Appendix A7
Modeling Approaches Used to Develop Unimpaired Watershed Hydrology

A7.1 Background

This appendix describes the Sacramento Water Allocation Model (SacWAM) approaches used to develop unimpaired watershed hydrology. 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. As such, this estimate represents something different than the "natural flow" that would have occurred absent human land use and infrastructure for water supply and flood control.

Previous work on unimpaired flows in the Sacramento River watershed has been completed by the California Department of Water Resources (DWR) Division of Flood Management and Bay-Delta Office to provide estimates throughout the Central Valley. DWR's unimpaired flow estimates, also termed "full natural flow," are produced by removing the effect of reservoir storage, water transfers, and diversions from historical observed flows. Land use, levees, flood bypasses, and weirs are all assumed to exist as they do now (^DWR 2007b, ^2016c). DWR's Bay-Delta Office has produced unimpaired flow estimates for 24 locations in the Central Valley for October 1921 through September 2014 on a monthly basis, summarized in a report titled *Estimates of Natural and Unimpaired Flows for the Central Valley of California: WY 1922-2014* (^DWR 2016c). DWR's Division of Flood Management also posts daily and monthly estimates of full natural flow (FNF) on the California Data Exchange Center (CDEC) website. The FNF estimates are produced on a monthly basis for over 70 locations around the state. FNF estimates also are produced on a daily basis for 19 locations, including 9 locations within the Sacramento/Delta (Table A7-1). Methods for estimating monthly FNF were developed by DWR's Division of Flood Management and are summarized in a report titled *Derivation of Unimpaired Runoff in the Cooperative Snow Surveys Program* (DWR 2016c).

Table A7-1. California Data Exchange Center Daily Full Natural Flow Locations

CDEC Station Name	CDEC Station ID	Tributary
Trinity Lake	CLE	Trinity River
Sacramento River at Bend Bridge	BND	Sacramento River
Shasta Dam (USBR)	SHA	Sacramento River
Whiskeytown Dam (USBR)	WHI	Clear Creek
Oroville Dam	ORO	Feather River
Yuba River near Smartville	YRS	Yuba River
Lake Natoma (Nimbus Dam)	NAT	American River
Cosumnes River at Michigan Bar	MHB	Cosumnes River
Mokelumne-Mokelumne Hill	MKM	Mokelumne River
New Hogan Lake	NHG	Calaveras River
Goodwin Dam	GDW	Stanislaus River
New Melones Reservoir	NML	Stanislaus River

CDEC Station Name	CDEC Station ID	Tributary
Tuolumne River-La Grange Dam	TLG	Tuolumne River
New Exchequer-Lake McClure	EXC	Merced River
San Joaquin River below Friant	SJF	San Joaquin River
Pine Flat Dam	PNF	Kings Rive
Terminus Dam	TRM	Kaweah River
Success Dam	SCC	Tule River
Isabella Dam	ISB	Kern River

Source: SacWAM results (Appendix A1)

DWR's Division of Flood Management is also the lead agency coordinating the California Cooperative Snow Surveys Program, which produces the DWR Bulletin 120 publication. Bulletin 120 is issued each February, March, April, and May; it contains forecasts of the volume of seasonal runoff from major watersheds in California and summarizes precipitation, snowpack, reservoir storage, and runoff in regions of California. These estimates are used to calculate indices of water availability such as water year types and the Eight River Index. The Eight River Index refers to the sum of the unimpaired runoff as published in DWR Bulletin 120 for the following locations: Sacramento River flow at Bend Bridge, near Red Bluff; Feather River, total inflow to Oroville Reservoir; Yuba River flow at Smartville; American River, total inflow to Folsom Reservoir; Stanislaus River, total inflow to New Melones Reservoir; Tuolumne River, total inflow to Don Pedro Reservoir; Merced River, total inflow to Exchequer Reservoir; and San Joaquin River, total inflow to Millerton Lake. These estimates are considered accurate higher in the watershed but are not as accurate lower in the valley floor and Delta. DWR's methods for estimating unimpaired flow in the valley floor and Delta do not explicitly account for any stream-groundwater interaction and take a simplified approach to estimating surface runoff from ungaged streams (^DWR 2007b, ^2016c).

The methods used by DWR do not provide unimpaired flow estimates at the bottom of each watershed, except for Sacramento Valley Total Outflow, which includes an estimate of valley floor runoff. To provide unimpaired flow estimates at the bottom of the tributary watersheds, 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 Sacramento/Delta tributaries do not have gages near the confluences, and it is very difficult to estimate stream gains and losses to groundwater. Many Sacramento/Delta tributaries have active, real-time streamflow data available through CDEC (Table A7-2). For many tributaries, additional CDEC streamflow gages are available for the upper watershed, upstream of major storage reservoirs; those gages are not identified in Table A7-2 below. Additional historical streamflow records (i.e., discontinued gages) or stage gage records are available through CDEC for several locations. Several tributaries (Antelope Creek, Bear Creek, Mokelumne River, Paynes Creek, and Stony Creek) currently lack an active telemetered CDEC streamflow record for the lower watershed, but historical streamflow records or real-time river stage information are available for some of these tributaries. Table A7-2 excludes any streamflow gage records that are not available on CDEC.

Table A7-2. Active Telemetered Streamflow Gages on Sacramento/Delta Tributaries Available through California Data Exchange Center

Tributary	Agency	CDEC Station ID	CDEC Station Name
American River	USGS	AFO	American River at Fair Oaks
Battle Creek	USGS/DWR	BAT	Battle Creek
Battle Creek	DWR	BNF	North Fork Battle Creek near Manton
Battle Creek	DWR	BAS	South Fork Battle Creek near Manton
Bear River	DWR	BPG	Bear River at Pleasant Grove Road
Bear River	USGS/DWR	BRW	Bear River near Wheatland
Bear River	DWR	CFW	Bear River at Camp Far West Dam
Big Chico Creek	DWR	BIC	Big Chico Creek near Chico
Butte Creek	USGS	BCK	Butte Creek near Chico
Butte Creek	DWR	BCD	Butte Creek near Durham
Cache Creek	USGS	CCY	Cache Creek at Yolo
Cache Creek	USGS/DWR	RUM	Cache Creek at Rumsey Bridge
Clear Creek	USGS/Reclamation	IGO	Clear Creek near Igo
Cosumnes River	USGS	MHB	Cosumnes River at Michigan Bar
Cottonwood Creek	USGS	CWA	Cottonwood Creek Auxiliary Gage
Cow Creek	USGS/DWR	COW	Cow Creek near Millville
Deer Creek	DWR	DVD	Deer Creek below Stanford-Vina Dam
Deer Creek	USGS	DCV	Deer Creek near Vina
Elder Creek	USGS	ECP	Elder Creek near Paskenta
Feather River	DWR	GRL	Feather River near Gridley
Feather River	DWR	FSB	Feather River at Boyd's Landing above Star Bend
Mill Creek	USGS	MLM	Mill Creek near Los Molinos
Mill Creek	DWR	MCH	Mill Creek below Hwy 99
Putah Creek	USGS	PUT	Putah Creek near Winters
Sacramento River	USGS/DWR	VON	Sacramento River at Verona
Sacramento River	DWR	FRE	Sacramento River at Fremont Weir
Sacramento River	USGS	WLK	Sacramento River below Wilkins Slough
Sacramento River	DWR	TIS	Sacramento River at Tisdale Weir
Sacramento River	USGS/DWR	COL	Sacramento River at Colusa
Sacramento River	DWR	CLW	Sacramento River at Colusa Weir
Sacramento River	DWR	MLW	Sacramento River at Moulton Weir
Sacramento River	DWR	BTC	Sacramento River at Butte City
Sacramento River	DWR	ORD	Sacramento River at Ord Ferry-Main Channel
Sacramento River	DWR	VNO	Sacramento River at Vina East Bank O/F
Sacramento River	USGS/ Reclamation	KWK	Sacramento River at Keswick

Tributary	Agency	CDEC Station ID	CDEC Station Name
Thomes Creek	DWR	THO	Thomes Creek at Paskenta
Yuba River	PG&E	YRS	Yuba River near Smartville
Yuba River	USGS	MRY	Yuba River near Marysville
Yuba River	DWR	YPB	Yuba River at Parks Bar Bridge

Source: SacWAM results (Appendix A1)

In addition to the DWR unimpaired flow products discussed above, DWR's Bay-Delta Office has recently published estimates of the natural flow that would have resulted if the precipitation and valley floor inflow hydrology of the water year 1922–2014 record had occurred in a natural landscape, unaltered by humans (^DWR 2016c). This involves making assumptions about pre-development groundwater accretions, distribution, and evapotranspiration of wetland and riparian vegetation; channel configurations; and detention of overbank flows—all of which differ from the current physical condition and land use of the watershed (^DWR 2016c).

The study described here was undertaken to better estimate unimpaired flows at the confluences of the tributaries in the Sacramento River watershed, at locations on the mainstem Sacramento River, and at the mouths of the Delta eastside tributaries. Unimpaired flows were estimated with SacWAM utilizing the unimpaired mode. This appendix describes the model assumptions and provides detailed unimpaired modeling results.

A7.2 Methods

SacWAM version 1.1, which assumes existing conditions, was modified as described in Sections A7.2.1 through A7.2.5 to generate estimates of unimpaired flow. A full description of model assumptions can be found in *Sacramento Valley Water Allocation Model, Model Documentation* (SacWAM documentation) (SWRCB 2019).

Draft modeling approaches used to develop unimpaired watershed hydrology are described in the 2016 *Working Draft Scientific Basis Report for New and Revised Flow Requirements on the Sacramento River and Tributaries, Eastside Tributaries to the Delta, Delta Outflow, and Interior Delta Operations* (SWRCB 2016) and the 2017 *Final Scientific Basis Report in Support of New and Modified Requirements for Inflows from the Sacramento River and its Tributaries and Eastside Tributaries to the Delta, Delta Outflows, Cold Water Habitat, and Interior Delta Flows* (Scientific Basis Report) (^SWRCB 2017). As described in the 2017 Scientific Basis Report, methods used to estimate unimpaired flows have been overhauled based on comments received and newly available models; however, the basic monthly mass balance approach remains. The improvements include further development of upper watershed unimpaired inflows, improved estimates of stream gains and losses to groundwater, dynamic calculation of valley floor rainfall runoff, and the use of SacWAM for network calculations.

The upper watershed unimpaired rim inflows account for the largest component of the unimpaired flows at the tributary confluences. These flows developed by DWR and their consultants have been extended through 2015 and have been further refined since the previous draft. These methods are described in Chapter 6 of the SacWAM documentation (SWRCB 2019).

The stream gains and losses have been updated to include a dynamic calculation based on streamflow and season. Previously, the stream gains and losses were estimated as a preprocessed time series based on results from a California Central Valley Groundwater-Surface Water Simulation Model (C2VSIM) "current conditions" run. Additional information on C2VSIM is available in the

User's Manual for the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) (DWR 2016b). SacWAM uses relationships of stream gains and losses to streamflow that are based on a C2VSIM current conditions simulation (SWRCB 2019). The updated method results in greater seasonal variation in stream gains and losses and a slight overall reduction in losses across the entire valley. These methods are described in Chapter 6 of the SacWAM documentation (SWRCB 2019).

Surface runoff estimated by SacWAM is dynamically calculated based on climate conditions, vegetation, and soil moisture, whereas previous estimates used in the unimpaired flow calculations were preprocessed based on results from the CalSimHydro model. In the unimpaired simulation in SacWAM, the surface runoff is lower than the current conditions. During summer months, on the unimpaired scenario, this is due to the reduction in applied water because no water is being diverted from the rivers and streams, and groundwater pumping has been limited to the existing conditions scenario. During winter months, in the unimpaired scenario, more rainfall infiltrates into the ground due to the drier soil conditions at the end of the growing season. The drier soil conditions are a result of less water being applied to the fields as no water is being diverted from the rivers and streams. In the unimpaired scenario, more rainfall is applied to the soil moisture deficit than in the existing conditions simulation, resulting in less runoff to the rivers. Previous estimates did not account for changes in soil moisture and, therefore, likely overestimated surface runoff. Additionally, previous estimates did not account for runoff covering a large non-gaged area surrounding the Delta. Runoff from this region is now included in the estimates of Delta inflow using SacWAM.

