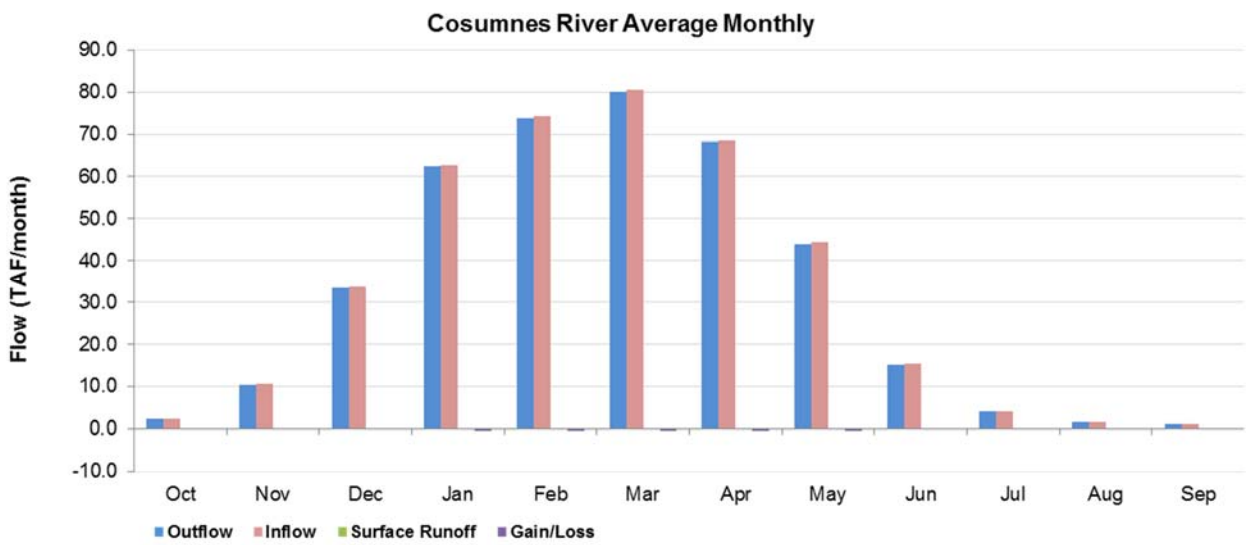

Figure A-14. Monthly Average Unimpaired Flow Components for the Cosumnes River

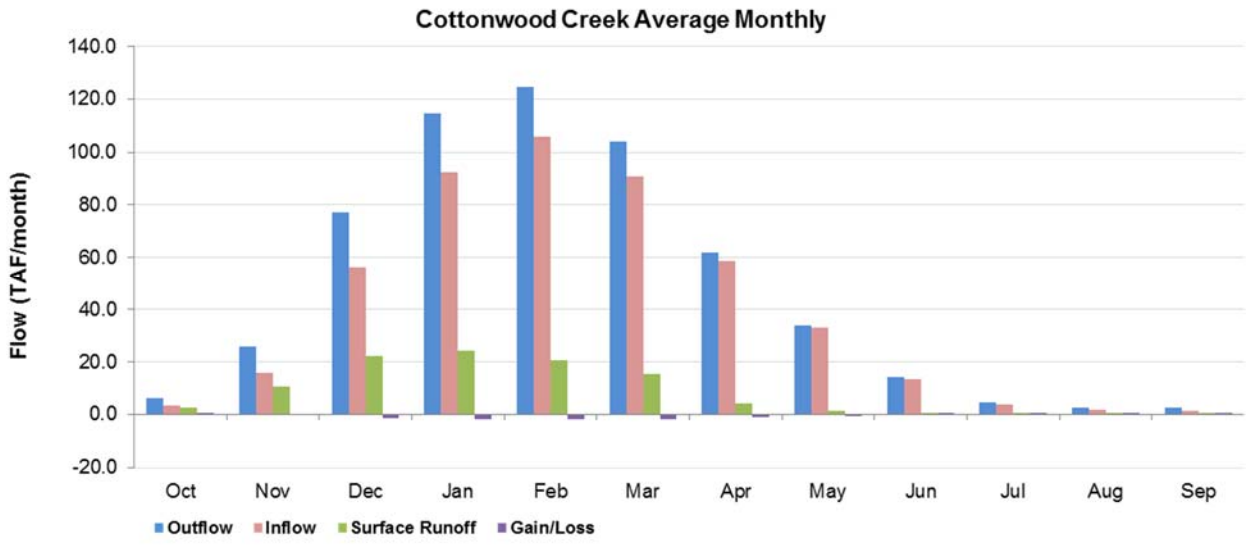

Figure A-15. Monthly Average Unimpaired Flow Components for Cottonwood Creek

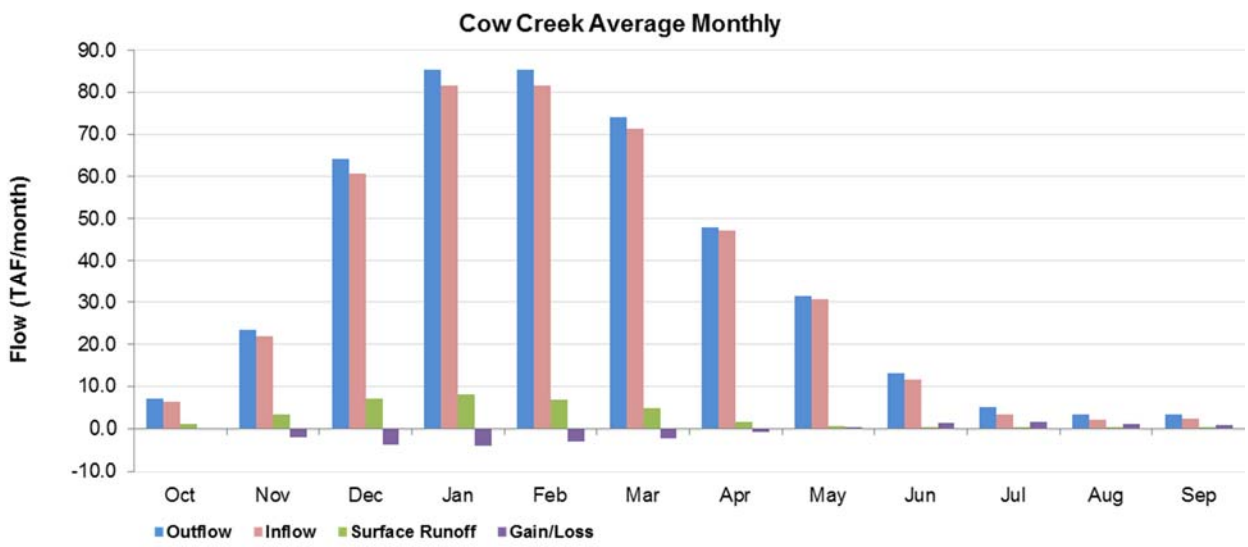

