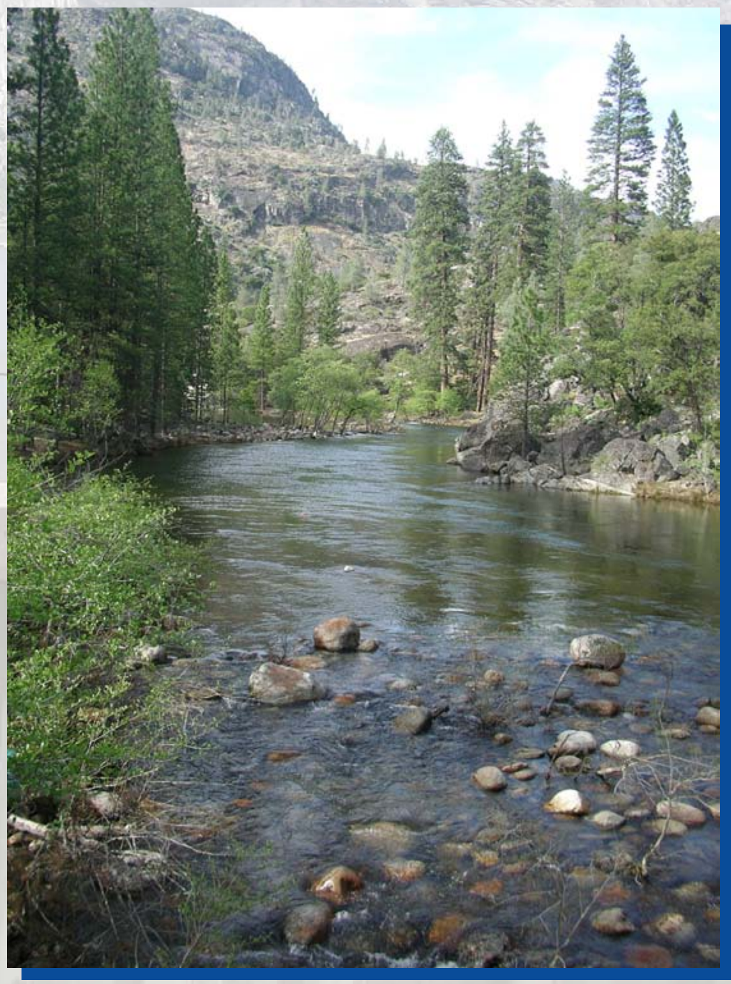
Upper Tuolumne River: Available Data Sources, Field Work Plan, and Initial Hydrology Analysis



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Upper Tuolumne River:
Available Data Sources, Field Work Plan, and Initial Hydrology Analysis

Final Report

Prepared by:

RMC Water and Environment

and

McBain & Trush, Inc.

October 2006

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List of Abbreviations

ab	above
CCblDHPH	Cherry Creek below Don Holm Powerhouse
CCblVD	Cherry Creek below Valley Dam
CCEI	Cherry Creek near Early Intake
CDFG	California Department of Fish and Game
CDT	Cherry Diversion Tunnel
CDWR	California Department of Water Resources
cfs	cubic feet per second
DA	drainage area
EC	Eleanor Creek near Hetch Hetchy
ECDT	Eleanor-Cherry Diversion Tunnel
FERC	Federal Energy Regulatory Commission
ft	feet
mi^2	square miles
MRPB	Merced River at Pohono Bridge near Yosemite
NPS	National Park Service
nr	near
Qe	estimated streamflow
Qg	gaged streamflow
RM	River Mile
S.J. River	San Joaquin River
S_d	reservoir storage
SFPUC	San Francisco Public Utilities Commission
TID	Turlock Irrigation District
TRblEI	Tuolumne River below Early Intake
TRBM	Tuolumne River near Buck Meadow
TRCC	Tuolumne River at Cherry Creek confluence
TRHH	Tuolumne River near Hetch Hetchy
TRPT	Tuolumne River Preservation Trust
USDI	U.S. Department of Interior
USFS	U.S. Forest Service
USFS	United States Forest Service

USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WY	water year

Section 1 Introduction

The San Francisco Public Utilities Commission (SFPUC) owns and operates the Hetch Hetchy Water and Power system. This system, located in the upper Tuolumne River watershed, includes dams and flow diversions on the Tuolumne River, Cherry Creek (a tributary to the Tuolumne River), and Eleanor Creek (a tributary to Cherry Creek). As part of establishing a common foundation of environmental information for the river and stream reaches affected by operation of the Hetch Hetchy system, the SFPUC Natural Resources and Hetch Hetchy Water and Power Divisions have embarked on an intensive one-year effort to describe current ecological and geomorphic conditions in the Tuolumne River from O'Shaughnessy Dam to New Don Pedro Reservoir, Cherry Creek downstream of Cherry Lake Dam, and Eleanor Creek downstream of Lake Eleanor Dam. Numerous agencies and other stakeholders are also contributing to this study, including the Yosemite National Park Service (NPS), U.S. Fish and Wildlife Service (USFWS), and the U.S. Forest Service (USFS). Study plans and reports will also be reviewed by the Tuolumne River Stakeholder Group, which includes representatives from federal, state, and local agencies; local water districts; environmental organizations; and the whitewater rafting community.