A7.2.1 SacWAM Key Assumptions

The key assumptions in SacWAM are settings that the user can easily modify to change the type of hydrologic simulation. More detail about key assumptions can be found in Chapter 9 of the SacWAM documentation (SWRCB 2019). To simulate unimpaired flows, the two changes to key assumptions were to turn off operations and to limit groundwater pumping.

A7.2.1.1 Turn Off Simulation of Operations

The key assumption called *Simulate Operations* was set to 0 for the unimpaired simulation. By turning off operations, SacWAM does not allow any diversions to occur or any storage in reservoirs, with two exceptions. These exceptions include storage in Clear Lake, discussed in Section A7.2.5, *Unimpaired San Joaquin Inflow at Vernalis*, and diversions to some Delta islands, discussed in Section A7.2.6, *Additional Model Assumptions*. By setting the simulate operations switch to 0, unimpaired San Joaquin River inflows at Vernalis are assumed by default. More details about unimpaired San Joaquin River flows are discussed in Section A7.2.7, *Model Limitations*.

A7.2.1.2 Limits on Groundwater Pumping

The key assumption called *Constrain GW Pumping* limits the maximum flow through each transmission link from a groundwater source to a demand site. The maximum limit can be set by the user as a time series for each transmission link defined in a comma-separated value (csv) input file. For this unimpaired flow study, the maximum groundwater pumping for each transmission link was set equal to the result from the existing conditions simulation. This ensured that groundwater pumping would not increase in response to a reduced surface water supply. The only effect this assumption has on streamflow is to prevent the relatively small amount of return flows associated with groundwater pumping from increasing.

A7.2.2 SacWAM User-Defined Linear Programming Constraints

The user-defined linear programing constraints (UDCs) in SacWAM are hard constraints primarily used to simulate operational logic, such as the Coordinated Operations Agreement and Old and Middle River reverse flows. For the unimpaired flow simulation, all of the UDCs are turned off except for the flow splits at all of the weirs, Knights Landing Ridge Cut, and Georgiana Slough.

A7.2.3 Clear Lake Evaporation

Clear Lake on Cache Creek is a large, natural, shallow lake that has relatively high evaporative losses compared to the mean annual inflow to the stream. Because Clear Lake is a natural lake with very little control on the reservoir elevation, minimal storage in this lake has been included in the unimpaired flow simulation. Initial storage, top of conservation, and top of inactive were all assumed to be 840 thousand acre-feet (TAF), which is the minimum operable level of storage in the existing conditions simulation. This constraint on Clear Lake does not allow storage to increase above 840 TAF but does allow evaporation to reduce storage below 840 TAF. During dry periods, when Clear Lake storage is reduced below 840 TAF, no water leaves the lake until storage has increased to 840 TAF.

A7.2.4 Delta Depletions

Many Delta islands are below sea level, causing seepage from Delta channels into the islands. In these areas, water is continuously pumped out of the islands even when diversions are not occurring. Even with unimpaired conditions, seepage water would be available for consumptive use by vegetation. To account for depletions in areas below sea level, some Delta diversions were included in the unimpaired simulation. Figure A7-1 shows the percentages of each Delta demand unit that is below sea level (A_50_NA1/Sacramento River RM 041 is 3% below sea level; A_50_NA2/Sacramento River RM 017 is 38%; A_50_NA3/Sacramento River RM 000 is 60%; A_50_NA4/Mokelumne River RM 004 is 47%; A_50_NA5/San Joaquin River RM 026 is 43%; A_50_NA6/San Joaquin River RM 013 is 54%; andA_50_NA7/Old River RM 027 is 32%). These percentages were applied to each month of the preprocessed Delta depletion time series, resulting in a total annual average Delta depletion of 31 percent of existing conditions.

A7.2.5 Unimpaired San Joaquin Inflow at Vernalis

Assumptions for unimpaired inflow from the San Joaquin River came from DWR's *California Central Valley Unimpaired Flow Data* and *Estimates of Natural and Unimpaired Flows for the Central Valley of California: Water Years 1922–2014* reports (^DWR 2007b, ^2016c). The San Joaquin Valley unimpaired runoff estimate using these methods suffers from issues similar to those discussed previously for the Sacramento Valley, such as not including stream gains and losses to groundwater. However, this is the best available estimate of unimpaired flows from the San Joaquin River at this time.

A7.2.6 Additional Model Assumptions

Land use was assumed to be the same as under existing conditions. Because no surface water diversions are in the unimpaired flow simulation and groundwater pumping is assumed not to increase, the crop demand for water may not always be met.

Stream–groundwater interaction is a dynamic calculation based on streamflow and season; therefore, the stream gains and losses associated with the unimpaired simulation differ from those associated with existing conditions. For example, losses to groundwater are generally higher in spring in the unimpaired flow simulation due to higher flows.

A7.2.7 Model Limitations

There are currently no abstractions of water from streams due to riparian vegetation. Many river channels in the Sacramento Valley are lined with levees and riprap to manage erosion and floods. This flood development reduces the riparian vegetation demands; however, there are many channels in the Sacramento Valley where riparian vegetation could theoretically be reducing the streamflow, and these areas have not been explicitly considered in this study.

Consideration was given to route surface runoff and return flows to the correct watershed as accurately as possible; consequently, flow estimates were considered most accurate at the confluences of each tributary. Along each tributary, unimpaired flows may not be accurate due to the spatial resolution and the consolidated representation of small stream and surface runoff arcs.

SacWAM calculates unimpaired flows on a monthly time step that underestimates flood peaks and can overestimate flows in severely dry conditions by averaging flows over an entire month. This should be considered, especially when examining the unimpaired flow results of flood bypasses and weir spills.

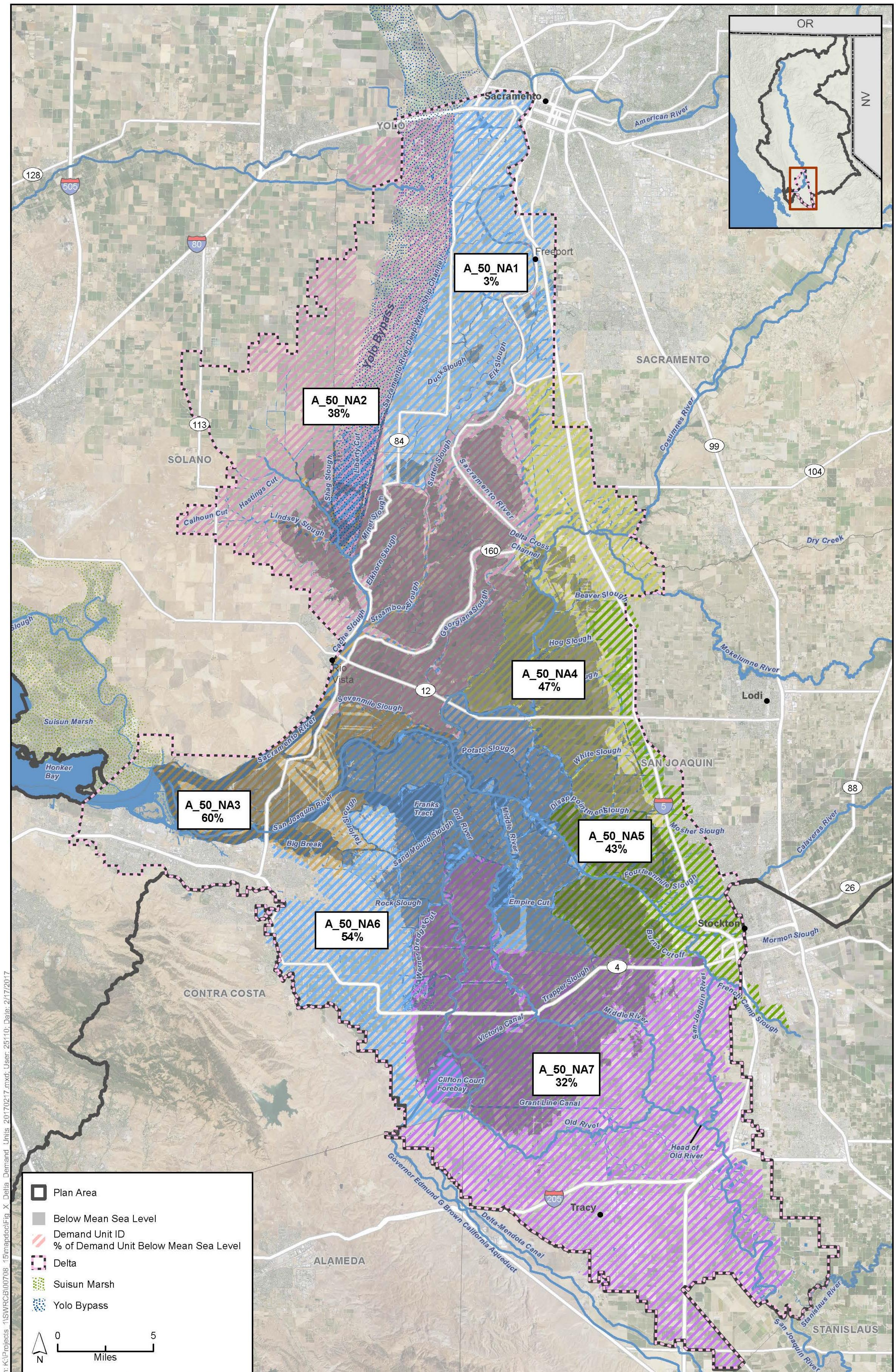


Figure A7-1. Demand Units within the Delta

A7.3 Results

Figures A7-2 through A7-27 show the monthly average unimpaired results for the Sacramento Valley and Delta eastside tributaries, excluding the Delta. Results are shown for each tributary and flow component and are presented in alphabetical order by tributary. The flow components include rim inflow, surface runoff, tributary inflow, accretions, depletions, evaporation, groundwater gain/loss, weir outflow, and outflow at tributary confluences. Table A7-3 shows the annual average unimpaired results by water year type.

Figures for the Feather River, the Sacramento River at Freeport, and the Yolo Bypass (Figures A7-16, A7-22, and A7-26, respectively) provide examples of how flow from multiple tributaries may contribute to unimpaired flows at some locations. Tributary inflow for the confluence of the Feather River shown in Figure A7-16 comes from the Bear River (Figure A7-5), Yuba River (Figure A7-27), Honcut Creek, and Jack Slough. Tributary inflow for the Sacramento River at Freeport (Figure A7-22) comes from all the upstream tributaries and includes outflow from the Sutter Bypass. “Inflows” (rim inflows) in Figure A7-22 are the Shasta Reservoir rim inflows. The weir spills, such as to the Yolo Bypass, shown in Figure A7-22 are negative because they represent water that leaves the Sacramento River system upstream of Freeport and does not return until downstream of Freeport. Note that the Yolo Bypass flows shown in Figure A7-22 are of smaller magnitude than the Yolo Bypass flows shown in Figure A7-26 because the Yolo Bypass flows in Figure A7-22 do not include water from Putah and Cache Creeks, whereas the Yolo Bypass flows shown in Figure A7-26 include Putah and Cache Creeks. Urban return flows are minimal in the unimpaired scenario and have been included in the tributary inflow component.

There are pattern differences between rain-fed and snowmelt-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 A7-2), the Feather River (Figure A7-16), the Mokelumne River (Figure A7-18), and the Yuba River (Figure A7-27). Most other streams show a pattern expected for streams that are fed by rainfall, with peak flows 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 A7-22). Almost all streams show substantially reduced unimpaired flow during July–October compared to other months. However, Battle Creek (Figure A7-4) and Mill Creek (Figure A7-17) show relatively high inflows during these dry months, which may indicate contribution from springs in the upper watershed.