Figure A-16. Monthly Average Unimpaired Flow Components for Cow Creek

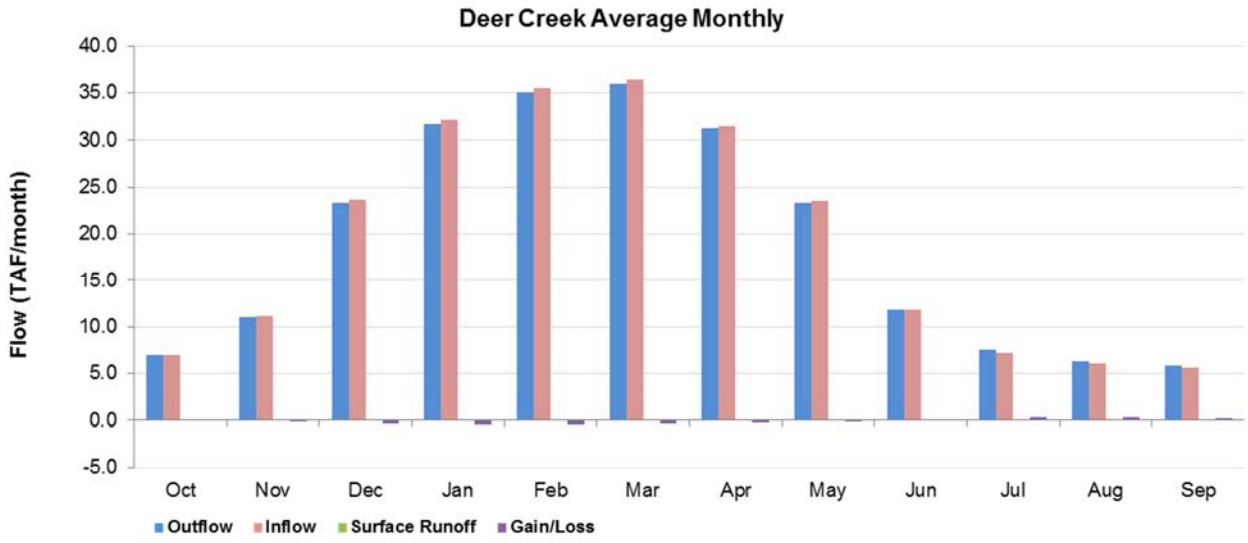

Figure A-17. Monthly Average Unimpaired Flow Components for Deer Creek (tributary of the Sacramento River)

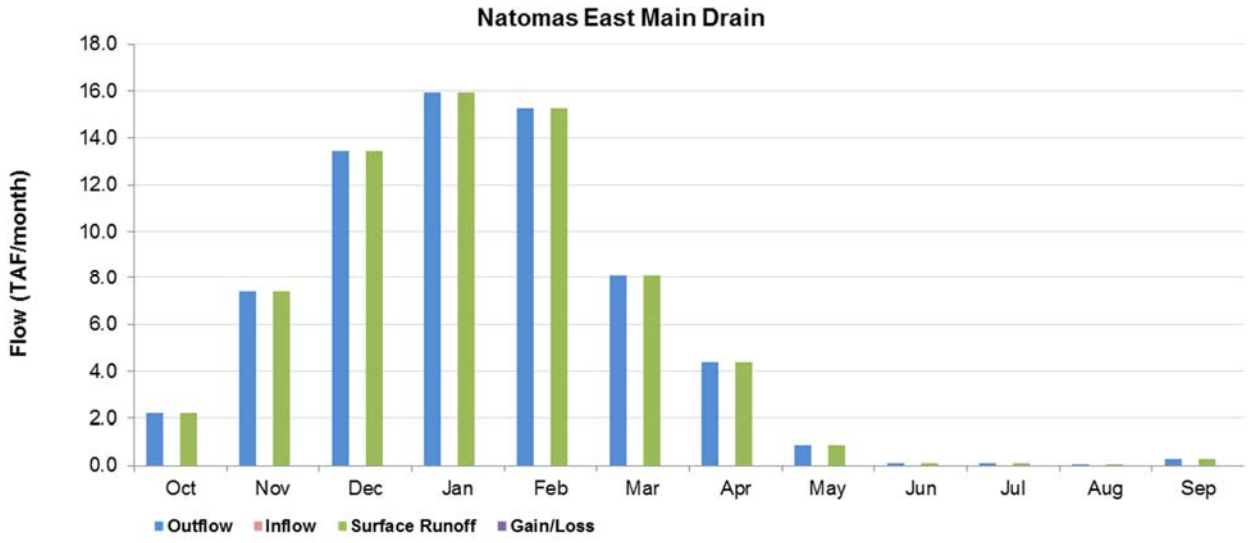

Figure A-18. Monthly Average Unimpaired Flow Components for Natomas East Main Drain

