Arnold Schwarzenegger
Governor

INTEGRATED FORECAST AND RESERVOIR MANAGEMENT (INFORM) FOR NORTHERN CALIFORNIA: SYSTEM DEVELOPMENT AND INITIAL DEMONSTRATION

Appendices F through I

PIER FINAL PROJECT REPORT

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California Energy Commission
Public Interest Energy Research Program

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March 2007
CEC-500-2006-109-APF

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Appendix F

Plots from the Evaluation of the INFORM Stand-Alone Distributed Hydrologic Model

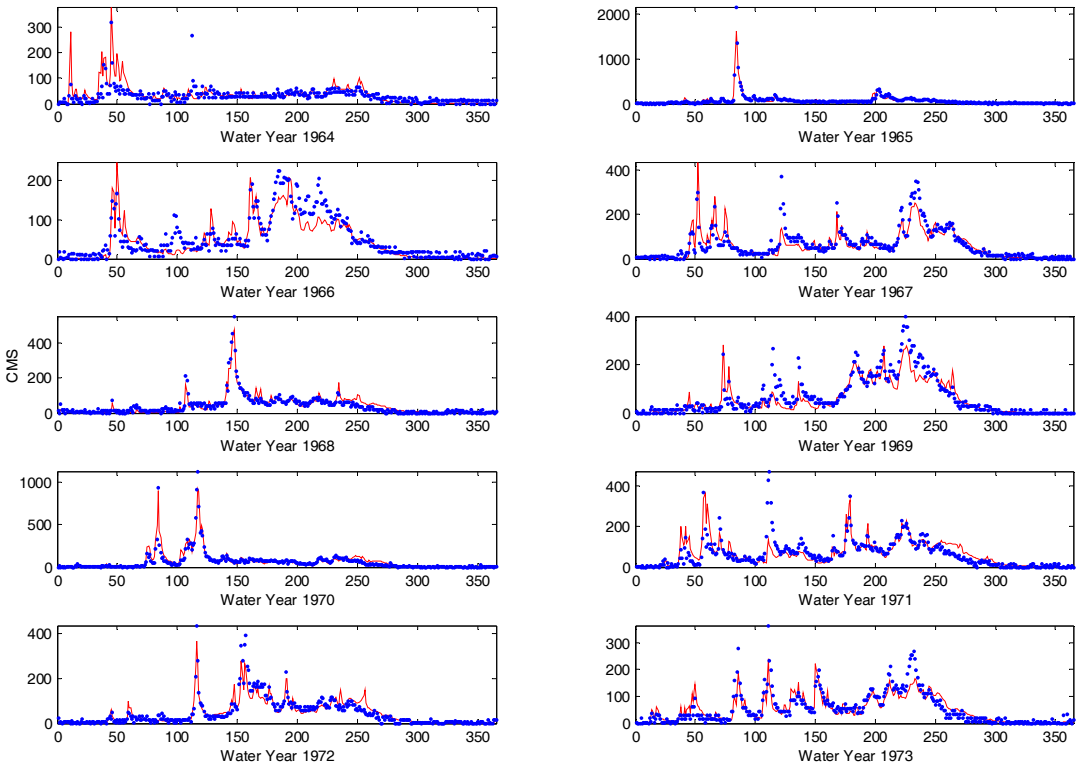


Figure APF-1. Plot of FNF (blue) and simulated (red) flow into Trinity Lake for the selected water years within the period of record