The valley rim inflows are by far the largest contribution to the unimpaired tributary outflows; however, for some locations, surface runoff has a large influence on the unimpaired tributary outflow, such as Butte Creek (Figure A7-7) and Natomas East Main Drain (Figure A7-19). In the case of Natomas East Main Drain, most of its inflow comes from surface runoff.

Almost all tributaries have stream gains or losses. 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 A7-15), Paynes Creek (Figure A7-20), and Thomes Creek (Figure A7-25).

For all watersheds represented in Figures A7-2 through A7-27, the total average annual rim inflow is approximately 22,800 TAF per year (TAF/yr), whereas the net stream-groundwater interaction (gain/loss) is an average net loss of approximately 880 TAF/yr (3 percent of the rim inflow), and the surface rainfall runoff from the valley floor is approximately 1,290 TAF/yr (5 percent of the rim inflow). There is very little change in unimpaired hydrology through the Delta, as shown in Figure A7-28. Nearly all of the unimpaired Delta outflow originates from its tributary inflows, and a relatively small amount comes from Delta accretions and is lost to depletions.

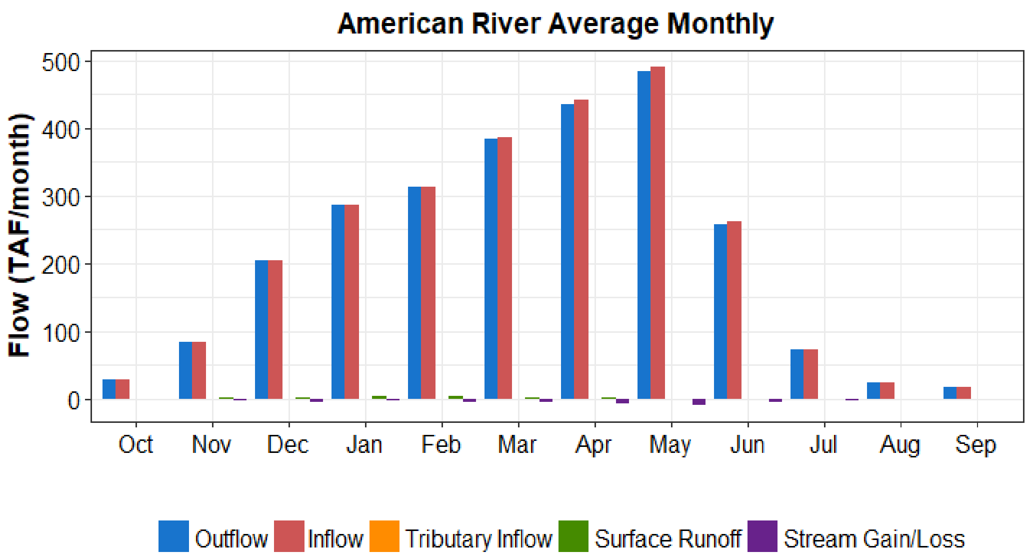


Figure A7-2. Monthly Average Unimpaired Flow Components for the American River

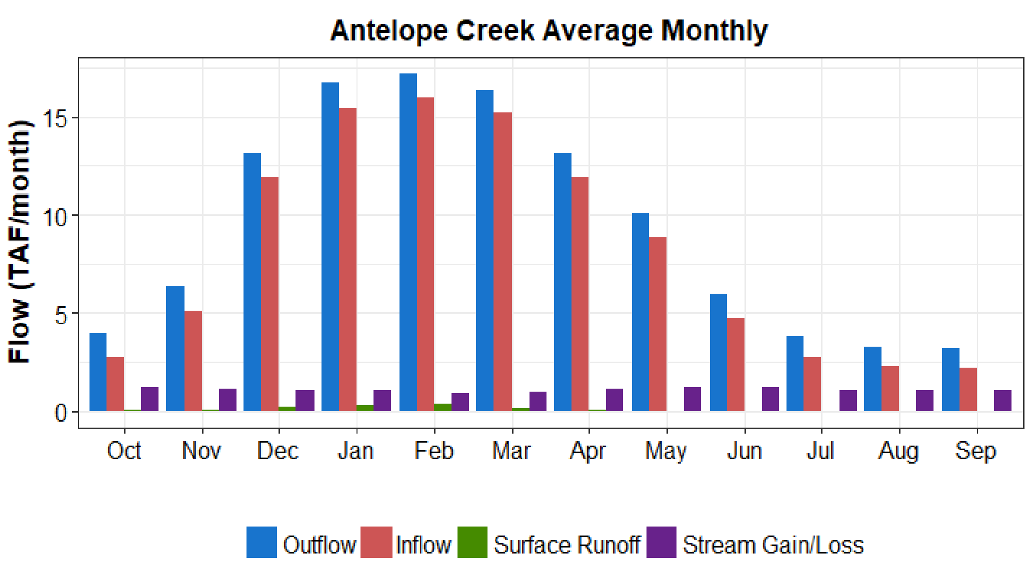


Figure A7-3. Monthly Average Unimpaired Flow Components for Antelope Creek

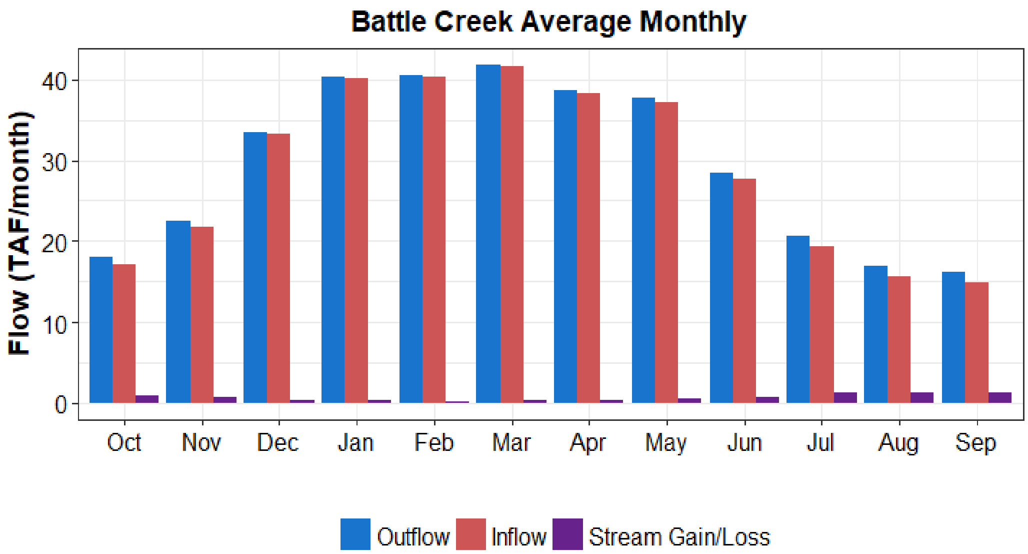


Figure A7-4. Monthly Average Unimpaired Flow Components for Battle Creek

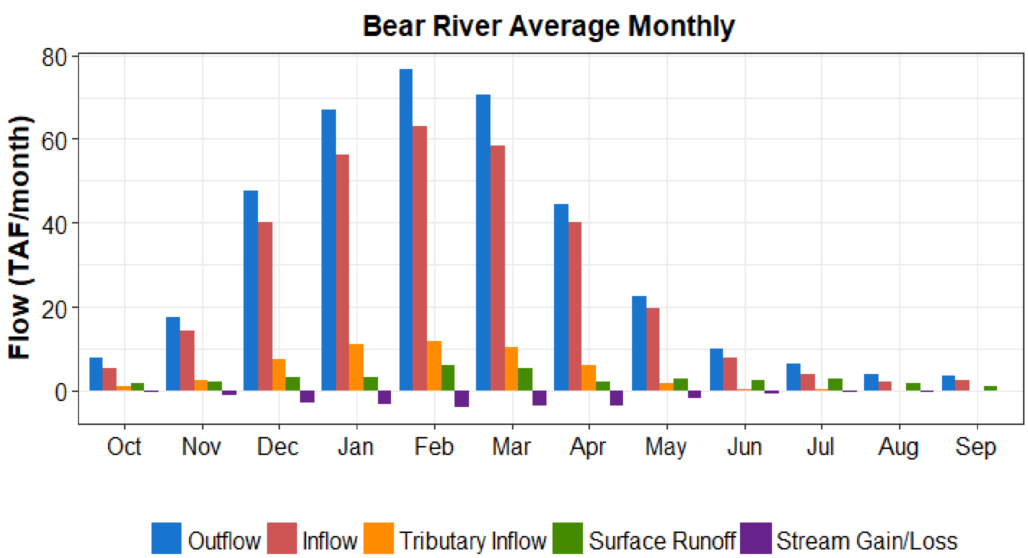


Figure A7-5. Monthly Average Unimpaired Flow Components for Bear River

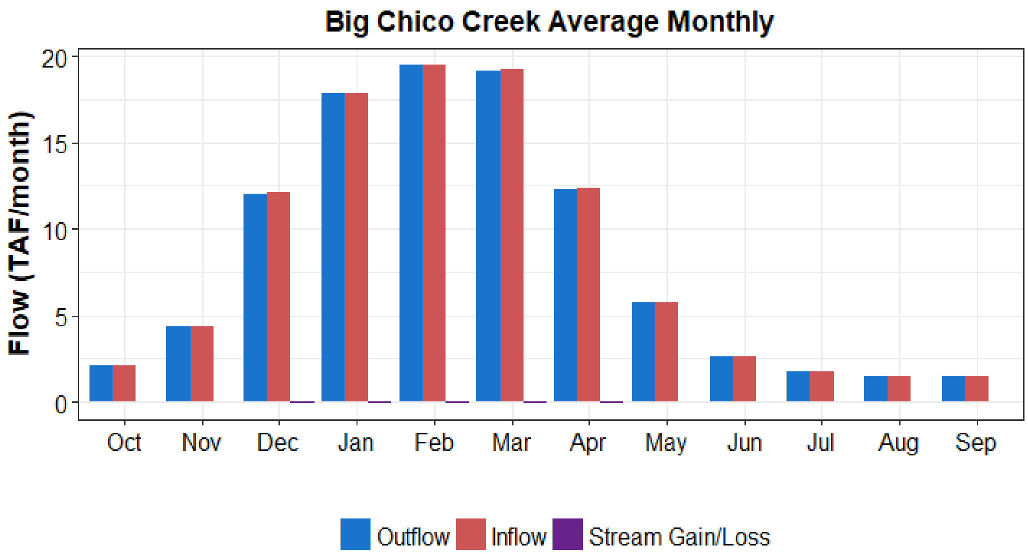


Figure A7-6. Monthly Average Unimpaired Flow Components for Big Chico Creek

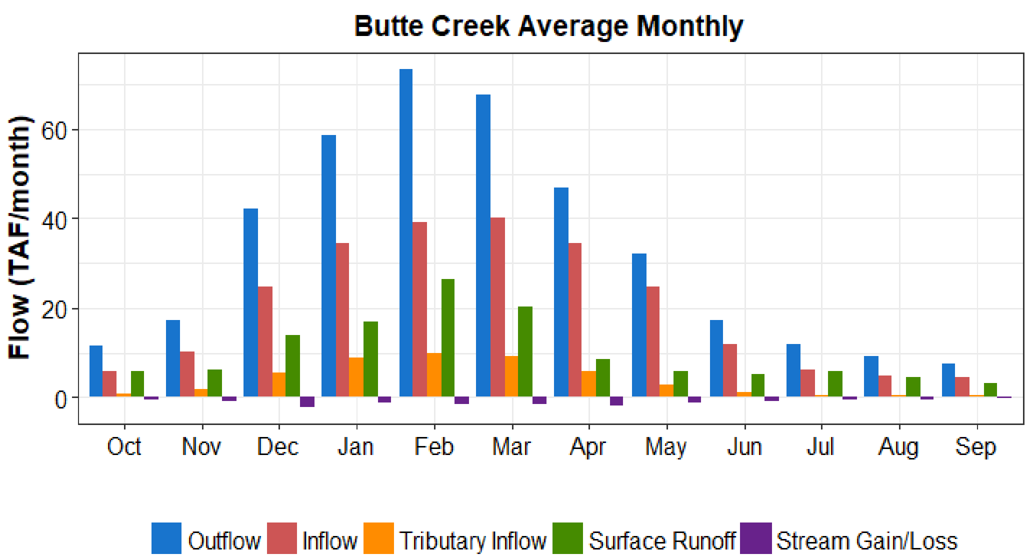


Figure A7-7. Monthly Average Unimpaired Flow Components for Butte Creek

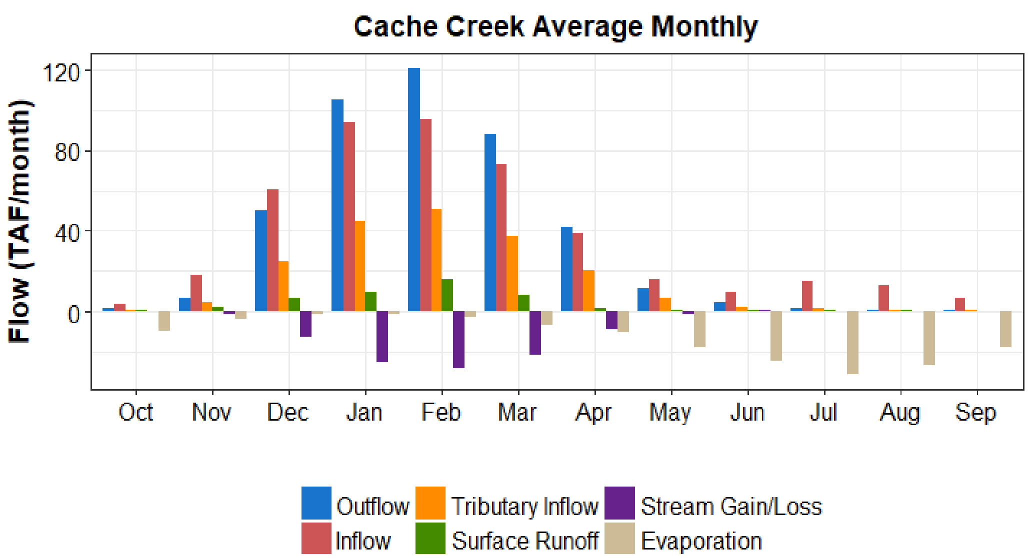


Figure A7-8. Monthly Average Unimpaired Flow Components for Cache Creek

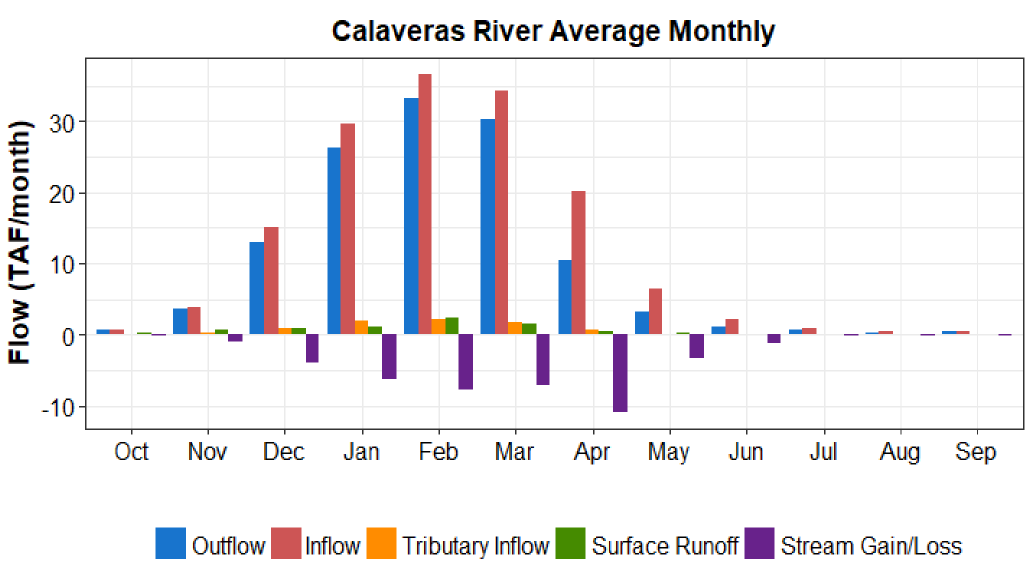


Figure A7-9. Monthly Average Unimpaired Flow Components for Calaveras River

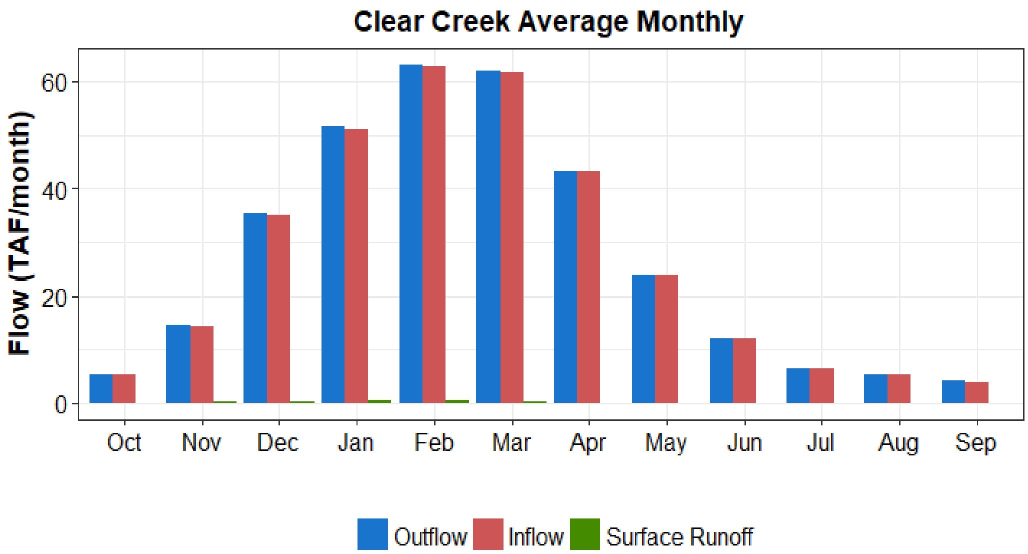