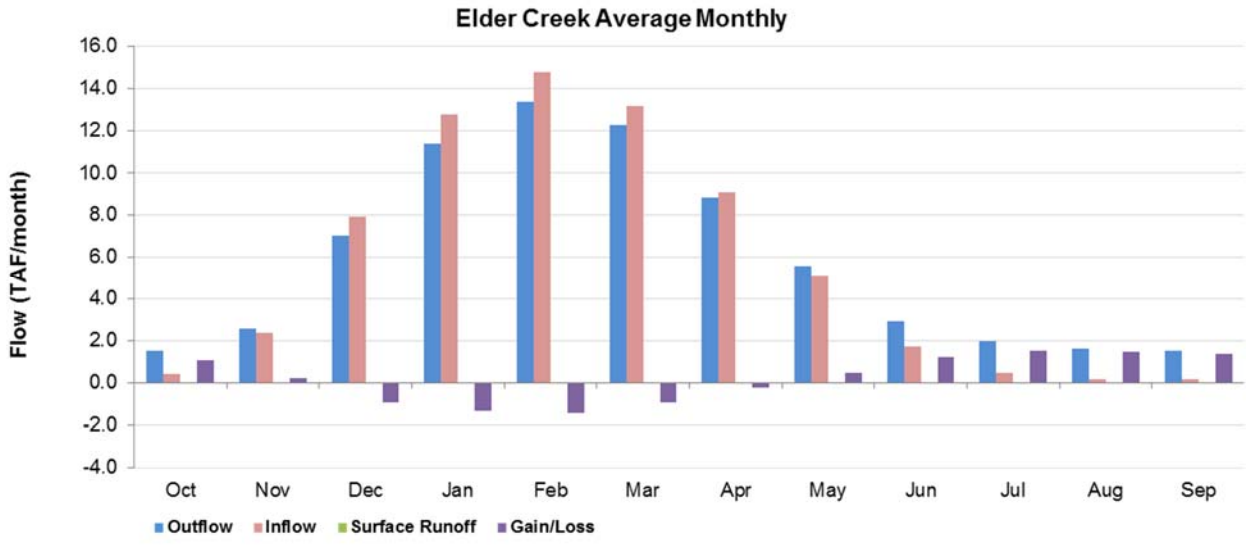

Figure A-19. Monthly Average Unimpaired Flow Components for Elder Creek

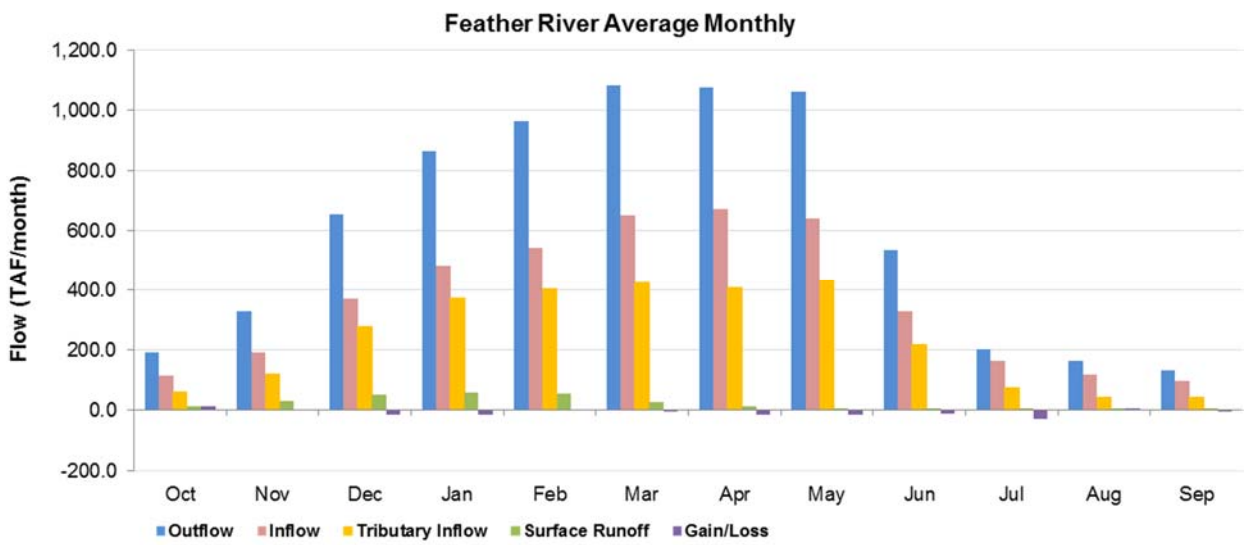

Figure A-20. Monthly Average Unimpaired Flow Components for the Feather River

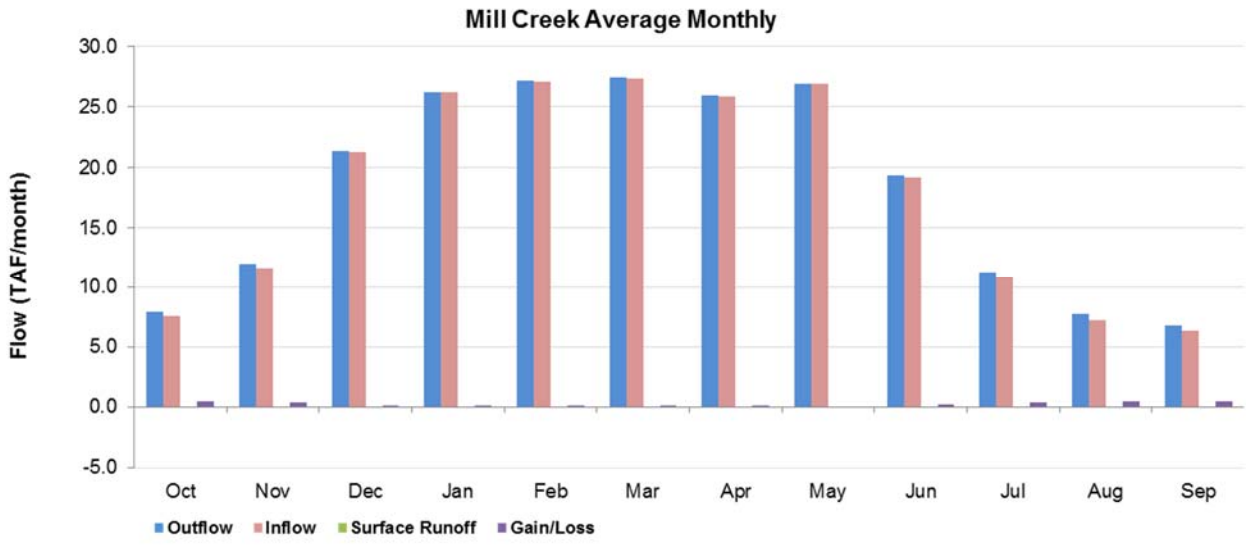

Figure A-21. Monthly Average Unimpaired Flow Components for Mill Creek

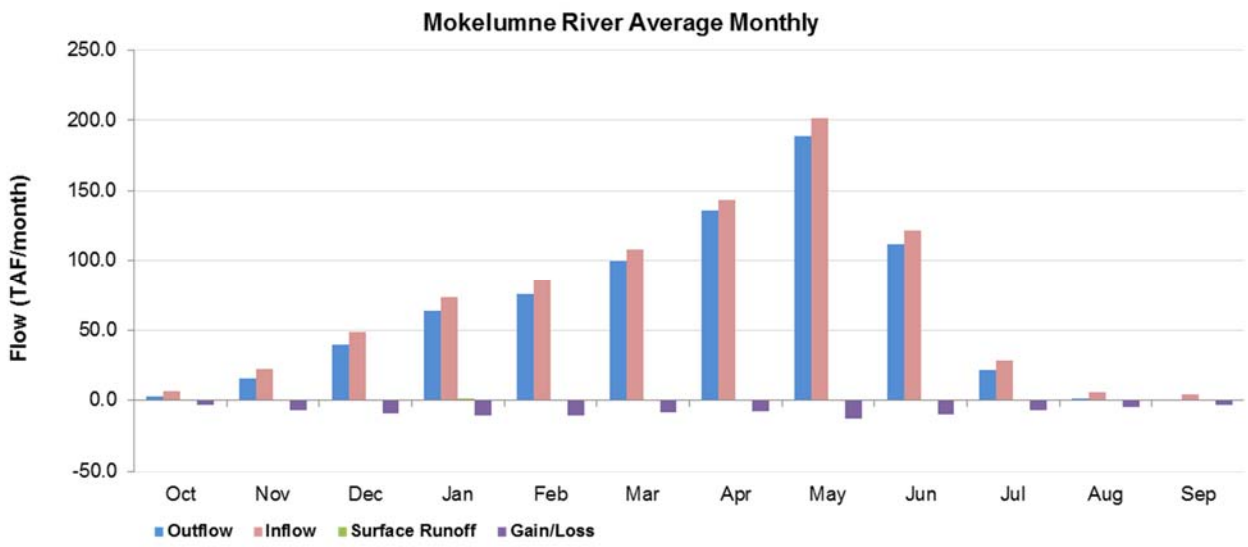