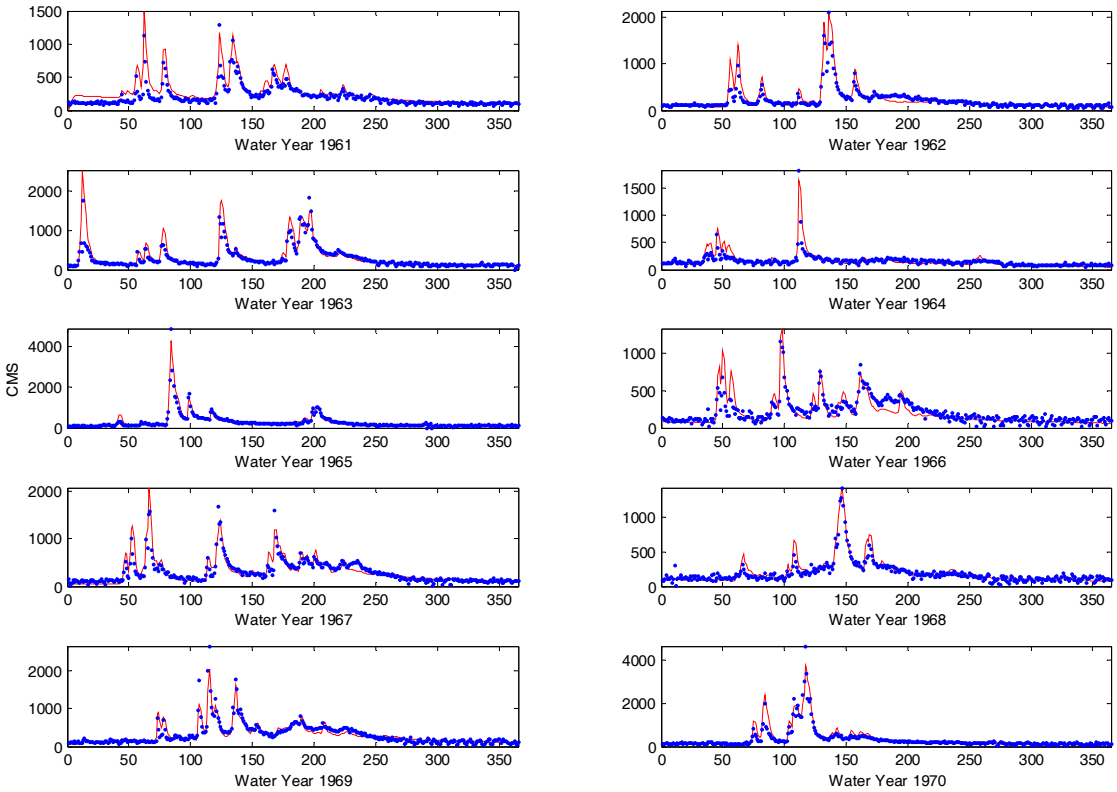


Figure APF-2. As in Figure APF-1 except presenting flows into Shasta Lake

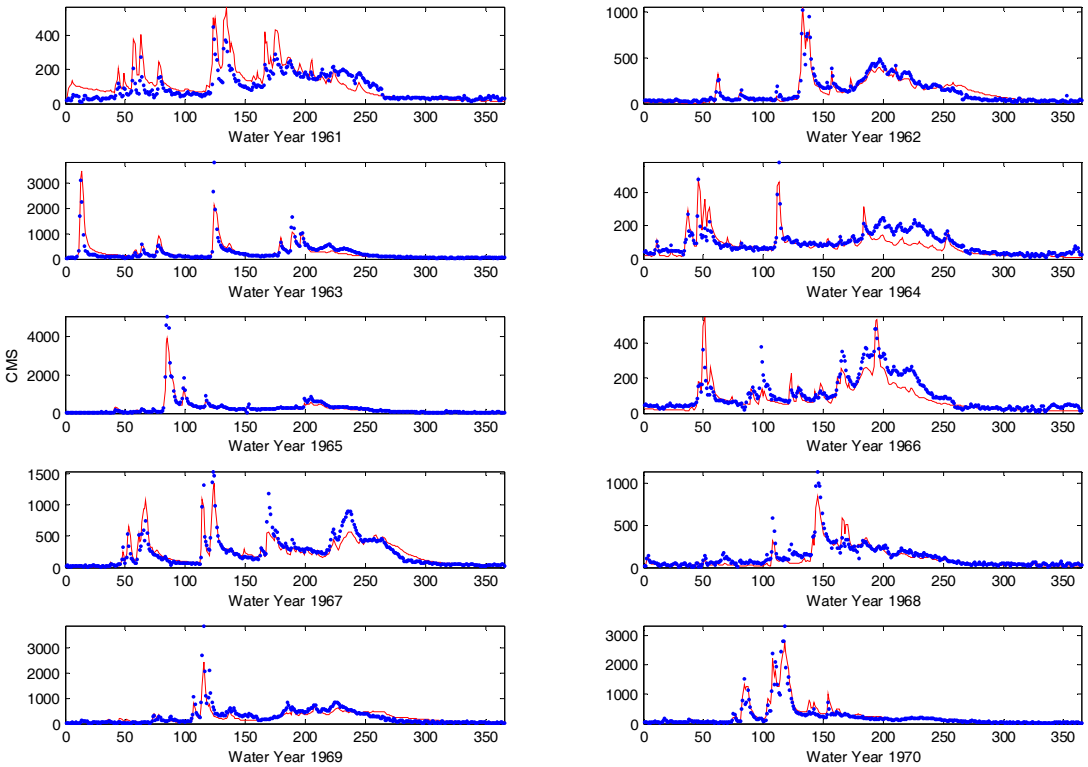


Figure APF-3. As in Figure APF-1 except presenting flows into Oroville Lake

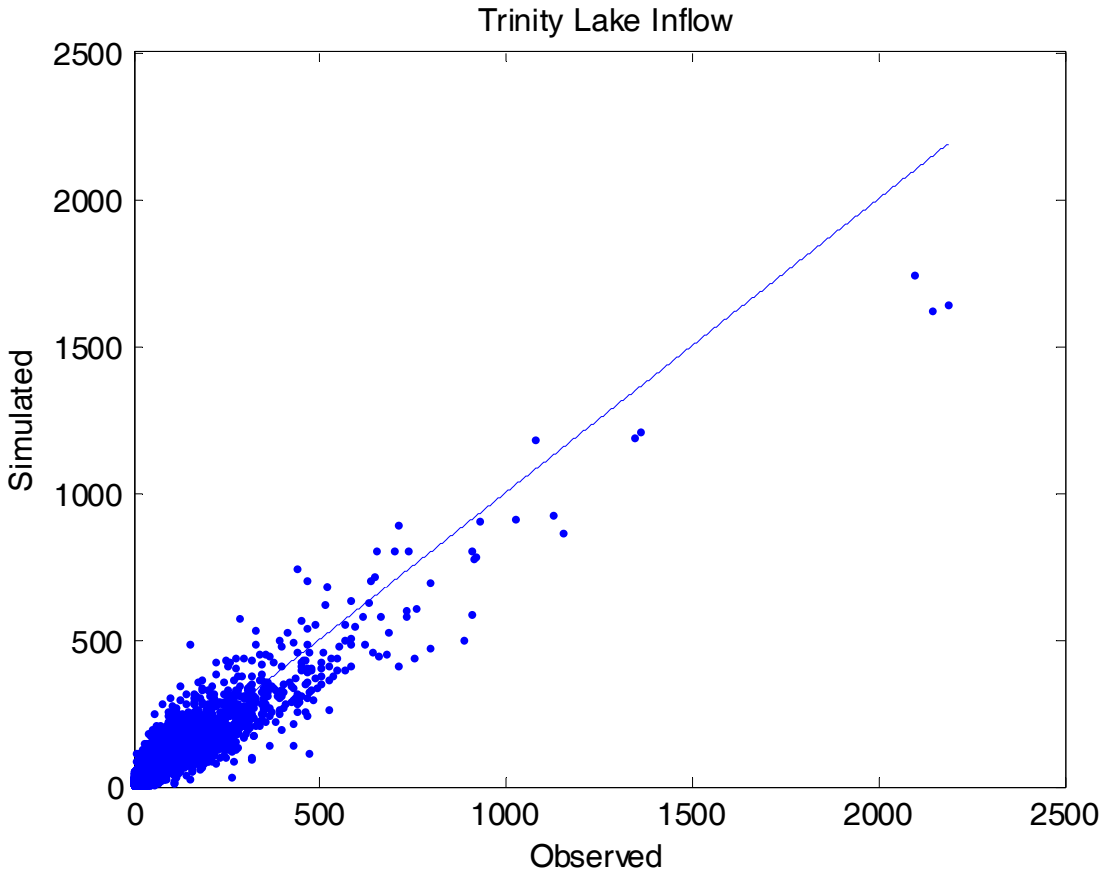


Figure APF-4. Mean daily FNF estimate (m^3/s) versus simulated flow into the Trinity Lake