Figure A7-10. Monthly Average Unimpaired Flow Components for Clear Creek

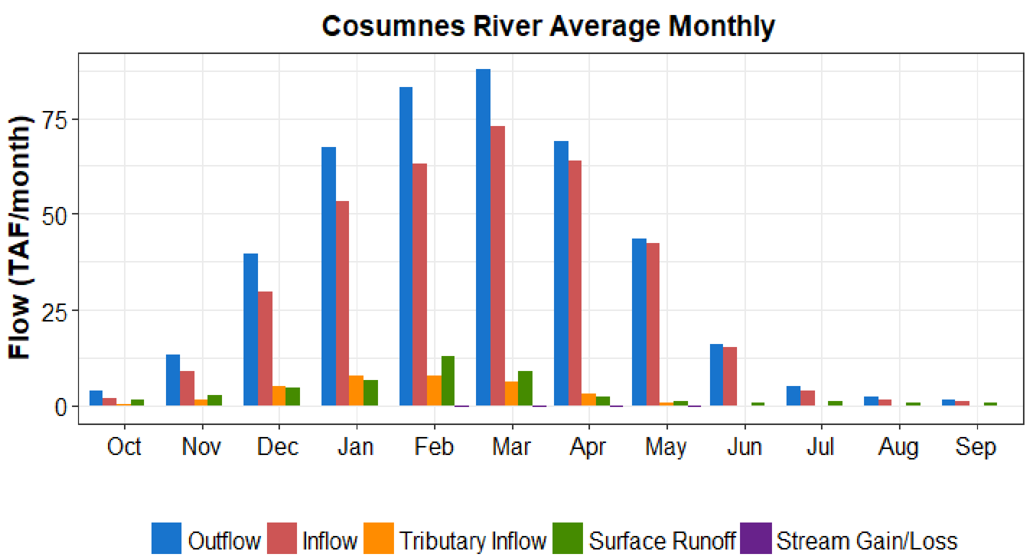


Figure A7-11. Monthly Average Unimpaired Flow Components for Cosumnes River

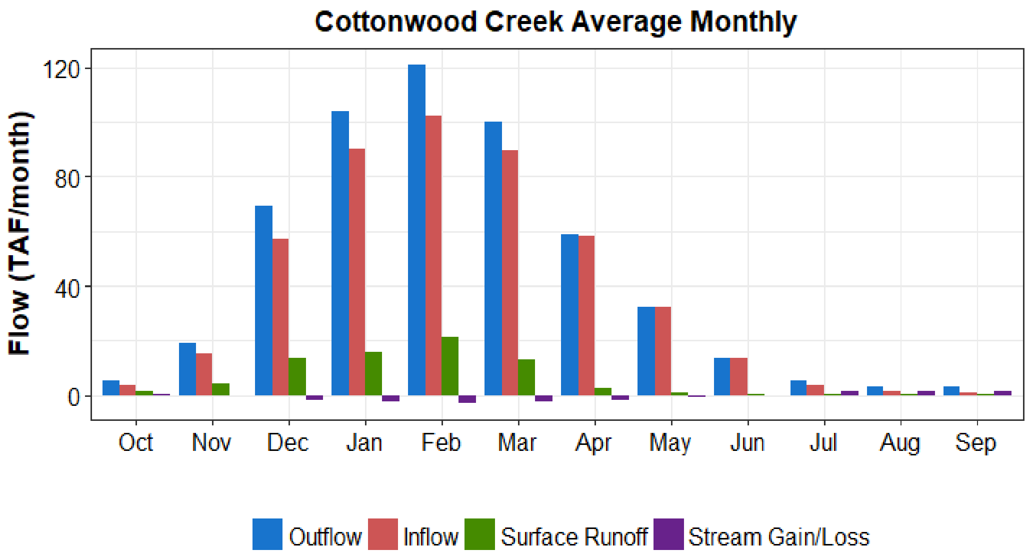


Figure A7-12. Monthly Average Unimpaired Flow Components for Cottonwood Creek

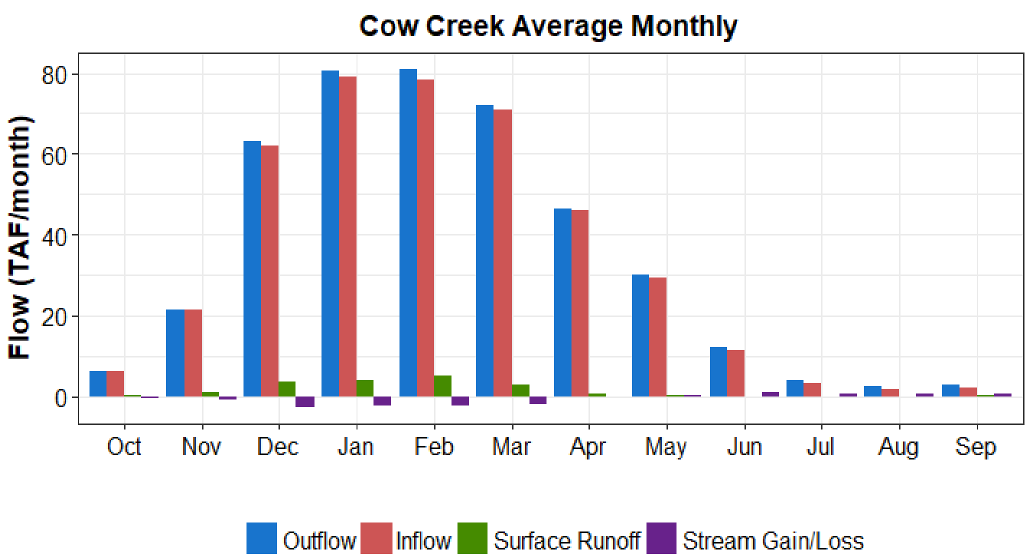


Figure A7-13. Monthly Average Unimpaired Flow Components for Cow Creek

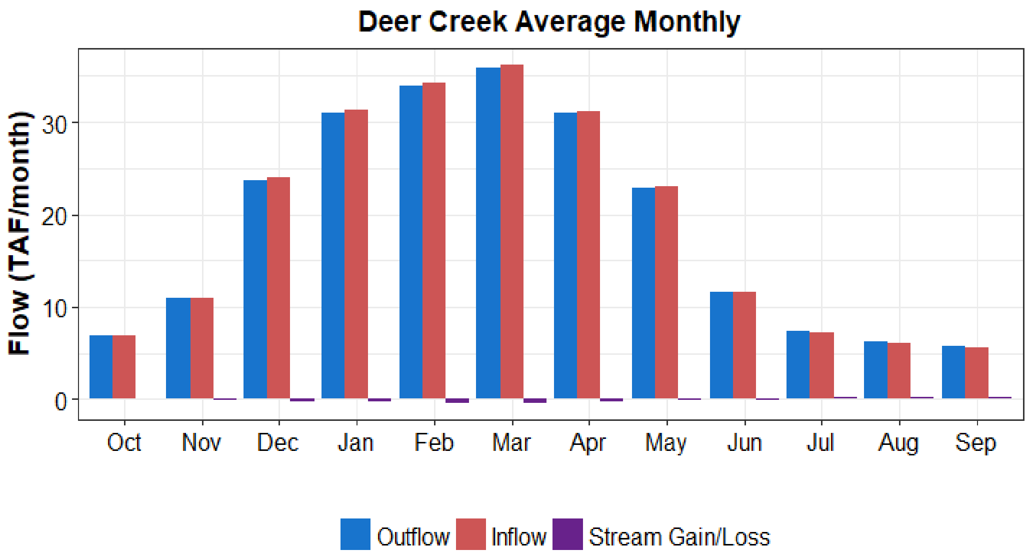


Figure A7-14. Monthly Average Unimpaired Flow Components for Deer Creek

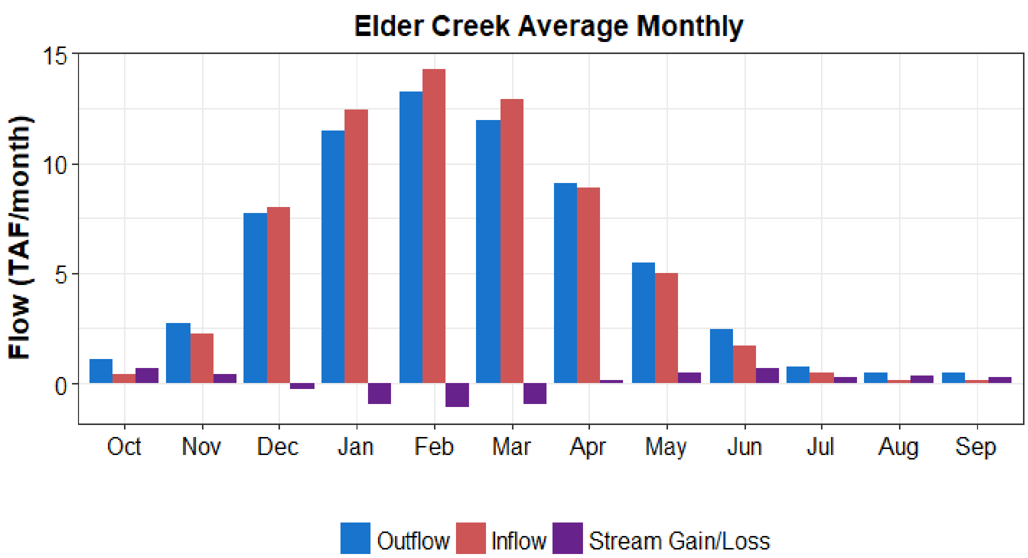


Figure A7-15. Monthly Average Unimpaired Flow Components for Elder Creek

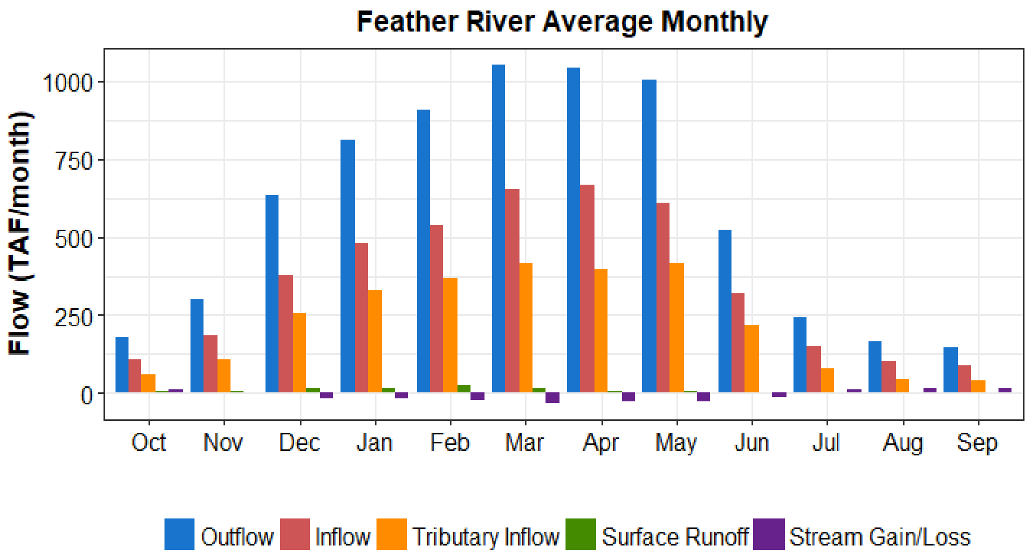


Figure A7-16. Monthly Average Unimpaired Flow Components for Feather River

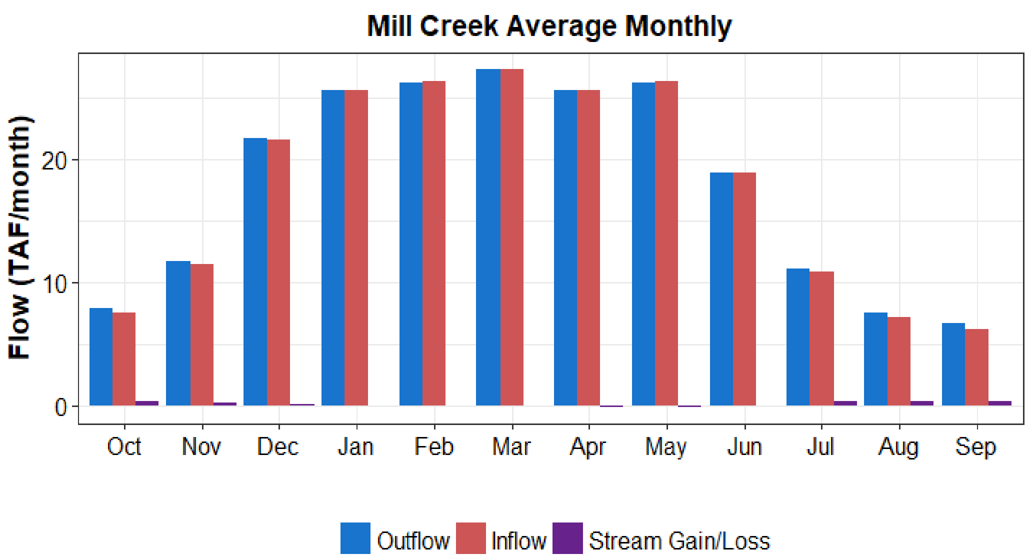


Figure A7-17. Monthly Average Unimpaired Flow Components for Mill Creek

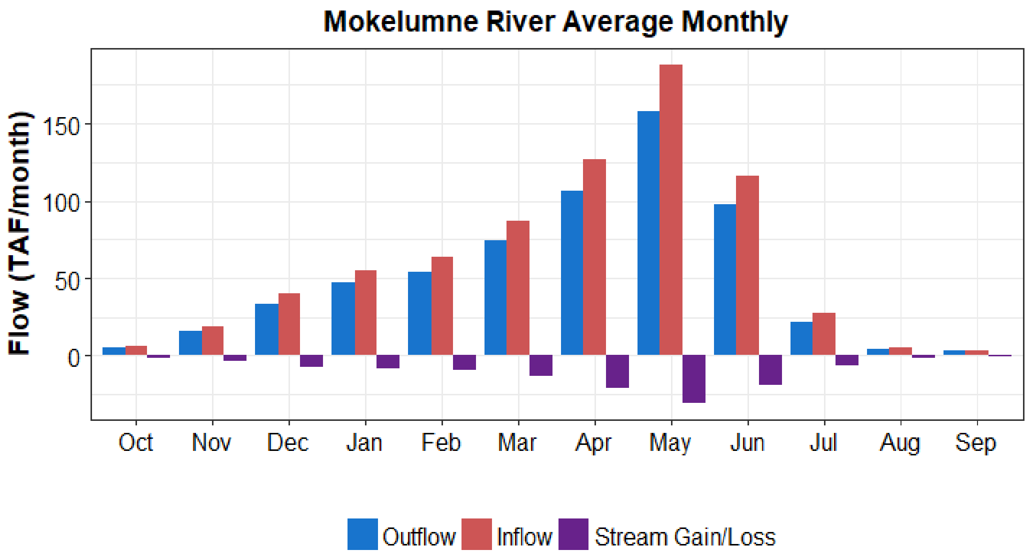


Figure A7-18. Monthly Average Unimpaired Flow Components for Mokelumne River

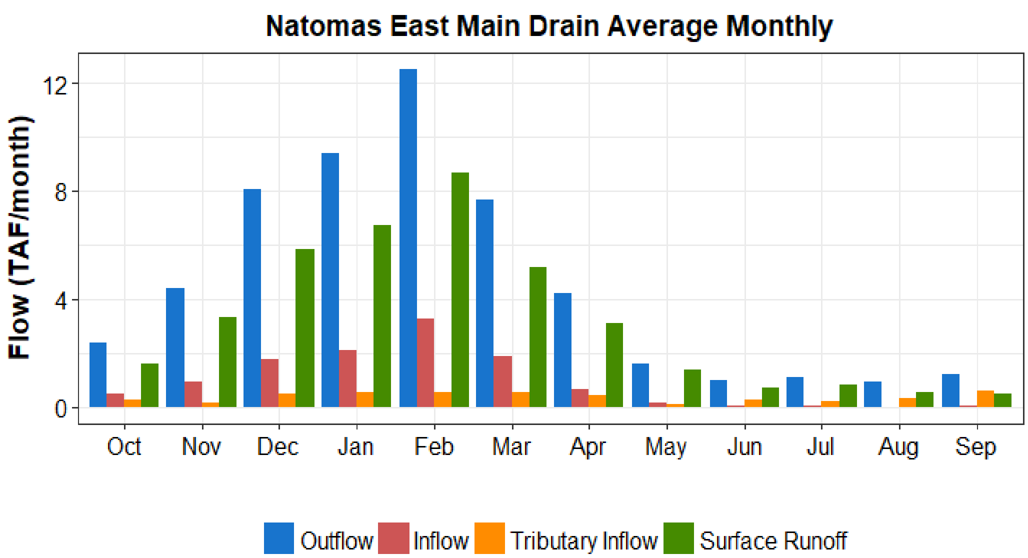


Figure A7-19. Monthly Average Unimpaired Flow Components for Natomas East Main Drain