Figure A-22. Monthly Average Unimpaired Flow Components for the Mokelumne River

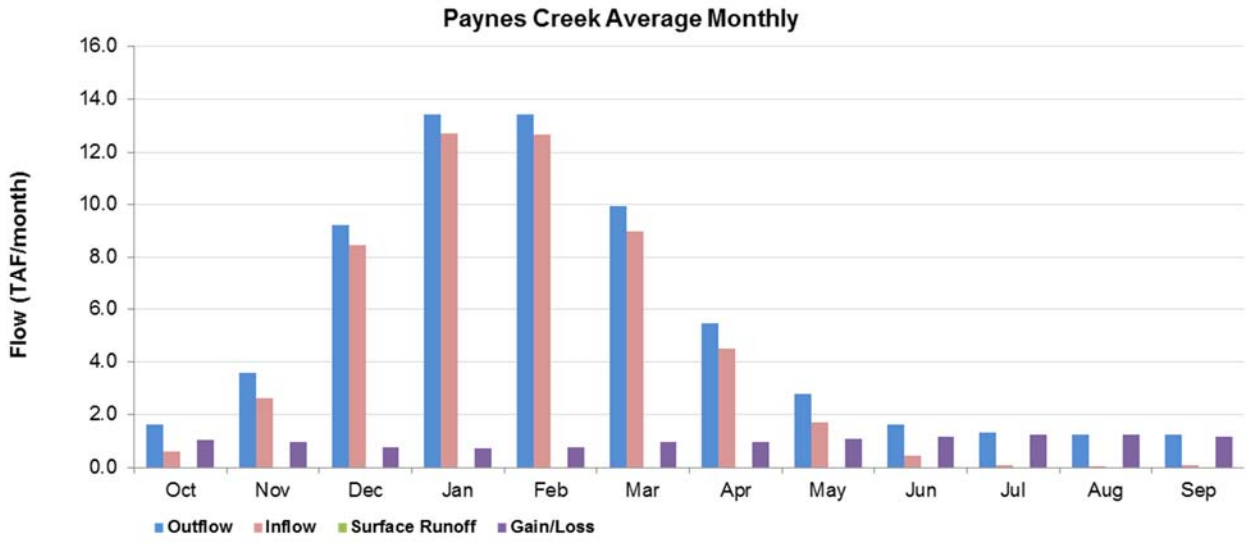

Figure A-23. Monthly Average Unimpaired Flow Components for Paynes Creek

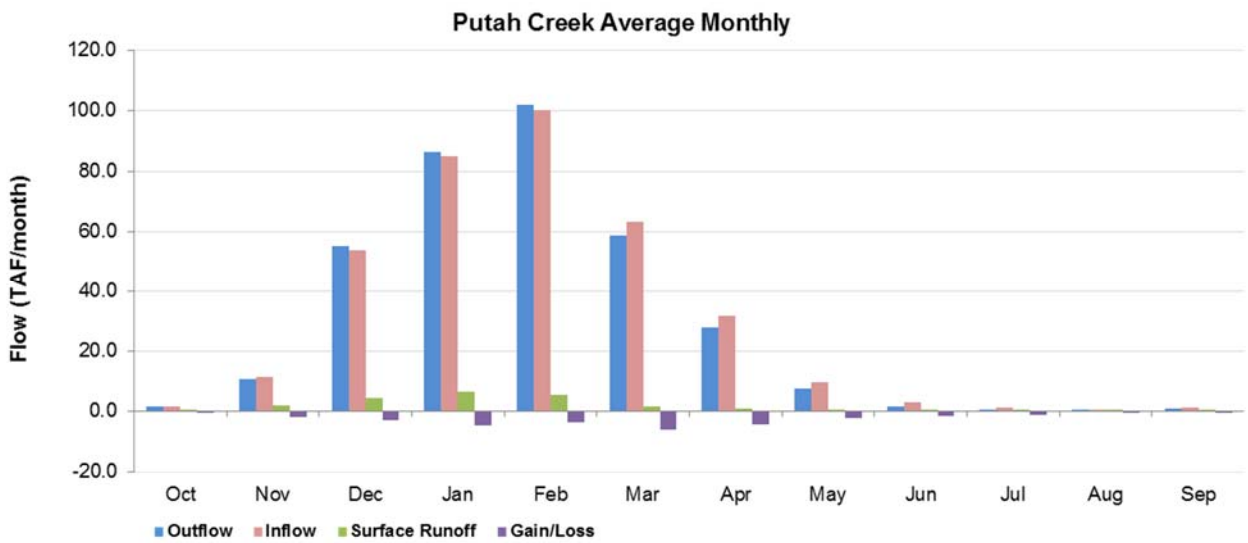

Figure A-24. Monthly Average Unimpaired Flow Components for Putah Creek

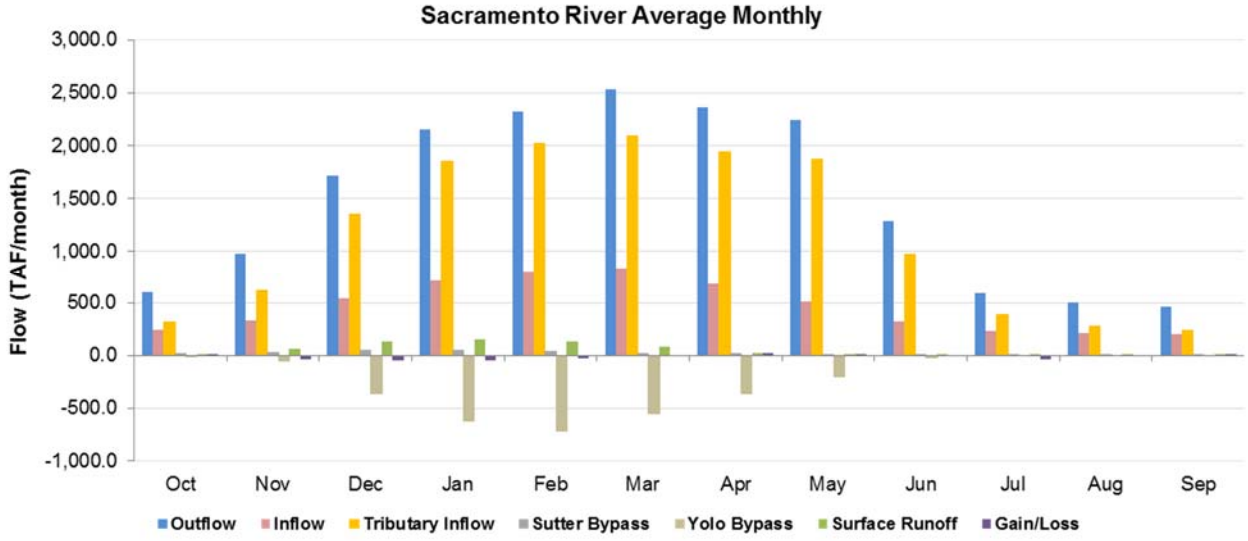

Figure A-25. Monthly Average Unimpaired Flow Components for the Sacramento River at Freeport