This first year effort to establish a common foundation from which future work will be developed includes four phases:

1. Identify and compile existing information, identify key information gaps, and develop a reconnaissance-level field plan to begin gathering additional information in 2006;
2. Implement the 2006 field plan;
3. Summarize and synthesize available information and information collected in 2006 in an initial report that describes current ecologic and geomorphic conditions in key reaches below the Hetch Hetchy project; and
4. Identify short- and long-term future monitoring activities necessary to build on this foundation.

This technical memorandum presents the results of the first phase described above.

The draft initial report is scheduled for completion in January 2007, and its purposes are to:

1. Inform existing Hetch Hetchy project operations to promote opportunities to protect ecologic and geomorphic values within the context of meeting current water supply, power generation, and water quality objectives, and minimum flow requirements;
2. Describe key flow-related river ecosystem processes and how these processes are affected by historic and current Hetch Hetchy project operations;
3. Guide future work to better understand the relationship between the Tuolumne River ecosystem and Hetch Hetchy project operations; and
4. Identify short- and long-term annual monitoring activities necessary to support this work.

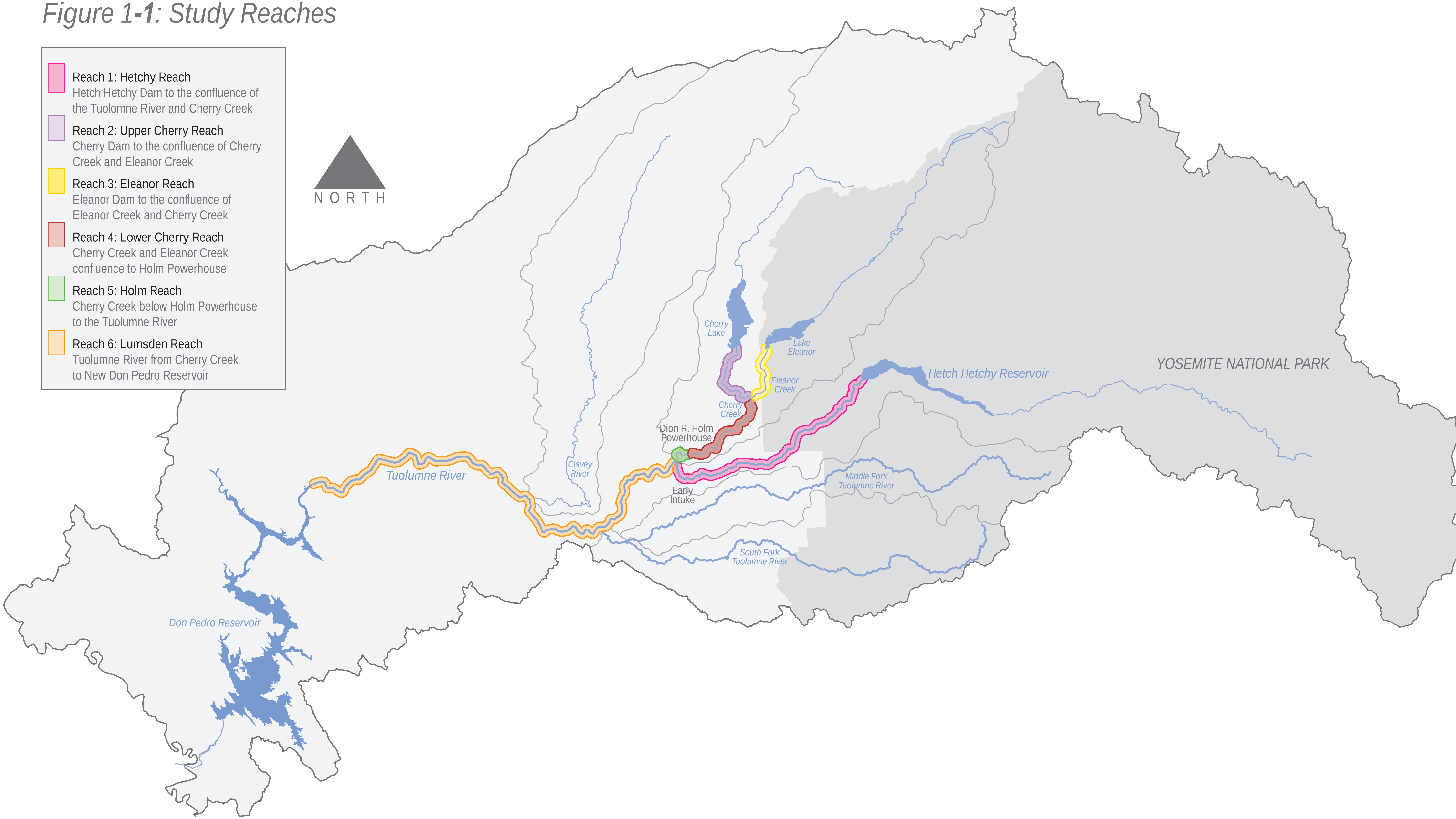
Supporting documents compiled or generated by this effort will be made available to the Tuolumne River Stakeholder Group and other interested parties.