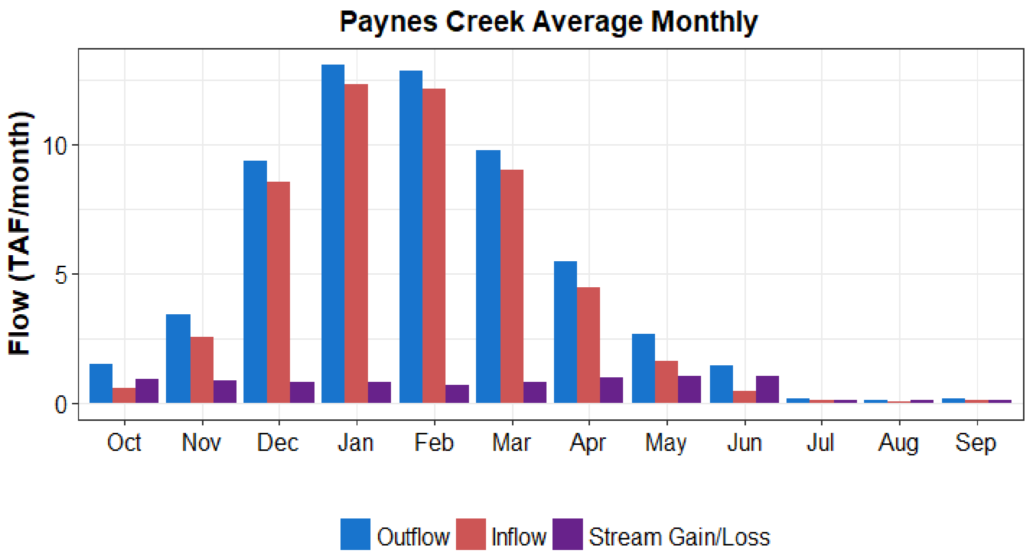


Figure A7-20. Monthly Average Unimpaired Flow Components for Paynes Creek

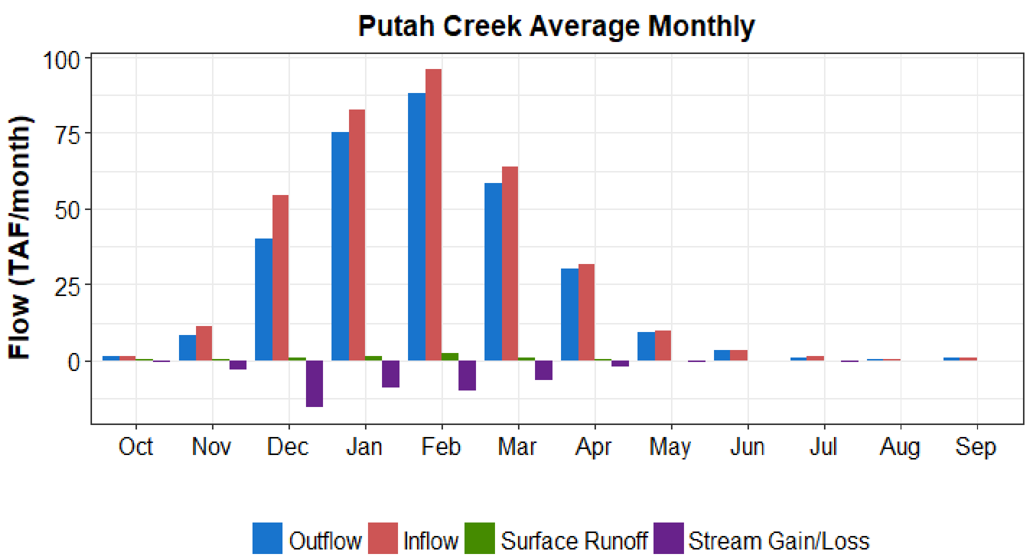
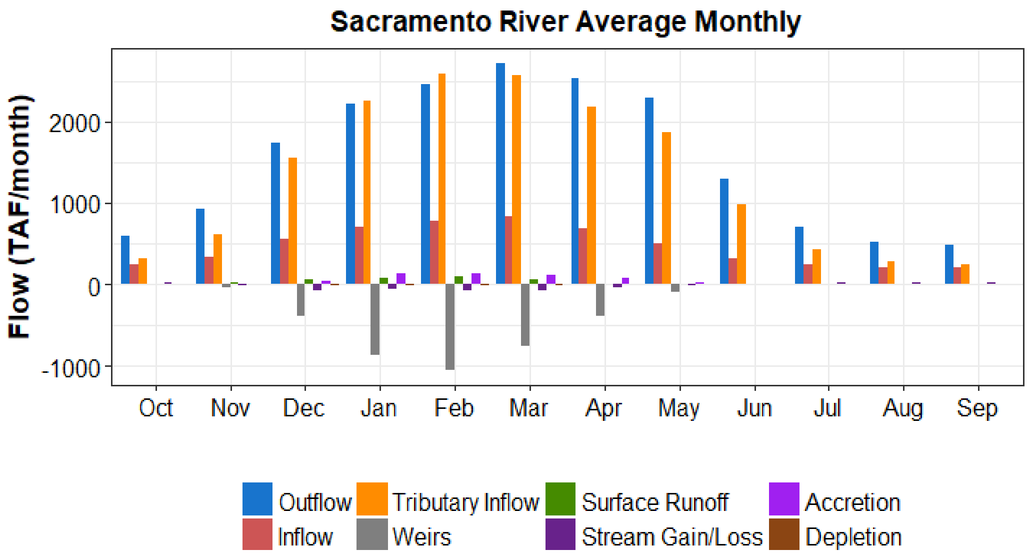


Figure A7-21. Monthly Average Unimpaired Flow Components for Putah Creek



Note: Weir outflows from the Sacramento River include those that spill into the Sutter Bypass and Yolo Bypass. Flows from the Sutter Bypass returning to the Sacramento River are included in the tributary inflow category. Flows from the Yolo Bypass do not return to the Sacramento River but are included as tributary inflow to the Delta in Figure A7-28.

Figure A7-22. Monthly Average Unimpaired Flow Components for Sacramento River[1]