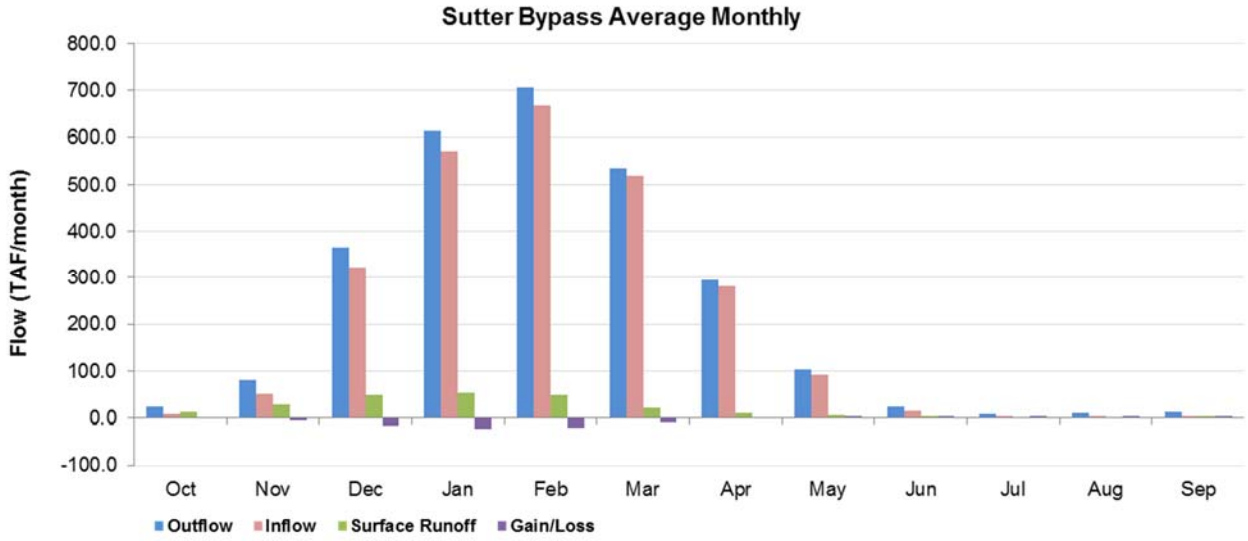

Figure A-26. Monthly Average Unimpaired Flow Components for the Sutter Bypass

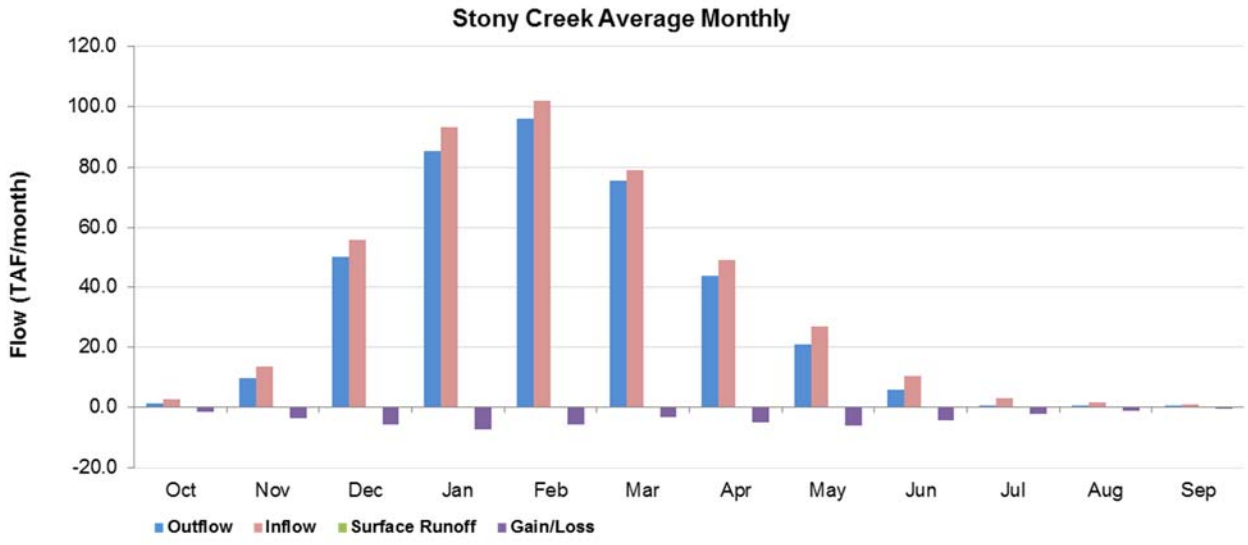

Figure A-27. Monthly Average Unimpaired Flow Components for Stony Creek

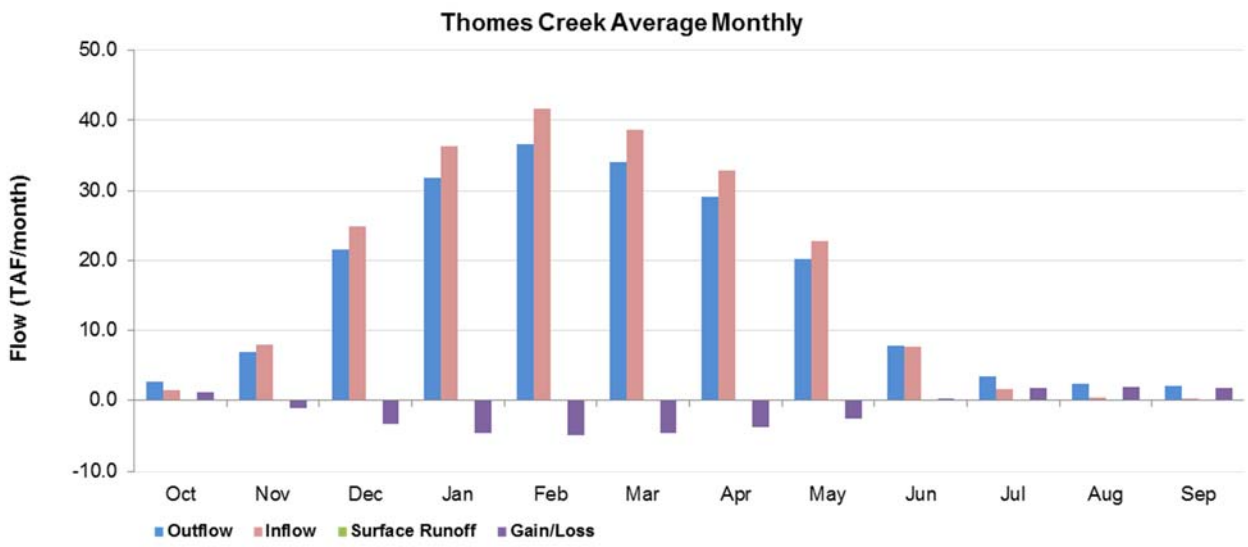

Figure A-28. Monthly Average Unimpaired Flow Components for Thomes Creek

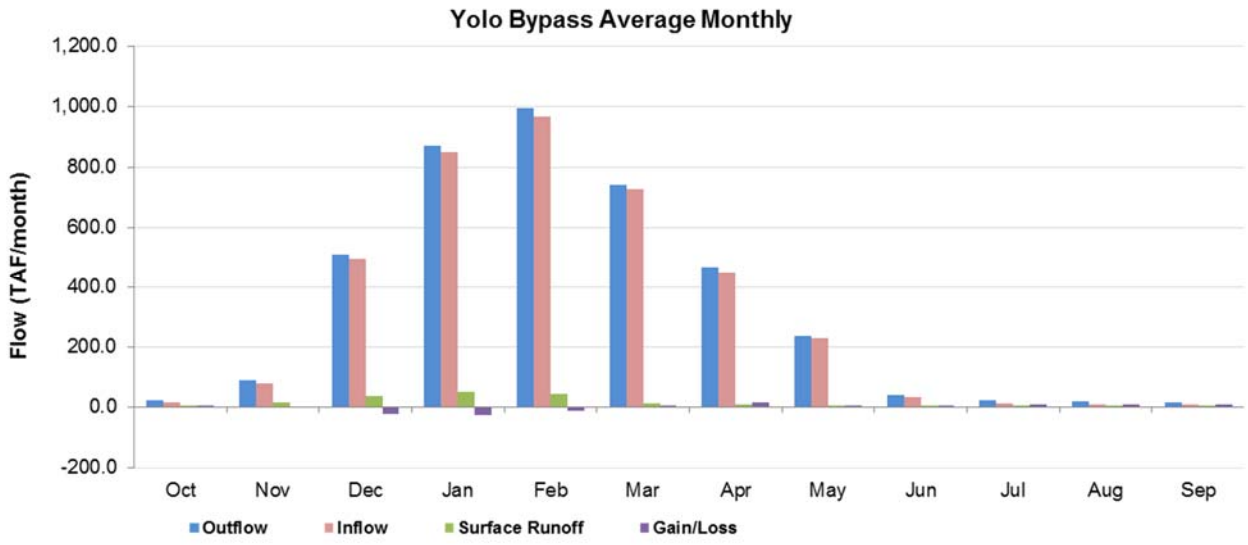

Figure A-29. Monthly Average Unimpaired Flow Components for the Yolo Bypass

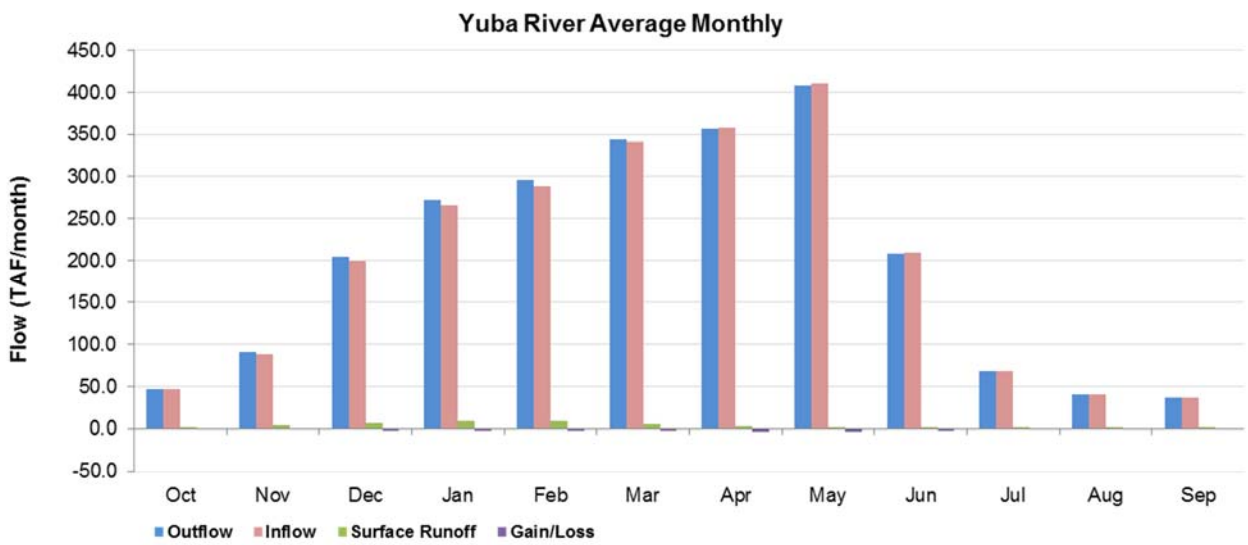

Figure A-30. Monthly Average Unimpaired Flow Components for the Yuba River

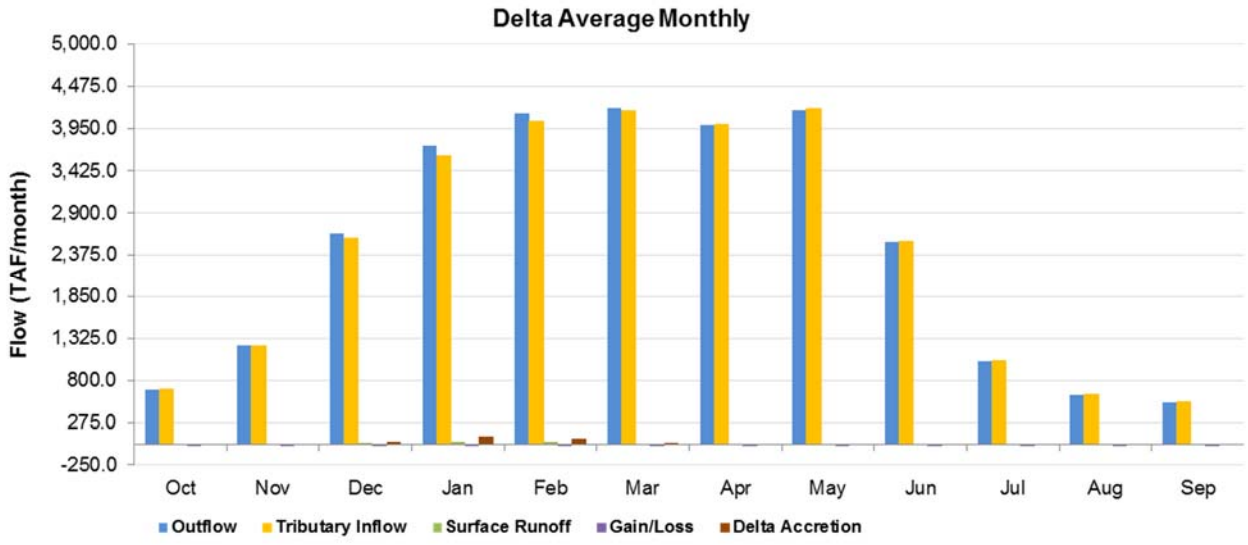

Figure A-31. Monthly Average Unimpaired Flow Components for the Delta

Table A-10. Average Annual Values per Water Year Type

	Mean Annual Values WY 1921–2009					
	All	W	AN	BN	D	C
Flow Component	**TAF**	**TAF**	**TAF**	**TAF**	**TAF**	**TAF**