Based on the effect of Hetch Hetchy project operations, the study area is broken down into six specific reaches (Figure 1-1):

- Hetchy Reach – O'Shaughnessy Dam (RM 117.5) to the Cherry Creek confluence (RM 103.8);
- Upper Cherry Reach – Cherry Valley Dam (RM 11.3) to the Eleanor Creek confluence (RM 7.0);
- Eleanor Reach – Eleanor Dam (RM 3.5) to the confluence with Cherry Creek (RM 0);
- Lower Cherry Reach –Eleanor Creek confluence (RM 7.0) to Holm Powerhouse (RM 0.8);

- Holm Reach –Holm Powerhouse (RM 0.8) to the confluence with the Tuolumne River (RM 0); and
- Lumsden Reach – Tuolumne River from Cherry Creek confluence (RM 103.8) to New Don Pedro Reservoir (RM 78.5).

Figure 1-1: Study Reaches



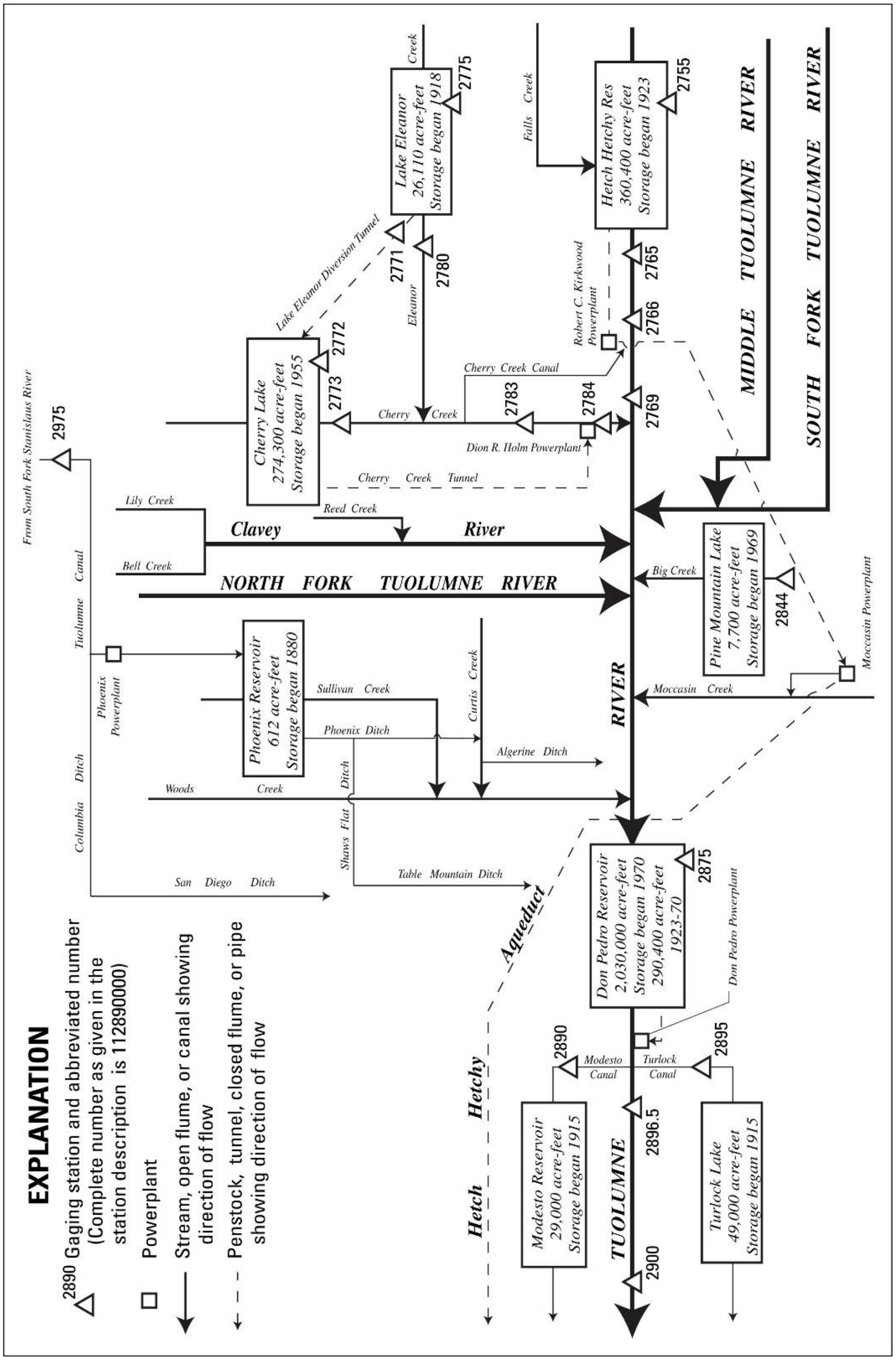
Section 2 Hetch Hetchy Facilities in the Study Area