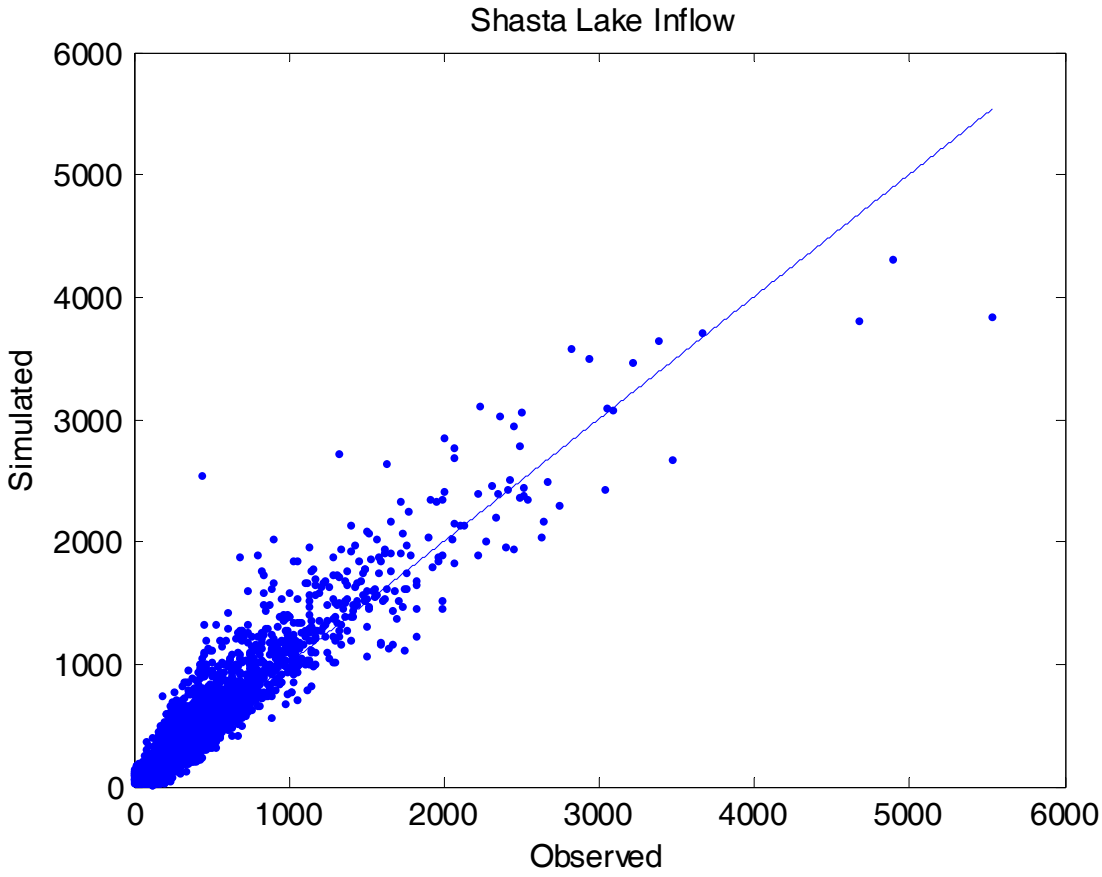


Figure APF-5. As in Figure APF-4 except presenting flows into Shasta Lake

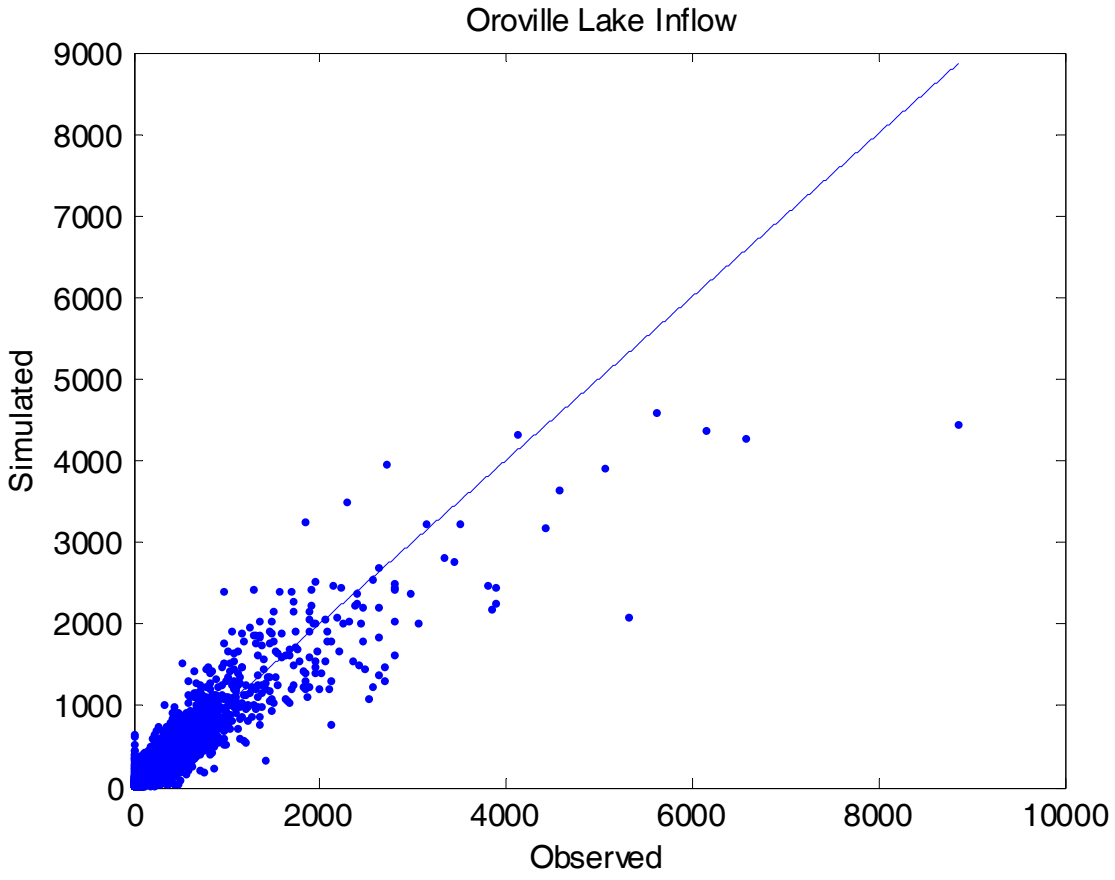


Figure APF-6. As in Figure APF-4 except presenting flows into Oroville Lake

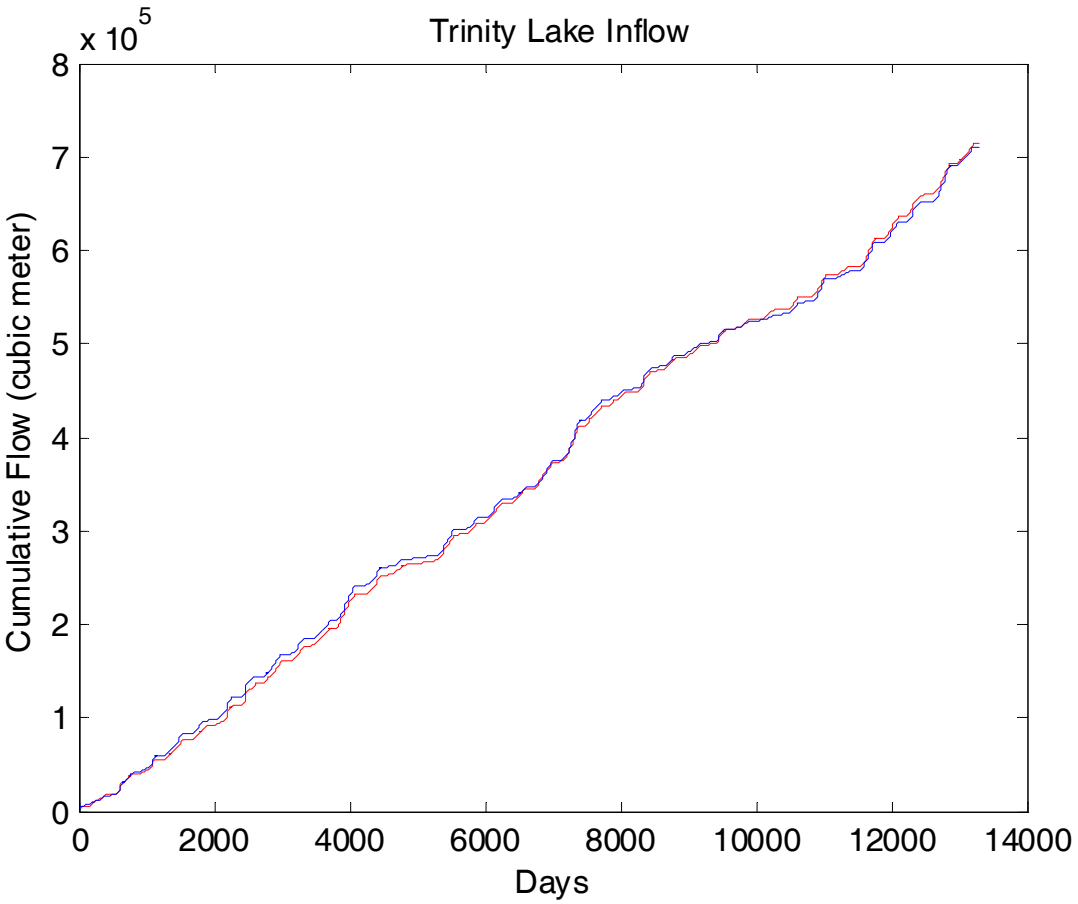


Figure APF-7. FNF estimated (blue) and simulated (red) cumulative flow into Trintiy Lake