American River Unimpaired Flows						
American River Outflow	2,684	4,270	3,059	2,184	1,749	1,028
American River Inflow	2,705	4,278	3,073	2,212	1,779	1,060
American River Surface Runoff	35	53	44	30	21	15
American River Stream Gain/Loss	-56	-60	-58	-58	-52	-47
Antelope Creek Unimpaired Flows						
Antelope Creek Outflow	114	177	130	95	74	52
Antelope Creek Inflow	101	162	116	82	61	40
Antelope Creek Surface Runoff	0	0	0	0	0	0
Antelope Creek Stream Gain/Loss	14	15	13	13	13	12
Battle Creek Unimpaired Flows						
Battle Creek Outflow	361	504	385	316	278	222
Battle Creek Inflow	351	497	375	305	266	210
Battle Creek Surface Runoff	0	0	0	0	0	0
Battle Creek Stream Gain/Loss	10	7	10	10	12	12
Bear River Unimpaired Flows						
Bear River Outflow	356	591	435	286	200	109
Bear River Inflow	372	610	454	302	214	120
Bear River Surface Runoff	22	33	26	20	15	11
Bear River Stream Gain/Loss	-39	-52	-45	-36	-29	-23
Big Chico Creek Unimpaired Flows						
Big Chico Creek Outflow	100	166	121	78	57	37
Big Chico Creek Inflow	101	167	122	79	57	37
Big Chico Creek Surface Runoff	0	0	0	0	0	0
Big Chico Creek Stream Gain/Loss	0	-1	-1	0	0	0
Butte Creek Unimpaired Flows						
Butte Creek Outflow	256	458	302	193	123	69
Butte Creek Inflow	293	476	347	236	172	114
Butte Creek Surface Runoff	72	106	83	63	50	36
Butte Creek Stream Gain/Loss	-109	-124	-128	-106	-98	-82
Cache Creek Unimpaired Flows						
Cache Creek Outflow	622	1,098	735	445	322	187
Cache Creek Inflow	636	1,091	740	469	349	219
Cache Creek Surface Runoff	52	84	67	40	27	22
Cache Creek Stream Gain/Loss	-66	-77	-72	-65	-54	-54
Calaveras River Unimpaired Flows						
Calaveras River Outflow	134	233	162	108	65	34
Calaveras River Inflow	162	291	195	130	74	34
Calaveras River Surface Runoff	0	0	0	0	0	0