The Tuolumne River is one of the largest rivers draining the western slope of the Sierra Nevada Range. Its watershed encompasses 1,960 mi^2 on the western slope of the Sierra Nevada Range and extends from the peaks of Mt. Lyell and Mt. Dana (peak elevations exceed 13,000 ft) in Yosemite National Park to the Central Valley's San Joaquin River (elevation 40 ft). Within the study area, most of the watershed is within Yosemite National Park and the Stanislaus National Forest. The upper 6.5 miles (47%) of the Hetchy Reach and the upper 2.8 miles (80%) of the Eleanor Reach are within Yosemite National Park. The remainder of Hetchy and Eleanor Reaches, as well as the Upper Cherry Reach, Lower Cherry Reach, Holm Reach, and the upper 22.2 miles (88%) of the Lumsden Reach are within the Stanislaus National Forest. The lower 3.1 miles of the Lumsden Reach are within lands managed by the Bureau of Land Management. At the downstream end of the study area, the river flows into New Don Pedro Reservoir. The entire mainstem river within the study area, except a short section at Early Intake, is federally-designated as a Wild and Scenic River.

In the Tuolumne River watershed, Hetch Hetchy Water and Power Project includes facilities on the Tuolumne River, Moccasin Creek (a tributary to the Tuolumne River), Cherry Creek (a tributary to the Tuolumne River), and Eleanor Creek (a tributary to Cherry Creek) (Figure 2-1). The project was constructed in phases beginning in 1917 and continues to evolve as facilities and operations are modified to meet current needs and objectives. Project facilities and key dates in project development relevant to its effects on flow are:

- 1918: Eleanor Dam and Early Intake Powerhouse begin storing and diverting runoff from the upper 78 mi^2 of the Eleanor Creek watershed to the Tuolumne River. Water is stored in Lake Eleanor (27,100 acre-feet). Water released from the reservoir flows through the Eleanor Reach and is diverted at the Lower Cherry Creek Aqueduct (160–200 cfs) to Early Intake Powerhouse on the Tuolumne River. Powerhouse outflow is released to the Tuolumne River.
- 1923: O'Shaughnessy Dam (Hetch Hetchy Reservoir [260,000 acre-feet]) begins storing runoff from the upper 457 mi^2 of the Tuolumne River watershed.
- 1925: Early Intake Diversion Dam and Mountain Tunnel begin diverting water from the Tuolumne River. Water released from Hetch Hetchy Reservoir and Early Intake Powerhouse (diverted from Cherry and Eleanor creeks) is diverted at Early Intake Diversion Dam to Mountain Tunnel, which conveys up to 670 cfs to Moccasin Powerhouse.
- 1938: O'Shaughnessy Dam crest raised 85.5 feet, increasing Hetch Hetchy Reservoir capacity to 360,360 acre-feet. Increased storage allows an increase in the annual volume of water that is diverted at Early Intake to Moccasin Powerhouse and then to the Bay Area. (Aqueduct connection to the Bay Area was completed in 1934.)
- 1950: Department of the Interior and SFPUC agree to minimum flow schedule for Cherry Creek downstream of Cherry Valley Dam.
- 1956: Department of the Interior and SFPUC agree to minimum flow schedule for Eleanor Creek downstream of Eleanor Dam.
- 1955: Cherry Valley Dam begins storing runoff from the upper 117 mi2 of the Cherry Creek watershed. Until the Holm Powerhouse is completed in 1960, water stored in Cherry Lake (274,300 acre-feet) is released downstream to the Upper Cherry and Lower Cherry reaches. The Lower Cherry Creek Aqueduct continues to divert 160–200 cfs to Early Intake Powerhouse on the Tuolumne River. Cherry Valley Dam is operated for hydropower generation and providing water to be stored at Don Pedro Reservoir. Until the New Don Pedro Project is completed in 1971, Cherry Valley Dam is also operated to reduce flood inflow to Don Pedro Reservoir.

Figure 2-1. Schematic Diagram Showing Reservoirs and Flow Diversions in the Tuolumne River Watershed (source: USGS 2004)



- 1960: Diversions from Lake Eleanor to Cherry Lake and from Cherry Lake to Holm Powerhouse begin. Water from Lake Eleanor is diverted to Cherry Lake via the Eleanor-Cherry Diversion Tunnel and Pump Station. Cherry Creek flows and inflow from Lake Eleanor are diverted from Cherry Lake to Holm Powerhouse via Cherry Power Tunnel. The tunnel, which can divert 810 cfs (with Cherry Lake empty) to 990 cfs (with Cherry Lake full), bypasses flows around the Upper Cherry, Eleanor, and Lower Cherry reaches. Outflow from Holm Powerhouse discharges to the Tuolumne River at the upstream end of the Holm Reach. With the completion of Holm Powerhouse, the Lower Cherry Aqueduct is no longer required for power generation, and the Early Intake Powerhouse is dismantled. The Lower Cherry Aqueduct is retained and used to divert water from Cherry Creek to the Hetch Hetchy Aqueduct during critical drought years.
- 1961: Department of the Interior and SFPUC agree to interim minimum flow schedule for the Tuolumne River downstream of O'Shaughnessy Dam.
- 1967: Canyon Power Tunnel begins operating. Canyon Tunnel diverts water from Hetch Hetchy Reservoir to Kirkwood Powerhouse. The project shifts the SFPUC point of diversion from Early Intake to O'Shaughnessy Dam (bypassing flow around the Hetchy Reach). Water stored in Hetch Hetchy Reservoir is either diverted to Kirkwood and then Moccasin powerhouses and into the SFPUC watery delivery system, or released downstream to Lake New Don Pedro from Kirkwood or Moccasin. Water from Hetch Hetchy Reservoir can be released through 14 outlet conduits, three of which connect to the Canyon Tunnel and 11 of which release water downstream. The downstream outlets have a maximum capacity of approximately 10,000 cfs.