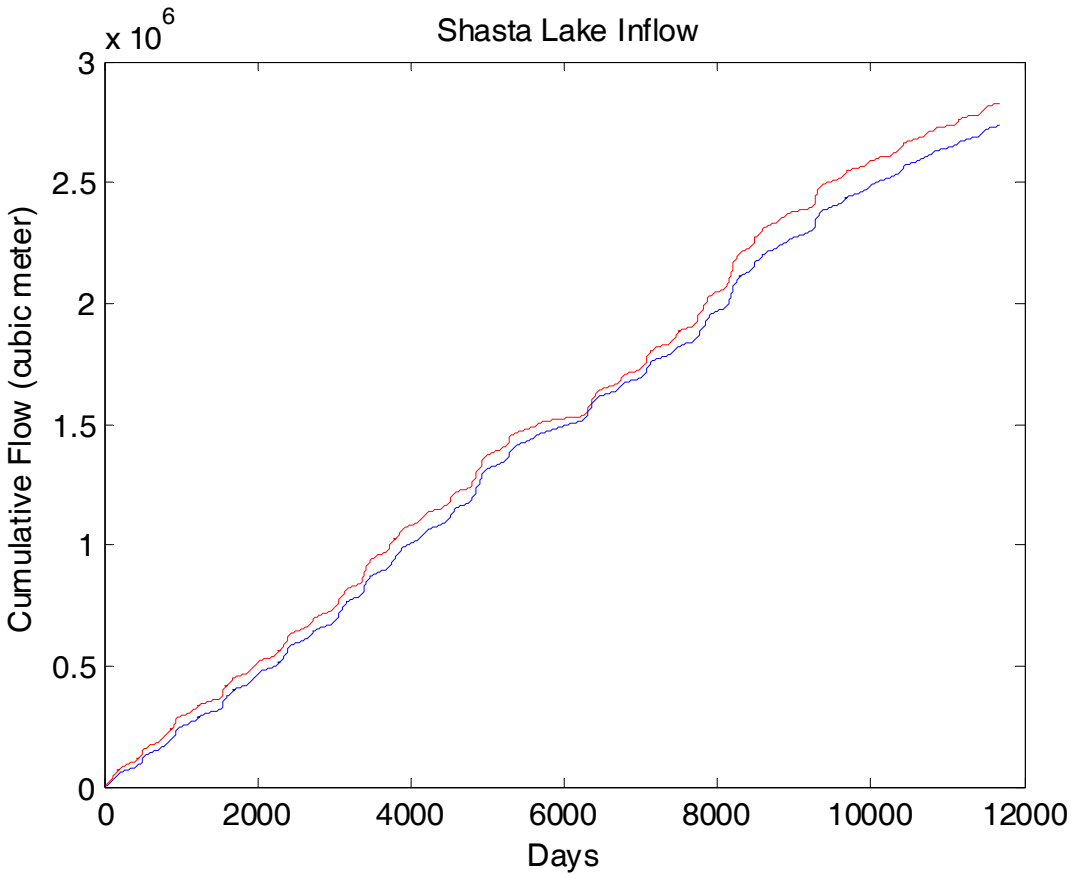


Figure APF-8. As in Figure APF-7 except presenting flows into Shasta Lake

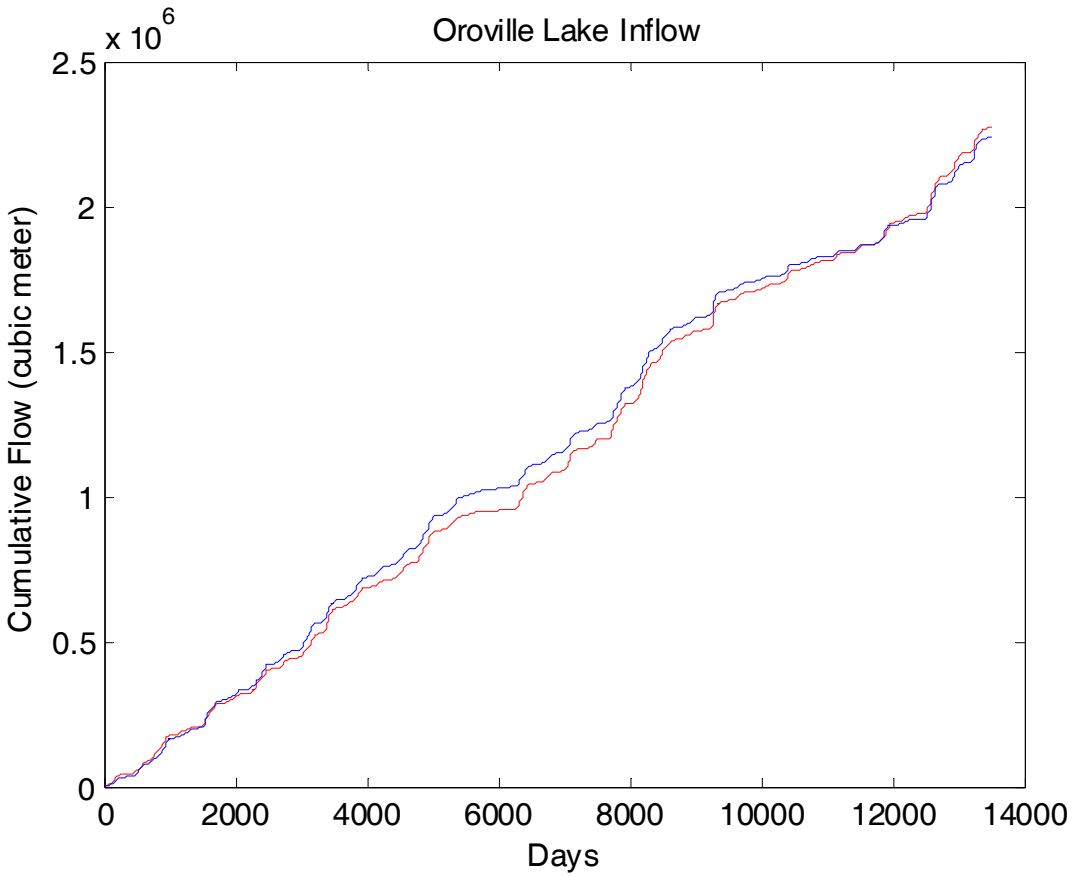


Figure APF-9. As in Figure APF-7 except presenting flows into Oroville Lake

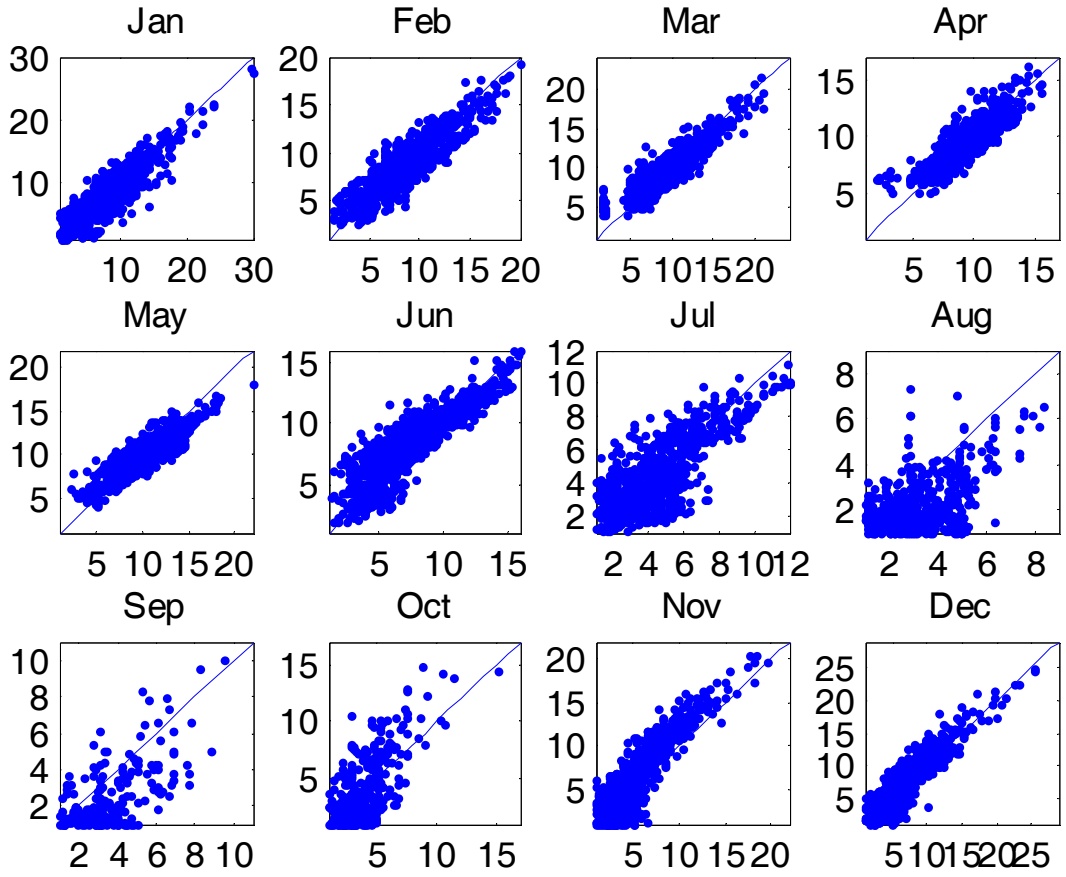


Figure APF-10. Scatter plots of simulated as a function of the FNF estimate monthly flows for the Trinity Lake inflow