	Mean Annual Values WY 1921–2009					
	All	W	AN	BN	D	C
Flow Component	**TAF**	**TAF**	**TAF**	**TAF**	**TAF**	**TAF**
Calaveras River Stream Gain/Loss	-29	-58	-33	-23	-9	0
Clear Creek Unimpaired Flows						
Clear Creek Outflow	332	531	414	234	206	141
Clear Creek Inflow	332	531	414	234	206	141
Clear Creek Surface Runoff	0	0	0	0	0	0
Clear Creek Stream Gain/Loss	0	0	0	0	0	0
Cosumnes Unimpaired River Flows						
Cosumnes River Outflow	396	697	475	326	190	90
Cosumnes River Inflow	399	701	478	329	193	92
Cosumnes River Surface Runoff	0	0	0	0	0	0
Cosumnes River Stream Gain/Loss	-3	-4	-3	-3	-3	-2
Cottonwood Creek Unimpaired Flows						
Cottonwood Creek Outflow	571	1,010	682	379	305	180
Cottonwood Creek Inflow	476	853	578	305	248	140
Cottonwood Creek Surface Runoff	102	168	114	79	63	42
Cottonwood Creek Stream Gain/Loss	-7	-11	-10	-6	-5	-2
Cow Creek Unimpaired Flows						
Cow Creek Outflow	443	719	520	359	268	162
Cow Creek Inflow	420	678	495	342	256	153
Cow Creek Surface Runoff	34	54	39	27	21	15
Cow Creek Stream Gain/Loss	-11	-13	-14	-11	-9	-6
Deer Creek Unimpaired Flows						
Deer Creek Outflow	230	369	258	184	144	100
Deer Creek Inflow	231	371	260	185	145	100
Deer Creek Surface Runoff	0	0	0	0	0	0
Deer Creek Stream Gain/Loss	-1	-2	-2	-1	-1	0
Natomas East Main Drain Unimpaired Flows						
Natomas East Main Outflow	68	103	84	61	42	29
Natomas East Main Inflow	0	0	0	0	0	0
Natomas East Main Surface Runoff	68	103	84	61	42	29
Natomas East Main Gain/Loss	0	0	0	0	0	0
Elder Creek Unimpaired Flows						
Elder Creek Outflow	71	120	89	46	39	27
Elder Creek Inflow	68	118	89	44	36	21
Elder Creek Surface Runoff	0	0	0	0	0	0
Elder Creek Stream Gain/Loss	2	2	0	2	4	5
Feather River Unimpaired Flows						
Feather River Outflow	7,246	11,513	8,276	5,947	4,612	2,902
Feather River Inflow	4,357	6,910	4,872	3,557	2,804	1,855
Feather River Surface Runoff	255	384	300	220	166	117

	Mean Annual Values WY 1921–2009					
	All	W	AN	BN	D	C
Flow Component	**TAF**	**TAF**	**TAF**	**TAF**	**TAF**	**TAF**
Feather River Stream Gain/Loss	-117	-102	-124	-119	-102	-161
Feather River Tributary Inflow	2,857	4,299	3,206	2,267	1,723	1,069
Mill Creek Unimpaired Flows						
Mill Creek Outflow	220	321	246	188	157	118
Mill Creek Inflow	217	319	244	185	153	114
Mill Creek Surface Runoff	0	0	0	0	0	0
Mill Creek Stream Gain/Loss	2	1	2	3	3	4
Mokelumne River Unimpaired Flows						
Mokelumne River Outflow	757	1,212	902	650	459	253
Mokelumne River Inflow	848	1,340	997	733	524	311
Mokelumne River Surface Runoff	4	6	5	3	2	1
Mokelumne River Stream Gain/Loss	-95	-134	-100	-86	-68	-60
Paynes Creek Unimpaired Flows						
Paynes Creek Outflow	65	102	73	54	42	27
Paynes Creek Inflow	53	89	60	43	31	16
Paynes Creek Surface Runoff	0	0	0	0	0	0
Paynes Creek Stream Gain/Loss	12	14	12	11	11	11
Putah Creek Unimpaired Flows						
Putah Creek Outflow	352	657	417	232	161	86
Putah Creek Inflow	362	658	424	249	175	103
Putah Creek Surface Runoff	21	34	28	17	11	9
Putah Creek Stream Gain/Loss	-31	-36	-34	-33	-26	-26
Sacramento River Unimpaired Flows						
Sacramento River Outflow	17,761	24,974	20,284	16,032	13,251	9,192
Sacramento River Inflow	5,667	8,067	6,237	4,862	4,216	3,276
Sacramento River Surface Runoff	632	1,045	706	480	383	256
Sacramento River Stream Gain/Loss	-179	-241	-237	-127	-107	-162
Sacramento River Tributary Inflow	13,942	22,231	16,029	11,220	8,842	5,625
Sutter Bypass	241	334	276	217	184	127
Yolo Bypass	-2,894	-7,069	-3,139	-891	-452	-47
Sutter Bypass Unimpaired Flows						
Sutter Bypass Outflow	2,779	6,003	3,200	1,322	841	324
Sutter Bypass Inflow	2,538	5,669	2,924	1,105	658	197
Sutter Bypass Surface Runoff	236	345	271	203	163	123
Sutter Bypass Stream Gain/Loss	-50	-91	-58	-34	-20	-25
Stony Creek Unimpaired Flows						
Stony Creek Outflow	388	730	479	239	166	99
Stony Creek Inflow	436	787	534	285	209	135
Stony Creek Surface Runoff	0	0	0	0	0	0
Stony Creek Stream Gain/Loss	-49	-57	-55	-46	-43	-36

	Mean Annual Values WY 1921–2009					
	All	W	AN	BN	D	C
Flow Component	**TAF**	**TAF**	**TAF**	**TAF**	**TAF**	**TAF**
Thomes Creek Unimpaired Flows						
Thomes Creek Outflow	198	336	237	139	116	71
Thomes Creek Inflow	217	361	259	155	130	78
Thomes Creek Surface Runoff	0	0	0	0	0	0
Thomes Creek Stream Gain/Loss	-18	-25	-22	-16	-14	-7
Yolo Bypass Unimpaired Flows						
Yolo Bypass Outflow	4,023	9,069	4,492	1,689	1,021	385
Yolo Bypass Inflow	3,868	8,824	4,292	1,568	935	319
Yolo Bypass Surface Runoff	173	276	224	137	93	74
Yolo Bypass Stream Gain/Loss	-19	-31	-24	-17	-7	-8
Yuba River Unimpaired Flows						
Yuba River Outflow	2,373	3,708	2,771	1,981	1,523	960
Yuba River Inflow	2,354	3,668	2,745	1,969	1,518	965
Yuba River Surface Runoff	41	63	49	34	26	17
Yuba River Stream Gain/Loss	-22	-22	-23	-22	-20	-21
Delta Unimpaired Flows						
Delta Outflow	29,529	46,421	34,121	24,334	18,770	12,401
Delta Tributary Inflow	29,258	45,859	33,720	24,158	18,708	12,432
Delta Surface Runoff	145	227	189	122	82	57
Delta Gain/Loss	-148	-138	-148	-154	-149	-162
Delta Accretion	251	403	327	193	133	106

WY = Water Year
W = Wet
AN = Above normal
BN = Below normal
D = Dry
C = Critical

A.5 Citations

Department of Water Resources (DWR) 2007. California Central Valley Unimpaired Flow Data. Fourth Edition – Draft. Available: http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/water_quality_control_planning/docs/sjrf_spprtinfo/dwr_2007a.pdf.

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