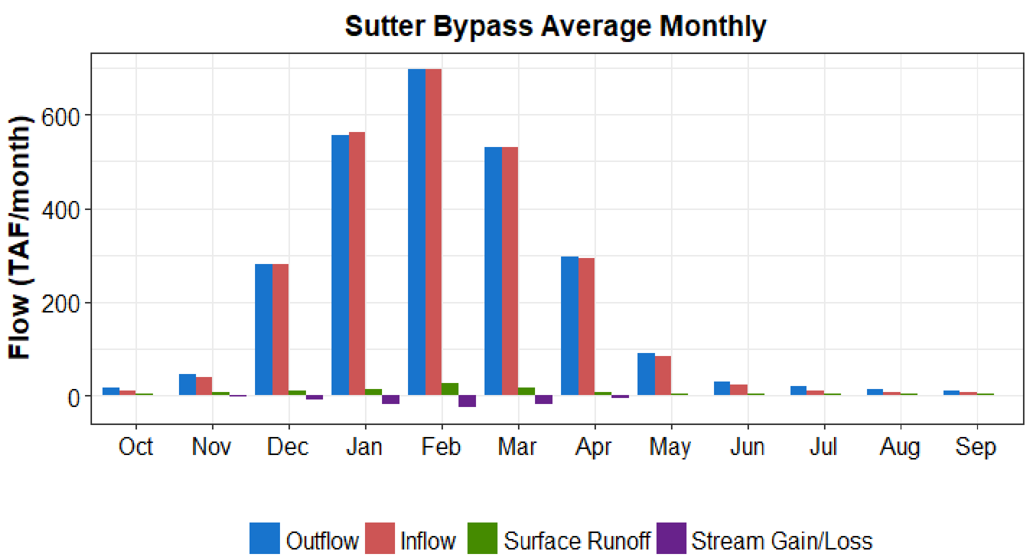


Figure A7-23. Monthly Average Unimpaired Flow Components for Sutter Bypass

1

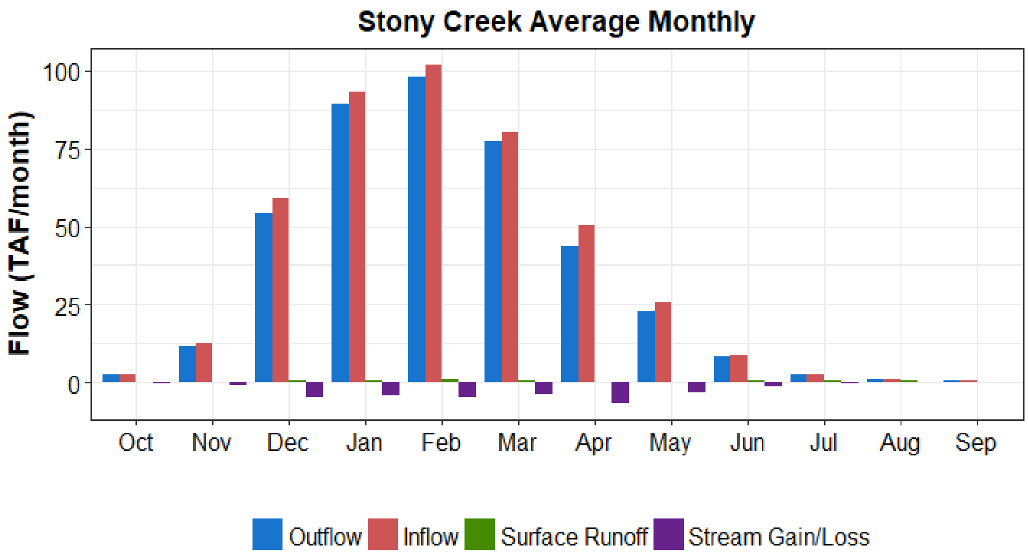


Figure A7-24. Monthly Average Unimpaired Flow Components for Stony Creek

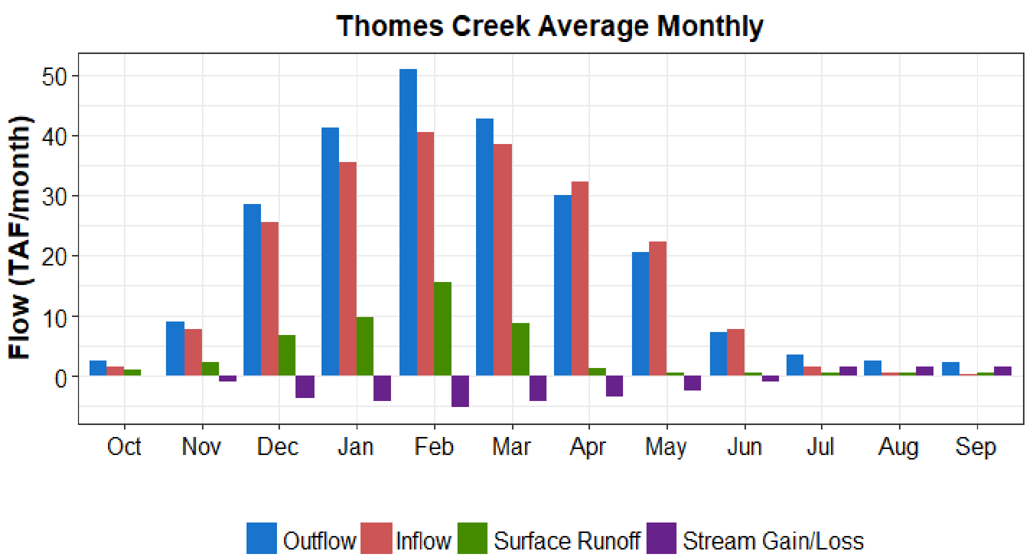


Figure A7-25. Monthly Average Unimpaired Flow Components for Thomes Creek

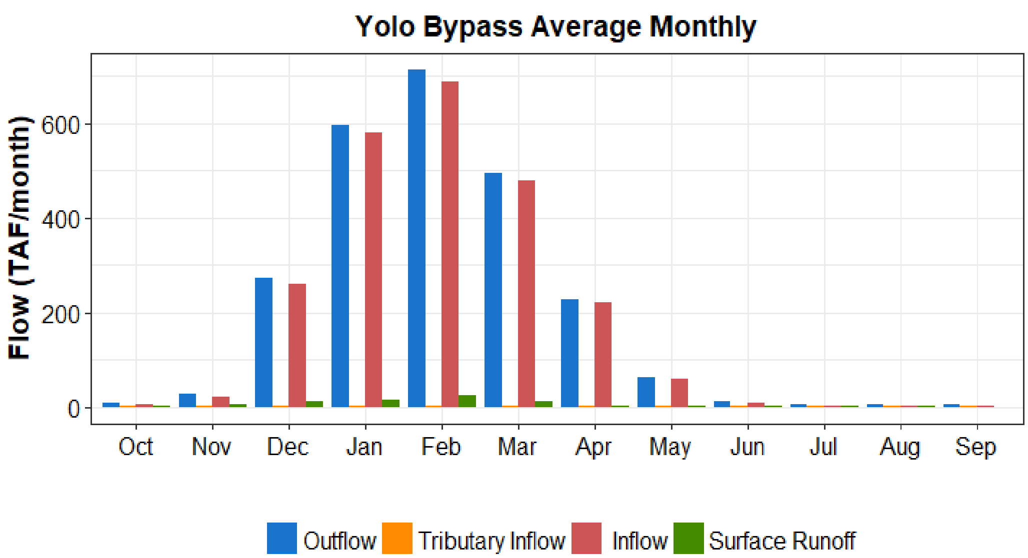


Figure A7-26. Monthly Average Unimpaired Flow Components for Yolo Bypass

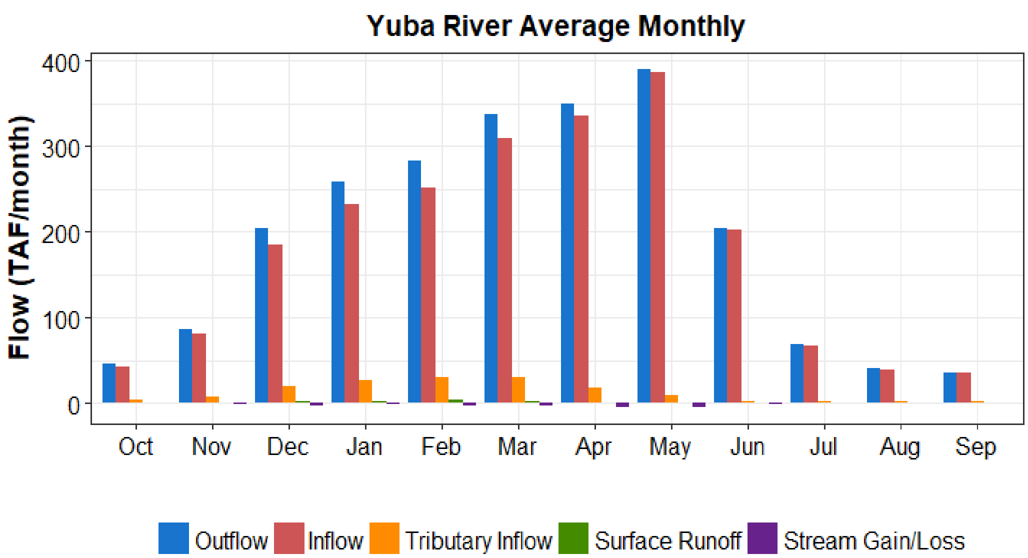
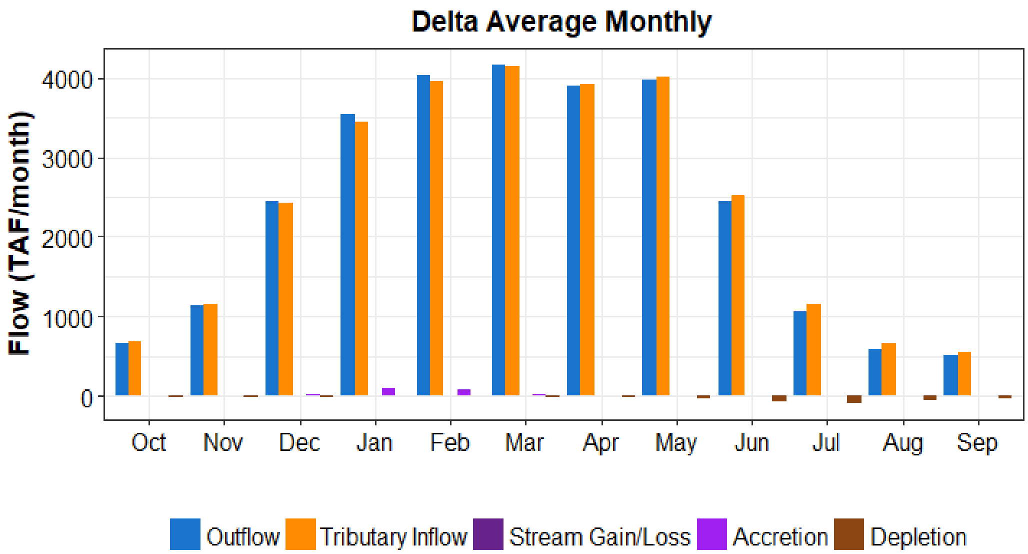


Figure A7-27. Monthly Average Unimpaired Flow Components for Yuba River



Note: Surface runoff and return flows included in tributary inflow.

Figure A7-28. Monthly Average Unimpaired Flow Components for the Delta

Table A7-3. Average Annual Values by Water Year Type

Unimpaired Flow Component	All	W	AN	BN	D	C
American River Inflow	2608	4263	3081	2213	1642	943
American River Outflow	2588	4227	3060	2194	1630	941
American River Stream Gain/Loss	-41	-67	-47	-35	-26	-15
American River Surface Runoff	18	28	24	14	11	11
American River Tributary Inflow	3	3	3	3	3	3
Antelope Creek Inflow	99	161	117	82	62	40
Antelope Creek Outflow	113	176	132	97	76	51
Antelope Creek Stream Gain/Loss	13	13	13	14	14	10
Antelope Creek Surface Runoff	1	2	1	1	1	1
Battle Creek Inflow	347	494	375	302	267	211
Battle Creek Outflow	355	499	383	313	278	219
Battle Creek Stream Gain/Loss	8	5	8	11	12	8
Bear River Inflow	313	520	383	259	189	106
Bear River Outflow	377	622	462	308	229	139
Bear River Stream Gain/Loss	-23	-37	-27	-19	-14	-8
Bear River Surface Runoff	34	46	39	27	26	28
Bear River Tributary Inflow	52	93	66	40	28	14
Big Chico Creek Inflow	101	173	119	78	58	35
Big Chico Creek Outflow	100	173	118	78	58	35
Big Chico Creek Stream Gain/Loss	0	0	0	0	0	0
Butte Creek Inflow	241	391	286	198	150	101
Butte Creek Outflow	396	627	471	326	251	187
Butte Creek Stream Gain/Loss	-14	-22	-16	-12	-9	-7

Unimpaired Flow Component	All	W	AN	BN	D	C
Butte Creek Surface Runoff	122	175	140	104	87	80
Butte Creek Tributary Inflow	47	83	61	36	24	13
Cache Creek Evaporation	155	151	155	155	158	160
Cache Creek Inflow	444	731	524	349	274	190
Cache Creek Outflow	433	817	549	301	199	104
Cache Creek Stream Gain/Loss	-99	-196	-126	-66	-41	-18
Cache Creek Surface Runoff	48	74	62	37	28	28
Cache Creek Tributary Inflow	195	365	251	132	91	50
Calaveras River Inflow	150	279	183	120	69	32
Calaveras River Outflow	123	224	154	98	59	29
Calaveras River Stream Gain/Loss	-42	-80	-49	-34	-19	-9
Calaveras River Surface Runoff	8	11	10	6	5	5
Calaveras River Tributary Inflow	8	14	10	6	3	1
Clear Creek Inflow	324	522	424	244	202	138
Clear Creek Outflow	326	525	426	245	203	139
Clear Creek Surface Runoff	2	3	2	1	1	1
Cosumnes River Inflow	358	645	437	292	177	84
Cosumnes River Outflow	433	771	532	351	219	116
Cosumnes River Stream Gain/Loss	-2	-3	-2	-1	-1	0
Cosumnes River Surface Runoff	45	68	55	34	29	27
Cosumnes River Tributary Inflow	32	60	42	26	15	5
Cottonwood Creek Inflow	469	843	601	314	248	147
Cottonwood Creek Outflow	535	943	684	369	294	183
Cottonwood Creek Stream Gain/Loss	-9	-19	-12	-4	-2	-1
Cottonwood Creek Surface Runoff	76	119	95	59	48	37
Cow Creek Inflow	412	674	497	336	258	159
Cow Creek Outflow	423	686	511	346	268	166
Cow Creek Stream Gain/Loss	-7	-15	-9	-4	-2	-1
Cow Creek Surface Runoff	18	28	23	14	12	9
Deer Creek Inflow	228	370	260	185	146	100
Deer Creek Outflow	227	367	258	185	146	100
Deer Creek Stream Gain/Loss	-1	-3	-2	-1	0	0
Delta Accretion	244	407	340	185	122	99
Delta Depletion	377	-349	-362	-389	-389	-409
Delta Outflow	28466	45049	33607	23873	18541	12495
Delta Stream Gain/Loss	-20	-19	-19	-19	-20	-22
Delta Tributary Inflow	28618	45010	33649	24096	18828	12828
Elder Creek Inflow	67	117	91	45	36	22
Elder Creek Outflow	67	113	90	47	39	24
Elder Creek Stream Gain/Loss	0	-4	-2	2	3	2
Feather River Inflow	4275	6894	4850	3516	2816	1829
Feather River Outflow	7008	11118	8050	5867	4683	3053

Unimpaired Flow Component	All	W	AN	BN	D	C
Feather River Stream Gain/Loss	-104	-290	-150	-24	11	28
Feather River Surface Runoff	109	164	130	85	74	65
Feather River Tributary Inflow	2728	4350	3220	2290	1781	1131
Mill Creek Inflow	215	319	245	185	154	115
Mill Creek Outflow	216	319	246	188	157	117
Mill Creek Stream Gain/Loss	2	0	1	2	3	2
Mokelumne River Inflow	740	1178	875	646	479	288
Mokelumne River Outflow	620	986	733	542	402	241
Mokelumne River Stream Gain/Loss	-120	-192	-141	-104	-77	-46
Natomas East Main Drain Inflow	11	18	15	8	7	6
Natomas East Main Drain Outflow	54	81	68	42	35	34
Natomas East Main Drain Surface Runoff	38	58	49	29	24	23
Natomas East Main Drain Tributary Inflow	5	5	5	4	4	5
Paynes Creek Inflow	52	88	60	43	31	16
Paynes Creek Outflow	60	97	69	51	40	23
Paynes Creek Stream Gain/Loss	8	8	8	9	9	6
Putah Creek Inflow	358	652	441	252	183	111
Putah Creek Outflow	316	573	392	224	161	99
Putah Creek Stream Gain/Loss	-48	-89	-57	-32	-26	-15
Putah Creek Surface Runoff	6	10	8	5	4	4
Sacramento River Accretion	506	1136	689	256	126	0
Sacramento River Depletion	87	-190	-138	-36	-24	0
Sacramento River Inflow	5599	8018	6372	4856	4206	3260
Sacramento River Outflow	18464	26744	21877	16517	13481	9457
Sacramento River Stream Gain/Loss	-241	-606	-360	-70	5	-5
Sacramento River Surface Runoff	374	558	456	302	251	216
Sacramento River Tributary Inflow	15872	26809	18778	12253	9535	6108
Sacramento River Weirs	3560	-8983	-3920	-1043	-617	-121
Stony Creek Inflow	438	791	569	299	220	138
Stony Creek Outflow	411	740	535	280	208	132
Stony Creek Stream Gain/Loss	-31	-56	-38	-22	-16	-10
Stony Creek Surface Runoff	4	5	4	4	4	4
Sutter Bypass Inflow	2554	5655	3220	1205	736	308
Sutter Bypass Outflow	2595	5637	3254	1273	808	389
Sutter Bypass Stream Gain/Loss	-67	-171	-90	-19	-5	3
Sutter Bypass Surface Runoff	108	152	124	87	76	78
Thomes Creek Inflow	213	357	265	158	130	83
Thomes Creek Outflow	241	397	299	181	148	102
Thomes Creek Stream Gain/Loss	-21	-38	-26	-13	-10	-7

Unimpaired Flow Component	All	W	AN	BN	D	C
Thomes Creek Surface Runoff	48	77	61	36	28	26
Yolo Bypass Inflow	2327	5655	2350	827	571	257
Yolo Bypass Outflow	2430	5798	2475	911	642	329
Yolo Bypass Surface Runoff	78	119	101	59	47	48
Yolo Bypass Tributary Inflow	25	25	25	25	25	25
Yuba River Inflow	2166	3428	2538	1836	1436	911
Yuba River Outflow	2302	3662	2704	1938	1514	960
Yuba River Stream Gain/Loss	-25	-40	-29	-21	-17	-11
Yuba River Surface Runoff	16	23	19	12	11	11
Yuba River Tributary Inflow	146	252	176	112	85	48

Source: SacWAM results (Appendix A1)
W = wet year; AN = above-normal year; BN = below-normal year; D = dry year; C = critical year

A7.3.1 Unimpaired Stream Gains and Losses to Groundwater

Stream gains and losses are difficult to estimate because they cannot be directly measured. Additionally, in most cases, they cannot be calculated using mass balance about each tributary because very few of the tributaries to the Sacramento River have stream gages at the confluence.

