Appendix S1. Hydrologic model description and performance evaluation

Hydrologic models were developed using Random Forests (RF) (Breiman 2001), a statistical modeling technique used for prediction and classification (e.g., Cutler et al. 2007). The RF modeling approach is described in detail in Carlisle et al. 2010 and applied here to predict expected, unimpaired flow metrics at select gage and dam locations. Briefly, RF are a model-averaging technique that produces thousands of regression trees, each with a bootstrapped sample of 70% of observations and a randomly selected subset of predictor variables considered at each branch. The remaining 30% of observations are withheld to evaluate model performance. RF models are implemented in R with the randomForest package (Liaw and Wiener 2002).

Separate RF models were developed to predict mean monthly, mean annual, and maximum 1-day flows. The models used data from 180 reference gages and 120 catchment predictor variables (e.g., climate, topography, soils and geology) in the Gages-II database (Falcone et al. 2011). Model predictions were compared with randomized subsets observed data withheld during RF model development to calculate several model performance metrics (Moriasi et al. 2007), including the coefficient of determination (r^2), Nash–Sutcliffe coefficient, and percent bias. In addition, predictive performance was assessed by sequentially excluding individual reference gages and re-running the models to evaluate observed against predicted (O/E) values at the omitted site. To improve predictive performance of the monthly and 1-day maximum flow models, separate models were developed for three subregions of California, which follow EPA Level-III ecoregion (Omernik 2007) boundaries and encompass the state's interior mountain, coastal mountain, and xeric regions. A single statewide model was used for predicting annual flow.

Flow alteration assessment at gages below dams. The models were used to predict unimpaired mean monthly and maximum 1-day flows at (non-reference) gages located below dams, based on the same set of catchment predictor variables used in model training. Observed values at the gage sites were obtained for each water year in the period of record between 1950 and 2010, and divided by model-predicted values from the respective water year. Mean O/E value for each metric was then calculated for each site over the period of record.

Model performance varied by region and by flow metric (Table S1.1-S1.3). The monthly and 1-day maximum flow models performed best in the Interior Mountain and Coastal Mountain regions, with $r^2 > 0.80$, percent bias less than 10% and NSE > 0.85 for most months. The monthly models were less accurate in the Xeric region, with lower r^2 and NSE values and greater bias. However, the monthly models for all regions performed well at predicting flows at omitted sites, with average O/E values of >0.90 for all months and SD <0.50. For maximum 1-day flows, the average O/E value at omitted sites was >0.85, with a SD < 0.4 for the Coastal Mountain and Interior Mountain regions and 0.78 for the Xeric Region.

Estimating degree of regulation (DOR). RF models were also developed to predict mean annual flow at all dam locations (n=753). The suite of geospatial predictor variables were generated for all delineated dam catchments. The annual model was used to predict flows at each dams for 61 water years (1950-2010), which were then averaged to obtain long-term mean annual flow. Units were converted to mean annual runoff (in m^3) and compared with the local and cumulative storage volume (i.e., total reservoir storage in the dam catchment), to estimate degree-of-regulation (DOR) and cumulative DOR (CDOR) metrics. The model performed well in predicting annual flow values at omitted sites, with high accuracy and limited bias (Table S1.4).

Table S1.1. Performance of monthly and maximum 1-day flow in Coastal Mountain Zone

Model	r^2	Nash Sutcliffe	% Bias	Mean O/E	SD O/E
January	0.92	0.91	3.26	0.94	0.31
February	0.88	0.88	-1.38	0.97	0.31
March	0.93	0.93	0	0.95	0.29
April	0.92	0.92	5.17	0.96	0.3
May	0.84	0.83	9.23	0.94	0.34
June	0.81	0.8	10.04	0.93	0.38
July	0.81	0.75	12.38	0.93	0.31
August	0.85	0.8	12.05	0.85	0.31
September	0.83	0.76	15.47	0.9	0.31
October	0.84	0.84	2.78	0.97	0.4
November	0.88	0.88	-2.1	0.94	0.37
December	0.94	0.94	1.57	0.93	0.32
Maximum 1-day	0.89	0.89	-4.1	0.93	0.39

Table S1.2. Performance of monthly and maximum 1-day flow in Interior Mountain Zone

Model	r^2	Nash Sutcliffe	% Bias	Mean O/E	SD O/E
January	0.72	0.78	3.38	0.98	0.43
February	0.73	0.73	6.74	0.97	0.4
March	0.88	0.86	5.01	0.97	0.3
April	0.87	0.87	3.78	0.97	0.28
May	0.93	0.92	7.3	0.95	0.26
June	0.94	0.94	1.68	0.93	0.31
July	0.90	0.90	-0.29	0.98	0.42
August	0.82	0.81	-9.15	0.95	0.39
September	0.67	0.67	-2.75	0.91	0.42
October	0.84	0.82	-8.33	1.01	0.38
November	0.83	0.82	-6.48	1.05	0.46
December	0.84	0.83	1.75	0.99	0.49
Maximum 1-day	0.91	0.89	-6.2	0.93	0.42

Table S1.3. Performance of monthly and maximum 1-day flow in Xeric Zone

Model	r^2	Nash Sutcliffe	% Bias	Mean O/E	SD O/E
January	0.51	0.48	-1.27	0.96	0.54
February	0.66	0.66	-0.69	0.95	0.49
March	0.56	0.54	-3.34	0.96	0.45
April	0.58	0.55	-5.17	0.95	0.45
May	0.68	0.66	-5.81	0.97	0.4
June	0.67	0.64	-7.64	0.98	0.37
July	0.63	0.57	-11.53	0.98	0.34
August	0.58	0.42	-16.77	0.98	0.35
September	0.61	0.56	-9.72	0.98	0.32
October	0.36	0.33	-12.74	0.97	0.38
November	0.61	0.61	-6.61	0.93	0.46
December	0.75	0.75	-1.27	0.95	0.54
Maximum 1-day	0.74	0.73	-1.06	0.86	0.78

Table S1.4. Performance of annual flow model, used for estimating degree-of-regulation (DOR) at dam locations

Model	r^2	Nash Sutcliffe	% Bias	Mean O/E	SD O/E
Annual flow	0.95	0.94	1.21	0.94	0.30

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