  After passing through the powerhouse, up to 670 cfs of the flow diverted from Hetch Hetchy can be routed directly to Mountain Tunnel and Moccasin Powerhouse without returning to the Tuolumne River. Powerhouse outflows exceeding 670 cfs are discharged to the Tuolumne River at Early Intake Reservoir. Moccasin Powerhouse flows in excess of SFPUC water delivery are discharged to Don Pedro Reservoir for 5-6 months per year. While the Canyon Tunnel diversion capacity is 1,400 cfs, the generation capacity limit at Kirkwood Powerhouse is 920 cfs. Until the additional generator is added at Kirkwood Powerhouse in 1988, Canyon Tunnel diversion is operated at or below 920 cfs.
- 1982: Department of the Interior and SFPUC agree to amend minimum flow schedule below Eleanor Dam.
- 1984: Department of the Interior and SFPUC agree to revised minimum flow schedule below O'Shaughnessy Dam.
- 1986: Cherry Lake operations revised to increase carry-over storage. Before 1986, operations typically drafted Cherry Lake to between 50,000 and 100,000 acre-feet each year. Revised operations increase minimum storage at Cherry Lake to between 150,000 and 200,000 acre-feet, increasing spill frequency and volume to the Upper Cherry and Lower Cherry reaches and reducing summer outflow from Holm Powerhouse.
- 1987: Department of the Interior and SFPUC agree to further revise minimum flow schedule below O'Shaughnessy Dam.
- 1988: Third generator added at Kirkwood Powerhouse increases powerhouse capacity to 1,400 cfs, allowing the Canyon Tunnel to operate at its diversion capacity.
- 1993: After facing water supply shortages during the six-year 1987–1993 drought, a major change is instituted to increase the firm yield of the SFPUC water system. Reservoir operations are modified significantly to increase water supply reliability. Increased carry-over storage at the three project reservoirs increases frequency and magnitude or duration of spills to all reaches in the study area.

Section 3 Preliminary Analysis of the Effects of Hetch Hetchy Project Facilities and Operations on Flow in Study Reaches

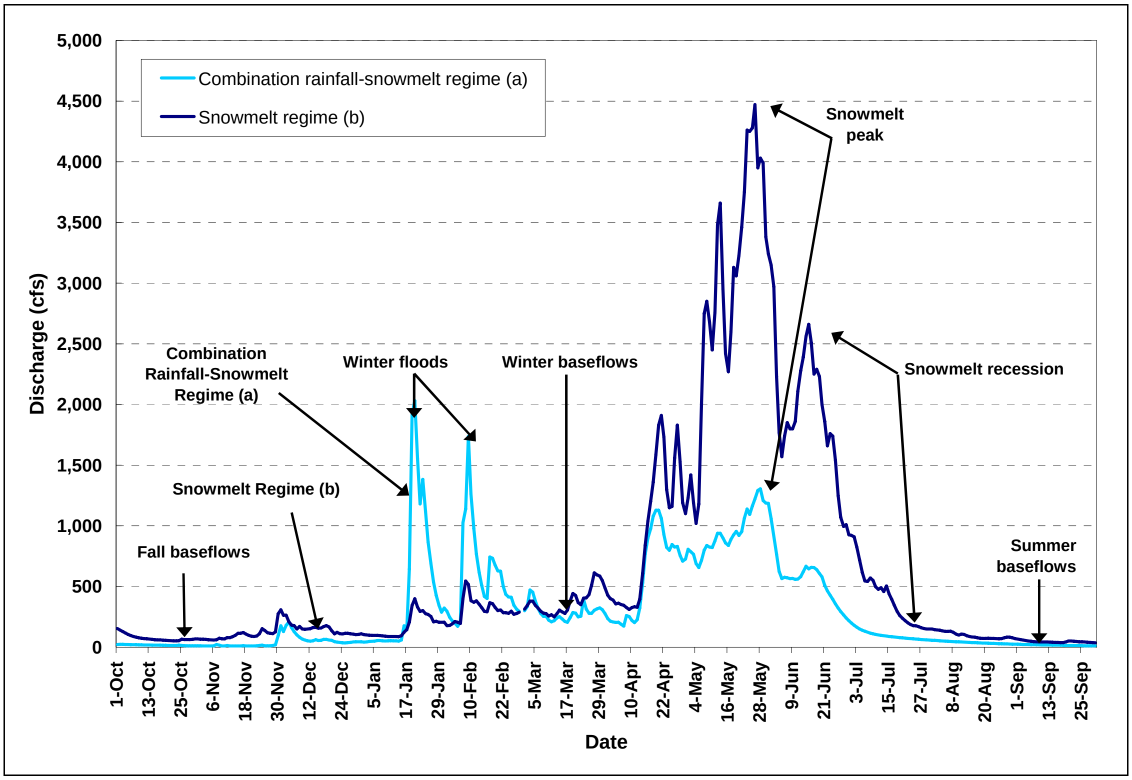
McBain & Trush, Inc. has completed preliminary analysis of the hydrologic effects of Hetch Hetchy facilities and operations in the six study reaches. The objectives of this preliminary analysis were to: (1) describe pre-dam (unregulated) flow conditions, (2) illustrate the general effects of current project operations by quantifying changes in the daily average flow for a representative (median) water year and comparing flood magnitude and frequency for the available period of record, and (3) develop initial hypotheses of potential effects of flow regulation and diversion on geomorphic processes and ecological conditions in each study reach. These preliminary results and hypotheses, which are neither conclusive nor comprehensive, are presented to help frame and prioritize questions or hypotheses to be investigated during the 2006 field season. Additional analysis and synthesis of available data and reports (see Section 4) and results from the 2006 field surveys will be completed over the next several months to develop a more comprehensive and detailed assessment of current ecologic and geomorphic conditions in the study reaches and short- and long-term future monitoring needed to address data gaps and uncertainties that affect resource management decisions.