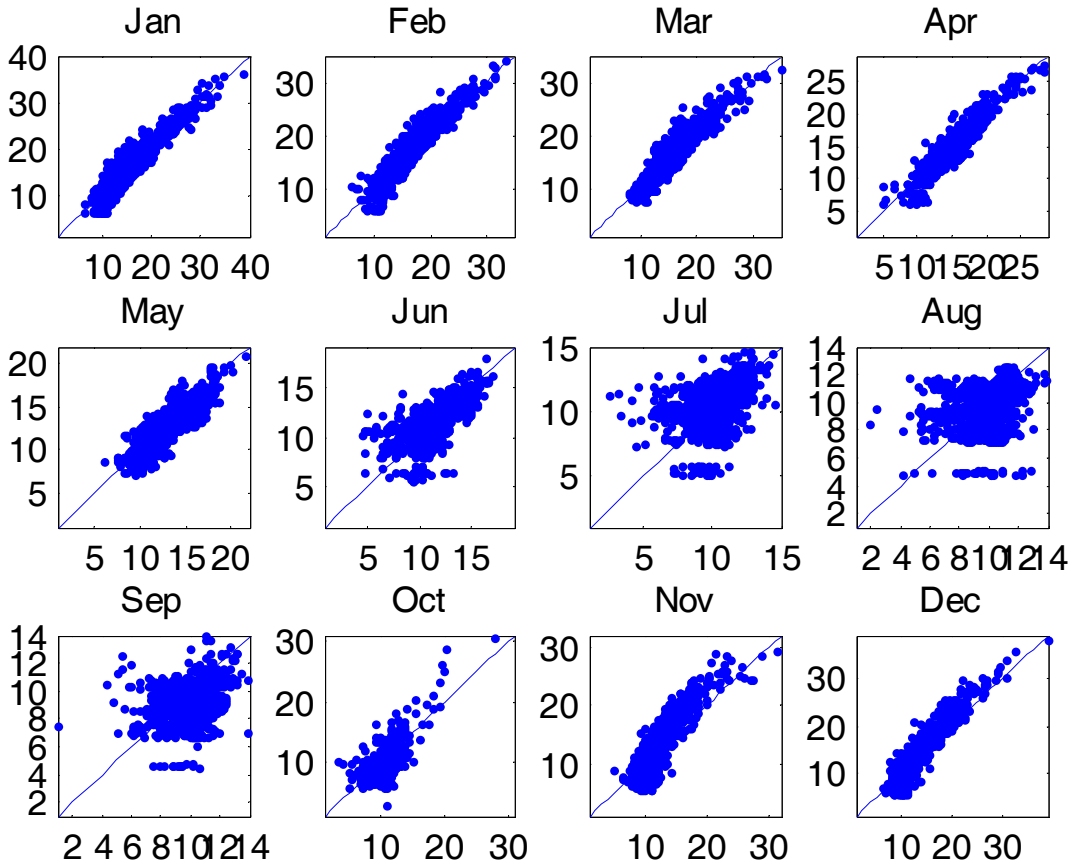


Figure APF-11. As in Figure APF-10 except presenting flows into Shasta Lake

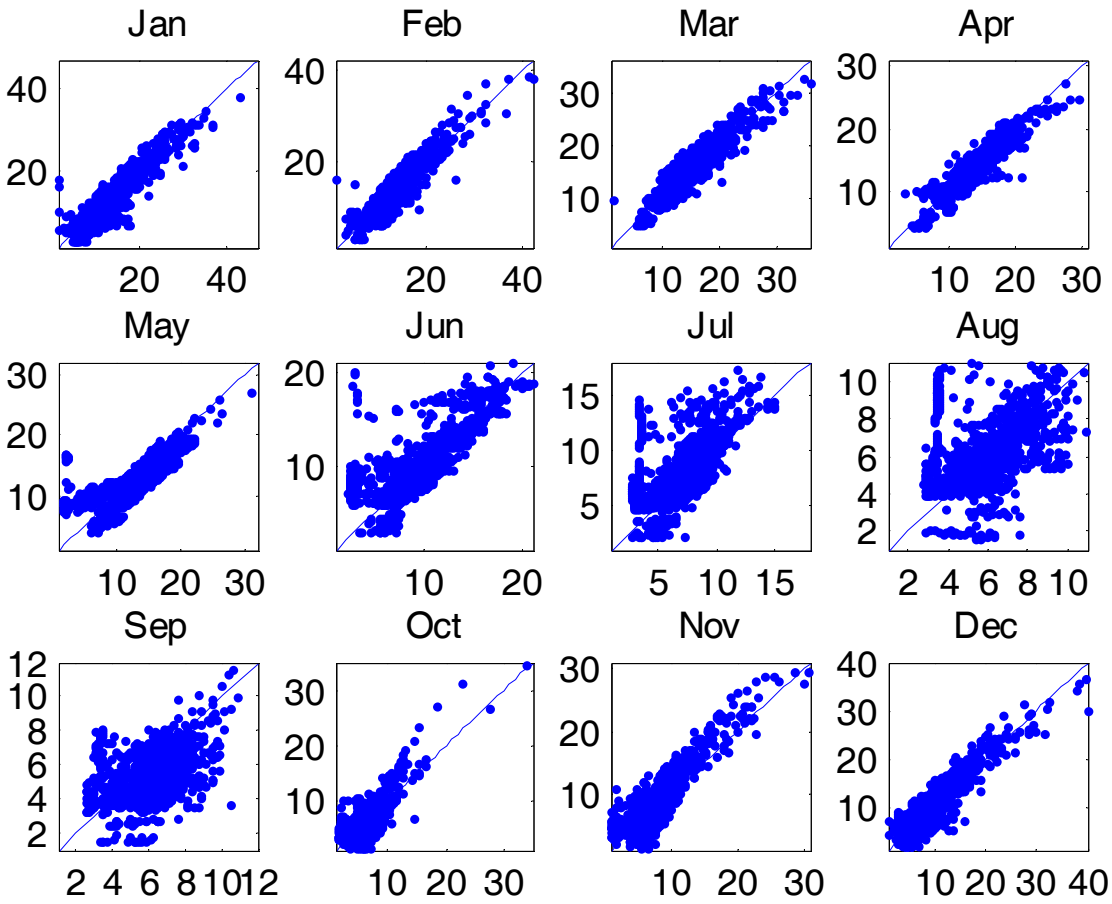


Figure APF-12. As in Figure APF-10 except presenting flows into Oroville Lake

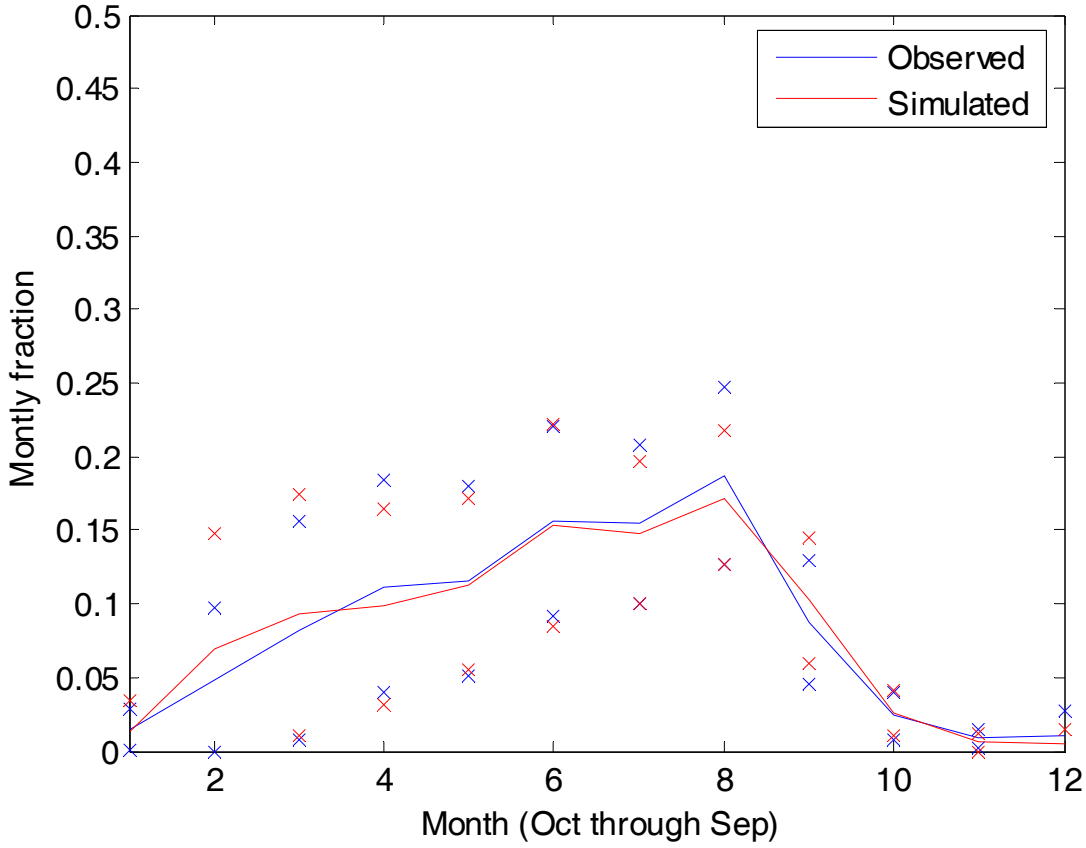


Figure APF-13. Observed and simulated monthly mean (± standard deviation) flow expressed as a fraction of annual flow volume for the Trinity Lake inflow