Although there is uncertainty in the estimation of this component of unimpaired flows, for most tributaries, the stream losses are estimated to be less than 10 percent of the tributary inflow, except for Antelope Creek, Cache Creek, Putah Creek, the Calaveras River, and the Mokelumne River (Table A7-4). Results for these tributaries are consistent with other studies that have shown large stream–groundwater interactions on the lower reaches (Yolo County 2006; Thomasson et al. 1960; DWR 2016a). Stream gains and losses are estimated as a function of streamflow; therefore, the unimpaired losses are larger than the losses under the existing conditions simulation because the streamflows are higher. For example, East Bay Municipal Utility District estimates the loss on the lower Mokelumne River to be about -45 TAF/yr (EBMUD 2017), which is consistent with the SacWAM estimates in the current conditions simulation (-57 TAF/yr in a below-normal year to -32 TAF/yr in a dry year). However, the unimpaired outflow for the Mokelumne River is much larger in the unimpaired simulation (620 TAF/yr) than the current conditions simulation (327 TAF/yr); therefore, the losses are greater in the unimpaired simulation.

The total annual average estimated unimpaired stream loss for the Sacramento River, its tributaries, and the Delta eastside tributaries is about -880 TAF/yr but averages -1,888 TAF/yr in a wet year and -123 TAF/yr in a critical year (Table A7-5). When compared with the total Delta outflow, the estimated system-wide stream loss is an annual average of 3.1 percent across all years. In critical years, the gain is only 1.0 percent of Delta outflow; in a wet year, the loss is nearly 4.1 percent of the total Delta outflow.

To get a sense of how sensitive the unimpaired flow estimates are to the stream gains and losses, the last row of Table A7-5 shows that if the stream gain/loss is doubled, the effect on Delta outflow is a decrease of 3.1 percent. Strictly this is not correct, however, because if the losses were increased on a tributary to the Sacramento River, the resulting inflow to the Sacramento River would be reduced, resulting in less loss along the Sacramento River. For a formal sensitivity analysis on the stream gains and losses, the entire model would need to be recalibrated, which would affect other areas of the model. Overall, there is some uncertainty in the stream gain/loss estimates, but the tributaries with the largest losses are consistent with other studies and the total gains and losses are small in terms of total Delta outflow.

Table A7-4. Average Stream Gains and Losses as Percentage of Rim Inflow by Tributary

Tributary	Stream Gain/Loss as Percentage of Inflow
American River	-1.6%
Antelope Creek	13.1%
Battle Creek	2.3%
Bear River	-7.3%
Big Chico Creek	0.0%
Butte Creek	-5.8%
Cache Creek	-22.3%
Calaveras River	-28.0%
Cosumnes River	-0.6%
Cottonwood Creek	-1.9%
Cow Creek	-1.7%
Deer Creek	-0.4%
Elder Creek	0.0%
Feather River	-2.1%
Mill Creek	0.9%
Mokelumne River	-16.2%
Paynes Creek	15.4%
Putah Creek	-13.4%
Sacramento River	-4.5%
Stony Creek	-7.1%
Sutter Bypass	-2.6%
Thomes Creek	-9.9%
Yuba River	-1.2%

Source: SacWAM results (Appendix A1)

Table A7-5. Total System-Wide Annual Average Stream Gain/Losses

	All	W	AN	BN	D	C
Total unimpaired stream gain/ loss (TAF/yr)	-880	-1,888	-1,163	-476	-243	-123
Percentage of Delta outflow	-3.1%	-4.2%	-3.5%	-2.0%	-1.3%	-1.0%
200% Total stream gain/ loss as percentage of outflow	-6.2%	-8.4%	-6.9%	-4.0%	-2.6%	-2.0%

Source: SacWAM results (Appendix A1)
All = all years; W = wet year; AN = above-normal year; BN = below-normal year; D = dry year; C = critical year

A7.3.2 Clear Lake Evaporation

The effect of including evaporation from Clear Lake in the calculation of unimpaired flows reduces the unimpaired outflow from Cache Creek by an average of 128 TAF/yr. The annual average evaporation for Clear Lake with the limited operations described in Section A7.2.5, *Unimpaired San Joaquin Inflow at Vernalis*, is 155 TAF/yr. When evaporation in Clear Lake is included, the streamflow below Clear Lake is reduced, resulting in less stream loss on Cache Creek; therefore, the effect on the unimpaired outflow from Cache Creek is less than the volume of evaporation.

The limited reservoir operation at Clear Lake results in streamflows that are not always uniformly lower due to evaporation. When inflows are very low, such as in summer 1984, evaporation reduces storage below the lake outlet elevation, which results in zero outflow (Figure A7-29). Zero outflow is maintained until storage rises to 840 TAF. This type of response is similar to what would be expected if there was no dam controlling releases at Clear Lake.

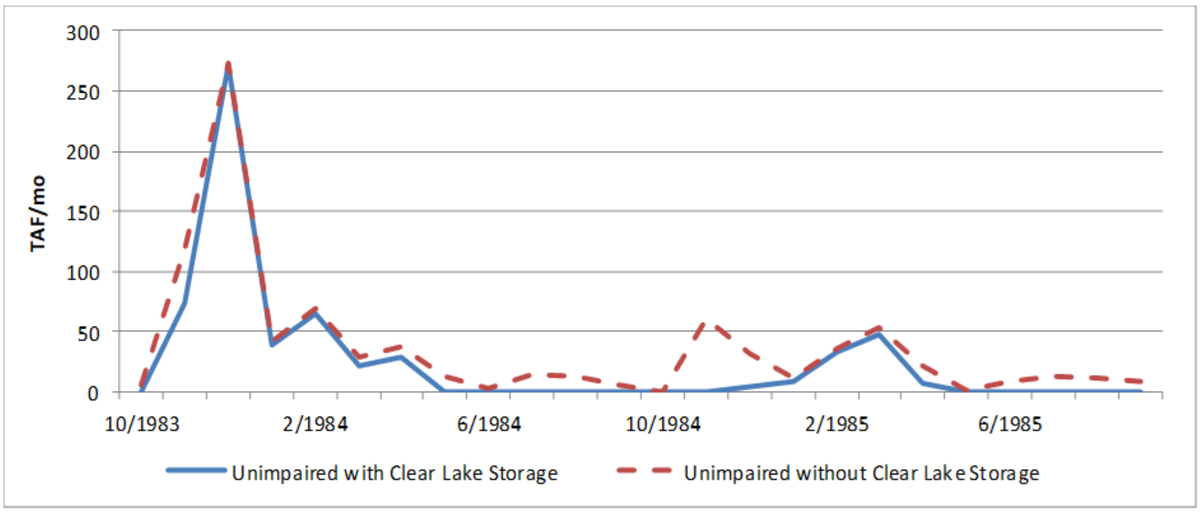


Figure A7-29. Monthly Unimpaired Flow on Cache Creek below Clear Lake for Water Years 1984–1985

A7.3.3 Delta Depletions

SacWAM does not include any stream gains and losses to groundwater in the Delta. This interaction was assumed to be included in the net channel depletions term described in Section A7.2.6, *Additional Model* Assumptions. The unimpaired Delta depletions are -365 TAF/yr on average, with an average monthly pattern shown in Figure A7-30. The figures shows the average total Delta depletions are lowest in January, increase throughout the first half of the year with a peak in July at around 80 TAF, and then decrease throughout the remainder of the year. The unimpaired Delta depletions are approximately 31 percent of the Delta depletions assumed under existing conditions (SWRCB 2019).

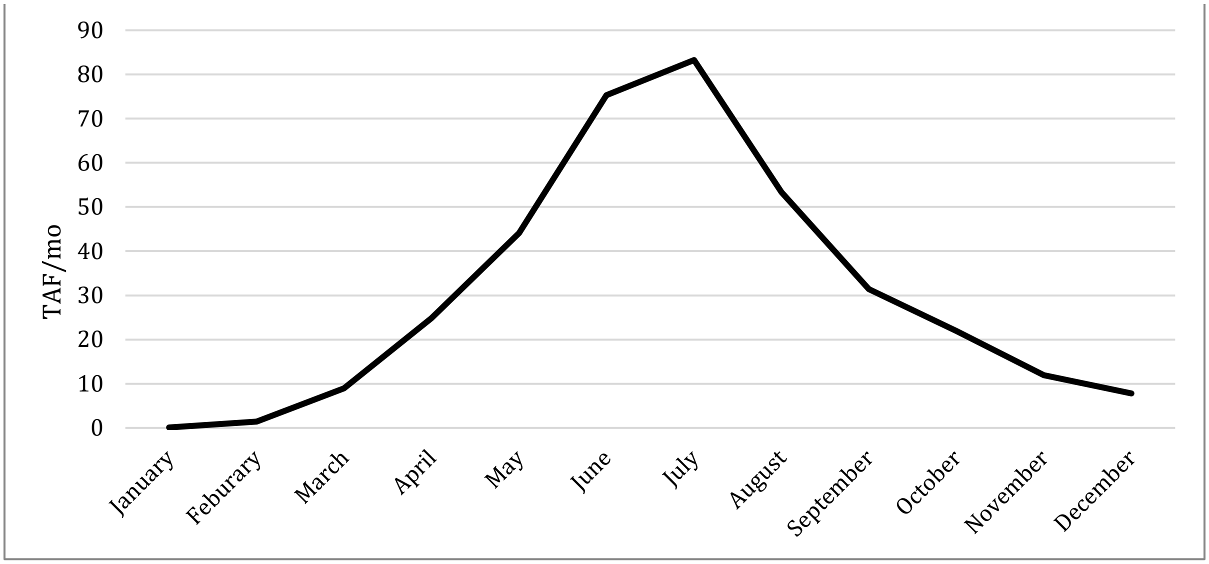


Figure A7-30. Monthly Average Total Delta Depletions

A7.4 References

A7.4.1 Common References

^California Department of Water Resources (DWR). 2007b. *California Central Valley Unimpaired Flow Data*. Fourth Edition. May.

^California Department of Water Resources (DWR). 2016c. *Estimates of Natural and Unimpaired Flows for the Central Valley of California: Water Years 1922–2014*. Bay-Delta Office. March.

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A7.4.2 Section References

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Yolo County. 2006. *Cache Creek Status Report and Trend Analysis 1996–2006*. July.