3.1 Analysis Approach

Unregulated rivers exhibit "natural flow regimes" that are controlled by climate, watershed topography, watershed geology, and other regional factors. For each flow regime, seasonal (intra-annual) flow patterns and the intra- and inter-annual variation in flow magnitude are fairly predictable over a range of water year types (i.e., from dry years to wet years). These predictable annual flow patterns can be broken down into seasonal "hydrograph components," each of which has important geomorphic and biological functions (Trush et al. 2000, McBain and Trush 2004). For example, floods transport sediment, erode channel banks, recruit large wood to the channel and perform other geomorphic functions that affect channel morphology and habitat structure. Also, native plant and animal species are often adapted to the "natural flow regime" for their specific river or region (e.g., Nilsson and Svedmark 2002, Naiman et al. 2002, Lytle and Poff 2004). In the Sierra Nevada, life history timing for many fish, amphibian, and riparian plant species is tied to the hydrograph components. Generalized hydrograph components for unregulated snowmelt and rainfall-and-snowmelt flow regimes in the project area are shown in Figure 3-1. Analyses to be completed during this study (and presented in the final report) will, to the extent feasible, identify and quantify linkages between each hydrograph component (timing, duration, and magnitude), geomorphic processes that maintain channel morphology, riparian vegetation recruitment and establishment, and habitat availability for selected analysis species (analysis species will be selected in the next phase of this study). These linkages enable hypotheses between project operations and ecosystem changes to be developed, and also provides information needed to evaluate trade-offs between potential flow management adjustments and ecosystem outcomes.

The preliminary analysis focuses on hydrograph shape and flow magnitude for a representative pre- and post-project median water years. Representative years were selected based on unimpaired runoff computed for the San Joaquin River Index (http://cdec.water.ca.gov/cgi-progs/iodir/wsihist). This index, which was specified in the 1995 State Water Resources Control Board Bay-Delta Water Quality Control Plan, is used for water management across the San Joaquin Basin. Unimpaired runoff is computed as the sum of Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River inflow to Millerton Lake.

Figure 3-1. Hydrograph Components for a Snowmelt-dominated and Combination Rainfall-snowmelt Flow Regimes similar to the Tuolumne River, Cherry Creek, and Eleanor Creek



Footnotes:

(a) WY1999 Estimated flow at USGS gage Clavey River nr Buck Meadows, CA (11283500): drainage area = 144 sq. mi., elev. = 2,374 ft NGVD (TID, unpublished data).

(b) WY1999 USGS gage Merced R at Pohono Bridge nr Yosemite CA (11266500): drainage area = 321 sq. mi., elev. = 3,862 ft NGVD.

For San Joaquin River Index period of record (1901–2005), unimpaired runoff was 5.61 million acre-feet. WY1917 was selected to represent median years for pre-project (pre-1918), and WY 1999 was selected to represent median years for current operations (1993–2005). San Joaquin River Index runoff for WY1917 was 6.66 million acre-feet, 19% above the 1901–2005 median (Table 3-1). Although WY1917 was wetter than the 1901–2005 median, it was the closest year for which complete flow data were available for the study reaches complete pre-project data were available for the Lumsden Reach for WY1913, WY1914, and WY1917. The San Joaquin River Index runoff for WY1999 runoff was 5.91 million acre-feet, 300,000 acre-feet (5%) more than the median unimpaired runoff (Table 3-1).