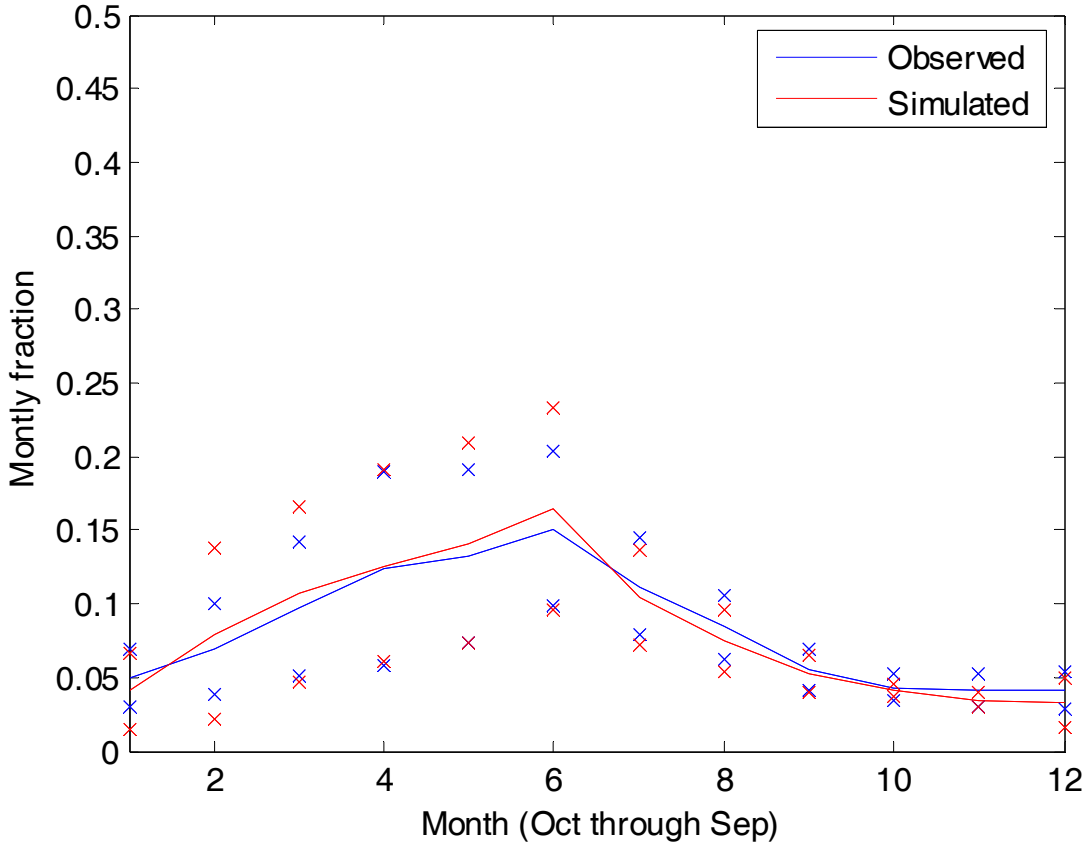


Figure APF-14. As in Figure APF-13 except presenting flows into Shasta Lake

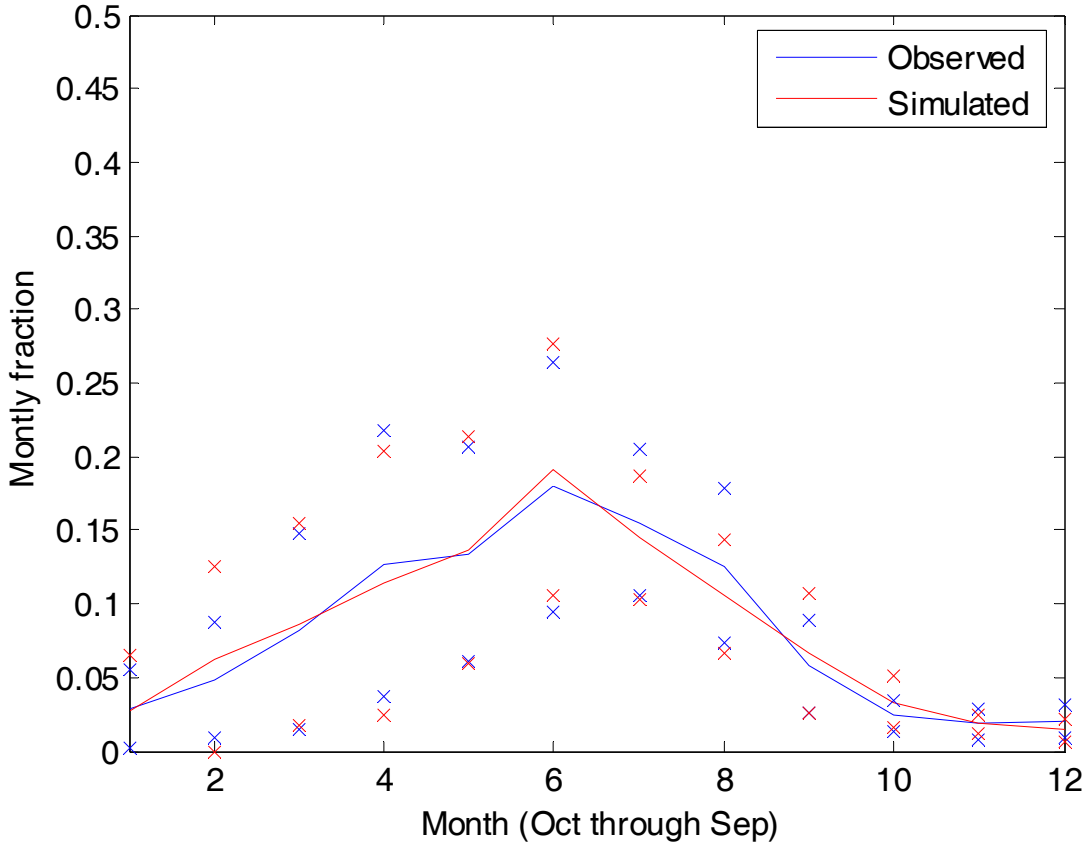


Figure APF-15. As in Figure APF-13 except presenting flows into Oroville Lake

Appendix G

Selected Reservoir, Hydropower Facility, and Demand Data

Table G-1. Reservoir Minimum and Maximum Elevations (H; meters) and Storages (S; thousand acre feet—TAF)

Reservoir Name	H^{min} (m)	H^{max} (m)	S^{min} (TAF)	S^{max} (TAF)
Clair Engle Lake	2145	2380	313	2617
Whiskeytown	1000	1223	0.23	284
Shasta	900	1068	1167	4347
Oroville	640	900	852.2	3537.8
Folsom	327	475.4	83	1082
New Melones	800	1100	273	2571
Tulloch	57	67	10	20
San Luis	300	546	15.5	2026
Black Butte	414.6	473.5	6.64	143.7
New Bullards Bar	1732	1955	233.6	960

Table G-2. Hydro Power Plant Units and Capacities (MW)

Power Plant	Units	Plant Capacity (MW)
Trinity	2	140
Lewiston	1	0.35
JF Carr	2	141.4
Spring Creek	2	150
Shasta	5	659
Keswick	3	75
Oroville	6	600
Folsom	3	210
Nimbus	2	13.5
New Melones	2	150
Black Butte		
New Bullards Bar	2	284

Table G-3. Monthly Average Inflows for Selected Locations (TAF)

Month	Whisktown	Keswick-Wilkens	Sacrament Misc	Eastside Streams	Delta Misc Creeks	New Melones	SJR
Jan	8.	-211.27	-100.	80.67	25.5	76.	133.
Feb	4.	-299.69	-220.	60.44	25.5	43.	31.
Mar	2.	-370.28	-330.	20.72	29.	34.	33.
Apr	1.	-267.47	-175.	21.89	19.	33.	28.
May	1.	-117.56	45.	28.71	11.1	31.	33.
Jun	2.	-125.	-15.	33.2	0.8	30.	71.
Jul	2.	-31.24	121.	30.74	0.9	30.	62.
Aug	4.	564.46	981.	21.52	1.2	30.	63.
Sep	8.	841.7	1465.	21.52	1.8	30.	78.
Oct	12.	1767.58	2482.	40.03	32.3	40.	94.
Nov	45.	1021.	1763.	67.33	17.4	70.	103.
Dec	16.	74.65	328.	146.34	15.4	110.	126.

Table G-4. Monthly Reservoir Parameters

Name	Month	S^{max} (TAF)	S^{min} (TAF)	S^{target} (TAF)	Evaporation Rate (feet)
Clair Engle	Jan	2287.00	312.63	2287.00	0.17
Clair Engle	Feb	2287.00	312.63	2287.00	0.13
Clair Engle	Mar	2287.00	312.63	2287.00	0.20
Clair Engle	Apr	2287.00	312.63	2287.00	0.39
Clair Engle	May	2287.00	312.63	2287.00	0.51
Clair Engle	Jun	2287.00	312.63	2287.00	0.58
Clair Engle	Jul	2287.00	312.63	2287.00	0.76
Clair Engle	Aug	2287.00	312.63	2287.00	0.71
Clair Engle	Sep	2287.00	312.63	2287.00	0.60
Clair Engle	Oct	2287.00	312.63	2287.00	0.30
Clair Engle	Nov	2287.00	312.63	2287.00	0.15
Clair Engle	Dec	2287.00	312.63	2287.00	0.09
WhiskeyTown	Jan	237.90	200.00	205.70	0.17
WhiskeyTown	Feb	237.90	200.00	205.70	0.13
WhiskeyTown	Mar	237.90	200.00	205.70	0.20
WhiskeyTown	Apr	237.90	200.00	237.90	0.39
WhiskeyTown	May	237.90	200.00	237.90	0.51
WhiskeyTown	Jun	237.90	200.00	237.90	0.58
WhiskeyTown	Jul	237.90	200.00	237.90	0.76
WhiskeyTown	Aug	237.90	200.00	237.90	0.71
WhiskeyTown	Sep	237.90	200.00	238.00	0.60
WhiskeyTown	Oct	237.90	200.00	230.00	0.30
WhiskeyTown	Nov	237.90	200.00	205.70	0.15
WhiskeyTown	Dec	237.90	200.00	205.70	0.09

Shasta	Jan	4552	1168	4552	0.17
Shasta	Feb	4552	1168	4552	0.13
Shasta	Mar	4552	1168	4552	0.20
Shasta	Apr	4552	1168	4552	0.39
Shasta	May	4552	1168	4552	0.51
Shasta	Jun	4552	1168	4552	0.58
Shasta	Jul	4552	1168	3882	0.76
Shasta	Aug	4552	1168	3252	0.71
Shasta	Sep	4552	1168	3252	0.60
Shasta	Oct	4552	1168	3872	0.30
Shasta	Nov	4552	1168	4252	0.15
Shasta	Dec	4552	1168	4552	0.09
Oroville	Jan	3538	855	3458	0.17
Oroville	Feb	3538	855	3538	0.13
Oroville	Mar	3538	855	3538	0.20
Oroville	Apr	3538	855	3538	0.39
Oroville	May	3538	855	3538	0.51
Oroville	Jun	3538	855	3343	0.58
Oroville	Jul	3538	855	3163	0.76
Oroville	Aug	3538	855	3163	0.71
Oroville	Sep	3538	855	3163	0.60
Oroville	Oct	3538	855	3163	0.30
Oroville	Nov	3538	855	3163	0.15
Oroville	Dec	3538	855	3163	0.09
Folsom	Jan	975	83	805	0.17
Folsom	Feb	975	83	975	0.13
Folsom	Mar	975	83	975	0.20
Folsom	Apr	975	83	975	0.39
Folsom	May	975	83	975	0.51
Folsom	Jun	975	83	975	0.58
Folsom	Jul	975	83	700	0.76
Folsom	Aug	975	83	575	0.71
Folsom	Sep	975	83	575	0.60
Folsom	Oct	975	83	575	0.30
Folsom	Nov	975	83	575	0.15
Folsom	Dec	975	83	675	0.09
New Melones	Jan	2420	273	2230	0.17
New Melones	Feb	2420	273	2420	0.13
New Melones	Mar	2420	273	2420	0.20
New Melones	Apr	2420	273	2420	0.39
New Melones	May	2420	273	2420	0.51
New Melones	Jun	2420	273	2270	0.58