Table 3-1: Unimpaired Annual Runoff for the Period of Record and Representative Water Years

Period		Median Runoff[a] (10^6 acre-feet)	Representative Year		
			Water Year	Runoff[a]	Water Year Type
S.J. River Index	1901-2005	5.61	N/A	N/A	N/A
Pre-Eleanor	1911-1917	6.66	1917	6.66	wet
Post-Eleanor/Pre-Hetchy	1911-1922	6.15	1921	5.90	above normal
Current Infrastructure and Operations	1993-2005	5.91	1999	5.91	above normal

Footnote:

a. Computed San Joaquin River unimpaired runoff (Source: http://cdec.water.ca.gov/cgi-progs/iodir/wsihist).

For each representative median water year, annual hydrographs were developed for each study reach using a combination of streamflow gage data (WY1917 and WY1999) and estimated unimpaired flow (WY1999). At certain locations where streamflow gages were not available, flow was estimated by summing flow from upstream gages. Also, where published unimpaired flow estimates were not available for WY1999, unimpaired streamflow was estimated by: (1) scaling data from a nearby unregulated river, or (2) computing unimpaired flow as a function of change in reservoir storage, diversion rate, and downstream flow releases. Regulated and unimpaired flows were computed as follows:

(Eq. 1) $Qe_{TRCC\ regulated} = Qg_{TRblEI} + Qg_{CCblDHPH}$

(Eq. 2) $Qe_{TRBM\ regulated} = (Qg_{TRblEI} + Qg_{CCblDHPH} + Qg_{SFTR} + Qg_{MTR}) * (DA_{TRBM}/(DA_{TRblEI} + DA_{CCblDHPH} + DA_{SFTR} + DA_{MTR})$

(Eq. 3) $Qe_{TRHH\ unimpaired} = Qg_{MRPB} * (DA_{TRHH/}\ DA_{MRPB})$

(Eq. 4) $Qe_{EC\ unimpaired} = (S_d – S_{d-1}) + Qg_{ECDT} + Qg_{EC}$

(Eq. 5) $Qe_{CCblVD\ unimpaired} = (S_d – S_{d-1}) - Qg_{ECDT} + Qg_{CCblVD\ regulated} + Qg_{CDT}$

(Eq. 6) $Qe_{CCEI\ unimpaired} = Qe_{CCblVD\ unimpaired} + Qe_{EC\ unimpaired}$

(Eq. 7) $Qe_{TRCC\ unimpaired} = Qe_{CCEI\ unimpaired} + Qe_{TRHH\ unimpaired}$

(Eq. 8) $Qe_{TRBM\ unimpaired} = Qe_{TRCC\ unimpaired} + Qg_{SFTR} + Qg_{MTR}$

Where: Qe is estimated streamflow; Qg is gaged streamflow; DA is drainage area; and S_d is reservoir storage on date (d) from USGS reservoir gages. Subscripts denote location as follows: Tuolumne River at Cherry Creek confluence (TRCC), Tuolumne River below Early Intake (TRblEI), Cherry Creek below Don Holm Powerhouse (CCblDHPH), Tuolumne River near Buck Meadow (TRBM), South Fork Tuolumne River (SFTR), and Middle Tuolumne River (MTR), Tuolumne River near Hetch Hetchy (TRHH), Merced River at Pohono Bridge near Yosemite (MRPB), Eleanor Creek nr Hetch Hetchy (EC), Eleanor-Cherry Diversion Tunnel (ECDT), Cherry Creek below Valley Dam (CCblVD), Cherry Diversion Tunnel (CDT), Cherry Creek near Early Intake (CCEI).

These flow estimates make several simplifications that limit their accuracy, including:

- Unimpaired flow estimates below Cherry Creek Valley Dam and Eleanor Dam do not include evaporation from the reservoirs. Also, the quality of reservoir data and diversion gaging data reported by the USGS is rated fair.
- Summing flows from upstream gages does not account for time required for flow to route from one gage to the next, and does not adjust for inflow downstream of each gage (except for equations 2 and 3 adjust estimated flow by drainage area).
- Flow estimates that sum multiple unimpaired or regulated estimates (equations 6, 7, and 8) can compound error from each individual estimate.

Because the effects of project operation on flow magnitude and timing typically exceed the error in the estimated flows, these flow estimates are useful for illustrating (though not necessarily quantifying) effects on most hydrograph components despite their simplifications. During low-flow periods, however, (such as summer baseflows), prediction error could exceed project effects. This is particularly true for unimpaired estimates downstream of Cherry Valley and Eleanor Dams and inflow to New Don Pedro Reservoir. At these locations, estimated unimpaired flow computed from equations 4 and 5 and reported by CDWR (For New Don Pedro Reservoir) is often negative during summer and fall baseflows.