New Melones	Jul	2420	273	1970	0.76
New Melones	Aug	2420	273	1970	0.71
New Melones	Sep	2420	273	1970	0.60
New Melones	Oct	2420	273	1970	0.30
New Melones	Nov	2420	273	1970	0.15
New Melones	Dec	2420	273	2040	0.09
Tulloch	Jan	67	57	57	0.00
Tulloch	Feb	67	57	57	0.00
Tulloch	Mar	67	57	58	0.00
Tulloch	Apr	67	57	60	0.00
Tulloch	May	67	57	67	0.00
Tulloch	Jun	67	57	67	0.00
Tulloch	Jul	67	57	67	0.00
Tulloch	Aug	67	57	67	0.00
Tulloch	Sep	67	57	62	0.00
Tulloch	Oct	67	57	57	0.00
Tulloch	Nov	67	57	57	0.00
Tulloch	Dec	67	57	57	0.00
San Luis	Jan	2027	450.00	1000.00	0.17
San Luis	Feb	2027	631.60	1464.02	0.13
San Luis	Mar	2027	748.10	1806.84	0.20
San Luis	Apr	2027	835.60	1975.02	0.39
San Luis	May	2027	879.92	1976.43	0.51
San Luis	Jun	2027	694.72	1546.00	0.58
San Luis	Jul	2027	442.12	1062.95	0.76
San Luis	Aug	2027	181.12	642.62	0.71
San Luis	Sep	2027	9.72	352.64	0.60
San Luis	Oct	2027	8.32	312.90	0.30
San Luis	Nov	2027	115.02	354.13	0.15
San Luis	Dec	2027	286.72	514.21	0.09

Table G-5. Monthly Minimum and Target River Flows

Name	Month	R^{min} (cfs)	R^{target} (cfs)
Lewiston	Jan	300	300
Lewiston	Feb	300	300
Lewiston	Mar	300	300
Lewiston	Apr	300	300
Lewiston	May	3939	300
Lewiston	Jun	2507	783

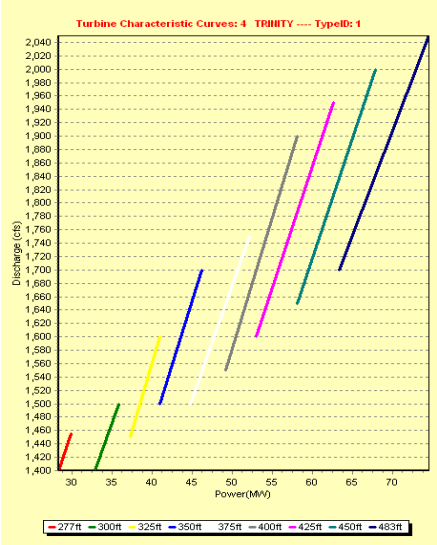
Lewiston	Jul	1102	450
Lewiston	Aug	450	450
Lewiston	Sep	450	450
Lewiston	Oct	373	0
Lewiston	Nov	300	300
Lewiston	Dec	300	300
Clear Creek	Jan	150	150
Clear Creek	Feb	200	200
Clear Creek	Mar	200	200
Clear Creek	Apr	200	200
Clear Creek	May	200	200
Clear Creek	Jun	200	200
Clear Creek	Jul	200	200
Clear Creek	Aug	200	200
Clear Creek	Sep	200	200
Clear Creek	Oct	200	200
Clear Creek	Nov	90	90
Clear Creek	Dec	90	90
Spring Creek	Jan	325	325
Spring Creek	Feb	306	306
Spring Creek	Mar	2749	2749
Spring Creek	Apr	252	252
Spring Creek	May	813	813
Spring Creek	Jun	1681	1681
Spring Creek	Jul	2602	2602
Spring Creek	Aug	2114	2114
Spring Creek	Sep	2017	2017
Spring Creek	Oct	1138	1138
Spring Creek	Nov	504	504
Spring Creek	Dec	244	244
Keswick	Jan	3250	3250
Keswick	Feb	3250	3250
Keswick	Mar	3250	3250
Keswick	Apr	8000	8000
Keswick	May	9600	9600
Keswick	Jun	11000	11000
Keswick	Jul	14500	14500
Keswick	Aug	12000	12000
Keswick	Sep	5500	5500
Keswick	Oct	7200	7200
Keswick	Nov	5700	5700
Keswick	Dec	3250	3250

Wilkins	Jan	0	0
Wilkins	Feb	0	0
Wilkins	Mar	0	0
Wilkins	Apr	5000	5000
Wilkins	May	5000	5000
Wilkins	Jun	5000	5000
Wilkins	Jul	5000	5000
Wilkins	Aug	5000	5000
Wilkins	Sep	5000	5000
Wilkins	Oct	5000	5000
Wilkins	Nov	0	0
Wilkins	Dec	0	0
FeatherBelowThermalito	Jan	1250	0
FeatherBelowThermalito	Feb	1250	0
FeatherBelowThermalito	Mar	1250	0
FeatherBelowThermalito	Apr	1250	0
FeatherBelowThermalito	May	2030	0
FeatherBelowThermalito	Jun	0	2706
FeatherBelowThermalito	Jul	0	5692
FeatherBelowThermalito	Aug	5040	5156
FeatherBelowThermalito	Sep	0	4386
FeatherBelowThermalito	Oct	1980	2683
FeatherBelowThermalito	Nov	1750	1815
FeatherBelowThermalito	Dec	1250	0
AmericanRiverbelowNimbus	Jan	800	0
AmericanRiverbelowNimbus	Feb	800	0
AmericanRiverbelowNimbus	Mar	1000	0
AmericanRiverbelowNimbus	Apr	1500	0
AmericanRiverbelowNimbus	May	2300	0
AmericanRiverbelowNimbus	Jun	1800	0
AmericanRiverbelowNimbus	Jul	0	0
AmericanRiverbelowNimbus	Aug	0	0
AmericanRiverbelowNimbus	Sep	0	0
AmericanRiverbelowNimbus	Oct	0	0
AmericanRiverbelowNimbus	Nov	1000	0
AmericanRiverbelowNimbus	Dec	800	0
Goodwin	Jan	175	175
Goodwin	Feb	150	150
Goodwin	Mar	268	268
Goodwin	Apr	760	760
Goodwin	May	800	800

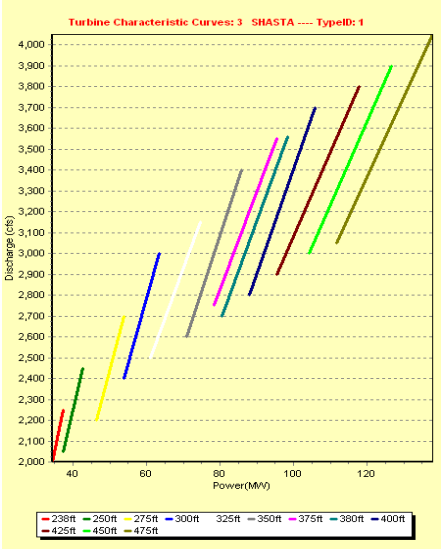
Goodwin	Jun	561	561
Goodwin	Jul	396	396
Goodwin	Aug	352	352
Goodwin	Sep	240	240
Goodwin	Oct	200	200
Goodwin	Nov	200	200
Goodwin	Dec	200	200
DeltaExit	Jan	6001	6001
DeltaExit	Feb	11398	11398
DeltaExit	Mar	11401	11401
DeltaExit	Apr	7848	7848
DeltaExit	May	9319	9319
DeltaExit	Jun	7092	7092
DeltaExit	Jul	6505	6505
DeltaExit	Aug	4261	4261
DeltaExit	Sep	3008	3008
DeltaExit	Oct	4001	4001
DeltaExit	Nov	4655	4655
DeltaExit	Dec	4505	4505

Table G-6. Monthly Base Demands (TAF)

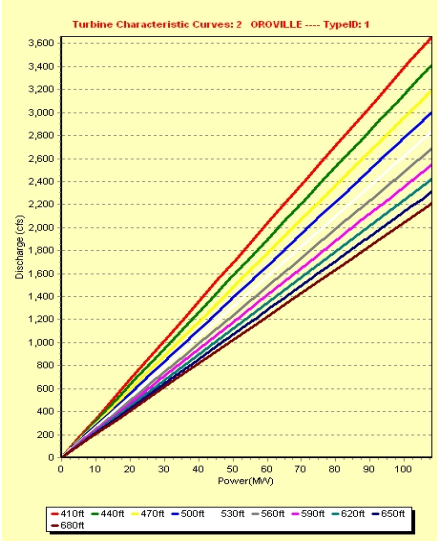
Month	Thermalito	Folsom Pumping	Folsom South Canal	OID/SSJID	Total Delta Consumption	Total South Export
1	35.00	4.00	0.96	0.00	-54.00	183.98
2	0.00	4.00	0.96	0.00	-31.90	245.18
3	11.00	4.00	1.20	14.00	-4.00	330.82
4	67.00	7.00	1.44	60.00	71.20	316.35
5	189.00	8.00	2.16	90.00	126.80	673.33
6	178.00	12.00	2.88	90.00	198.70	777.04
7	200.00	13.00	3.60	95.00	275.10	961.33
8	178.00	12.00	3.60	95.00	259.10	835.98
9	78.00	10.00	2.88	74.00	179.90	537.74
10	95.00	7.00	1.92	14.00	120.00	391.78
11	104.00	5.00	1.44	0.00	56.80	282.92
12	71.00	4.00	0.96	0.00	4.30	135.80



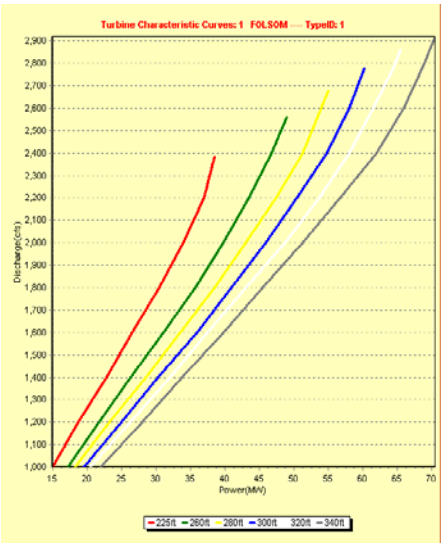
a) Trinity



b) Shasta



c) Oroville



d) Folsom

Figure G-1. Turbine Characteristic Curves for Trinity, Shasta, Oroville, and Folsom

Appendix H

Historical Analog Streamflow Forecasting Model

The Historical Analog model (*Yao and Georgakakos, 2001*) produces forecasts based on information derived from the historical record. The underlying idea is that similar climatic and hydrologic conditions are followed by similar conditions for some time in the future. More specifically, streamflows and other hydrologic quantities materialize as a result of a nonlinear hydro-climatic process orbiting around an unknown attractor set. Although this set is not easily definable, this premise leads to the following conjecture: If the process is presently at a certain point in its orbit, its position in the near future can potentially be inferred by observing the movement it experienced on similar occasions in the past.

For example, streamflows are the result of the rainfall-runoff process, and the values they assume over a certain time period depend on various hydro-climatic factors including watershed rainfall, temperature, and soil moisture conditions. Thus, if the climate-watershed system tends to revisit the neighborhood of certain conditions (states), it should also tend to generate similar streamflow patterns.

In keeping with the above, the historical analog model "searches" the historical record and selects several inflow traces which, at some time in the past, have started from conditions similar to those of the current inflow sequence. Each one of these traces is a possible future realization of the inflow process and all together constitutes a set on which to base probabilistic, multi-lead forecasts.

Thus, suppose that the present time is April 1st, and the previous days' inflows were $W_1, W_2,...,W_n$, where subscript "1" represents the last day in March, "2" the day before that, etc., and n is a parameter related to the process memory. Namely, $[W_1, W_2,...,W_n]$ is the most recent inflow sequence to April 1st. The next step in the implementation of the historical analog model is to retrieve all inflow traces of the same month and date as the $W_1, W_2,...,W_n$ from the historical record and compute their Euclidian distance, E_j , from the current sequence:

$$E_j = [(W_1 - W_{1,j}) + (W_2 - W_{2,j}) \ldots + (W_n - W_{n,j})]^{0.5} \;,\; j=1, 2, \ldots, m,$$

where $W_{i,j}$ is the historical inflow of year j at the same calendar date as W_i; m is the number of years in the historical record; and E_j measures the proximity of $[W_{i,j}$, i=1, 2, ..., n] to the most recent inflows $[W_i$, i=1, 2, ..., n]. A small value of E_j implies that the $W_{i,j}$ sequence is in the neighborhood of W_i. The inflows following $W_{i,j}$ are known (as part of the historical record) and can be used as the forecasts of the inflows following W_i. To generate multiple forecast traces, one can rank the E_j's from smallest to largest, select the top portion of the ranked list, and use the corresponding historical inflows following $W_{i,j}$ as possible future inflow realizations. It is noted that several other ways may be used to measure the proximity of the historical to the most recent streamflow sequences. The reasons for using this particular scheme are that it is easy to implement while providing a benchmark for comparing other forecast schemes.

Appendix I

River Index Calculation and Water Year Characterization

Water Year Type and River Index Definitions

River Indices

(http://cdec.water.ca.gov/cgi-progs/iodir/wsi; Website of the California Department of Water Resources)

The Sacramento valley 40-30-30 index for water year types; Wet, Above Normal, Below Normal, Dry, and Critical, is used to determine year types for Delta outflow criteria and Sacramento system requirements.

The San Joaquin Valley 60-20-20 Index is used to determine year types for flow requirements at Vernalis.

The Sacramento River Index (SRI), is used to trigger relaxation criteria related to May-June Net Delta Outflow (NDO) requirements. The SRI refers to the sum of the unimpaired runoff in the water year as published in the DWR Bulletin 120 for the Sacramento River at Bed Bridge, Feather River inflow to Oroville, Yuba River at Smartville, and American River inflow to Folsom reservoir.

The Eight River Index is used to trigger criteria related to January Net Delta Outflow, February to June X2 standards and February export restrictions. The eight river index refers to the unimpaired runoff for the four locations mentioned under SRI plus Stanislaus River inflow to New Melones Reservoir, Tuolumne River inflow to Don Pedro Reservoir, Merced River inflow to Exchequer Reservoir and San Joaquin River inflow to Millerton Lake.

Sacramento River Runoff is the sum of unimpaired flow in million acre-feet at:

- Sacramento River above Bend Bridge;
- Feather River at Oroville (aka inflow to Lake Oroville);
- Yuba River near Smartville;
- American River below Folsom Lake.

Also known as the "Sacramento River Index", this index was previously used to determine year type classifications under SWRCB Decision 1485.

Also previously referred to as the "4 River Index" or "4 Basin Index".

Index = 0.4 * Current Apr-Jul Runoff *(1)*

+ 0.3 * Current Oct-Mar Runoff *(1)*

+ 0.3 * Previous Year's Index *(2)*

Notes:

(1) Runoff is the sum of unimpaired flow in million acre-feet at:

Sacramento River above Bend Bridge;

Feather River at Oroville (aka inflow to Lake Oroville);

Yuba River near Smartville;

American River below Folsom Lake.

(2) Maximum 10.0 for previous year index term.

Year Type Classification

- Index based on flow in million acre-feet:

Wet	Equal to or greater than 9.2
Above Normal	Greater than 7.8, and less than 9.2
Below Normal	Greater than 6.5, and equal to or less than 7.8
Dry	Greater than 5.4, and equal to or less than 6.5
Critical	Equal to or less than 5.4

This index, originally specified in the 1995 SWRCB Water Quality Control Plan, is used to determine the Sacramento Valley water year type as implemented in SWRCB D-1641. Year types are set by first of month forecasts beginning in February. Final determination is based on the May 1 50% exceedence forecast.

- San Joaquin Valley Water Year Type Index (60-20-20)

Water Year Index based on flow in million acre feet

Index = 0.6 * Current Apr-Jul Runoff *(1)*

+ 0.2 * Current Oct-Mar Runoff *(1)*

+ 0.2 * Previous Year's Index *(2)*

Notes:

(1) Runoff is the sum of unimpaired flow in million acre-feet at:

Stanislaus River below Goodwin Reservoir (aka inflow to New Melones Res.)

Tuolumne River below La Grange (aka inflow to New Don Pedro Reservoir)

Merced River below Merced Falls (aka inflow to Lake McClure)

San Joaquin River inflow to Millerton Lake;

(2) Maximum 4.5 for previous year index term

- Year Type Classification: Index based on flow in million acre-feet:

Wet	Equal to or greater than 3.8
Above Normal	Greater than 3.1, and less than 3.8
Below Normal	Greater than 2.5, and equal to or less than 3.1
Dry	Greater than 2.1, and equal to or less than 2.5
Critical	Equal to or less than 2.1

This index, originally specified in the 1995 SWRCB Water Quality Control Plan, is used to determine the San Joaquin Valley water year type as implemented in SWRCB D-1641. Year types are set by first of month forecasts beginning in February. Final determination for San Joaquin River flow objectives is based on the May 1 75% exceedence forecast.

- Sacramento Valley and San Joaquin 8 River Index

This index is the sum of the previous month's unimpaired runoff for the 8 rivers that are included in the above Sacramento River Unimpaired Runoff and San Joaquin Valley Water Year Type Index. A listing of reconstructed indices based on historical observed runoff is posted at http://cdec.water.ca.gov/water_supply.html. The official year types are based on May 1st's forecasts, not the observed runoff.