3.2 The Natural Hydrograph

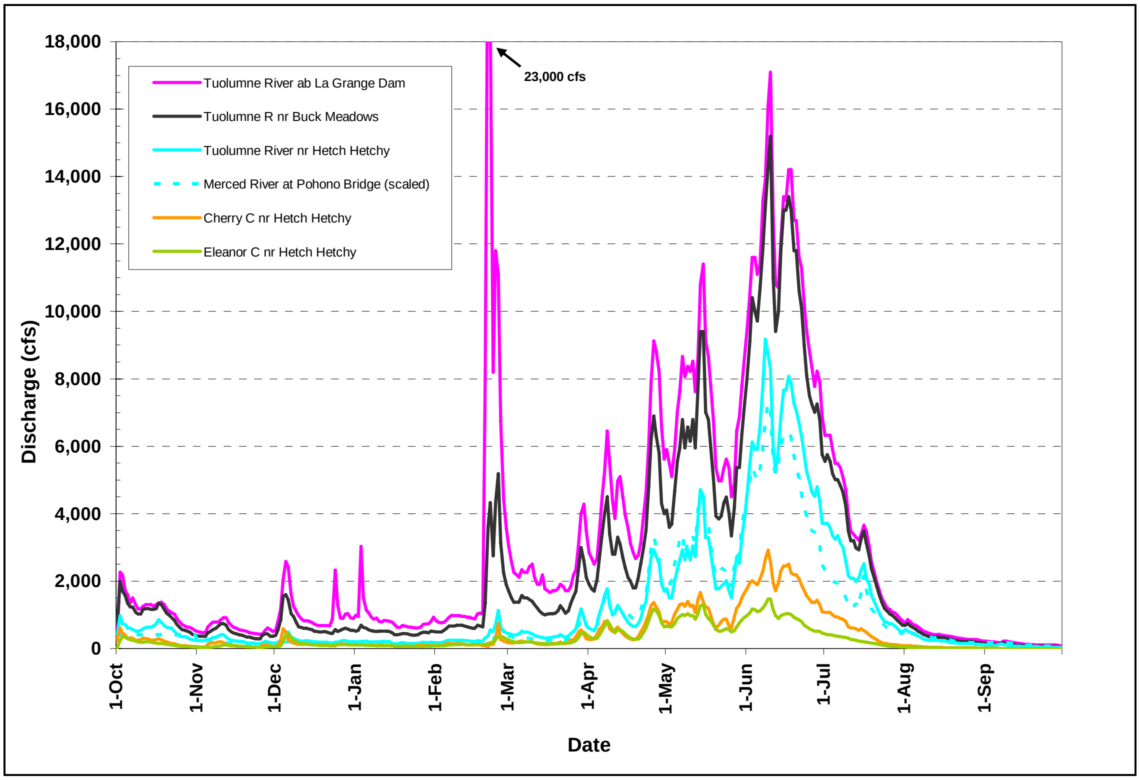
The Tuolumne River's unregulated flow regime is snowmelt in the upper watershed and combination rainfall-snowmelt at lower elevations (Figure 3-2, Table 3-2). In the Hetchy Reach (Tuolumne River), Eleanor Reach, and all Cherry Creek reaches, watershed elevations range from 2,100 ft to more than 13,000 ft, and flow regime is snowmelt-dominated. For WY1917:

- winter baseflow was 80 cfs in Eleanor Creek to 200 cfs in the Hetchy Reach;
- winter rainfall generated small peaks in daily average flow, but winter peak flow magnitude was insignificant relative to spring peak flow;
- snowmelt flow extended from late March through late August; and
- peak snowmelt flow was in late spring (June 9–10) and ranged 1,580 cfs in Eleanor Creek to 10,000 cfs in the Hetchy Reach;
- summer baseflow was 2–4 cfs in Eleanor and Cherry creeks and 72 cfs in the Hetchy Reach.

Flow regime transitions from snowmelt-dominated to combination rainfall-and-snowmelt-dominated in the Lumsden Reach, where river elevation ranges from 2,100 ft (at the Cherry Creek confluence) to 830 ft (at Lake New Don Pedro). Pre-project flows in this reach are represented by data from the Tuolumne River at Buck Meadows (elevation 1,420 ft) and Tuolumne River at La Grange Dam gages (elevation 330 ft). For WY1917:

- Winter baseflow was 500 cfs at Buck Meadows and 700 cfs at La Grange.
- Snowmelt flow extended from late March through late August;
- Peak daily average snowmelt flow was in late spring (June 9) and was 15,200 cfs at Buck Meadows and 17,100 cfs at La Grange;
- The annual flood at Buck Meadows was in spring (17,700 cfs [instantaneous peak]). Late February rain-on-snow generated a moderate peak (5,190 cfs), but this peak was only 1/3 the spring peak magnitude (15,200 cfs [daily average peak]).
- At La Grange, the February rain-on-snow peak was the annual flood. Flow peaked at 36,500 cfs, a 10-year flood.

Figure 3-2. Tuolumne River Natural Hydrograph (WY1917)



Footnotes:

a. USGS gage Tuolumne R ab La Grange Dam nr La Grange CA (11288000)
b. USGS gage Tuolumne R nr Buck Meadows CA (11283000)
c. USGS gage Tuolumne River nr Hetch Hetchy, CA (11276500)
d. USGS gage Merced R at Pohono Bridge nr Yosemite CA (11266500) scaled by drainage area to Tuolumne River nr Hetch Hetchy
e. USGS gage Cherry Creek near Hetch Hetchy, CA (11277000)
f. USGS gage Eleanor C nr Hetch Hetchy CA (11278000)

Table 3-2: Pre-project Streamflow Gages, Elevation, and Hydrograph Components

Streamflow Gage	Elevation (ft NGVD)	Drainage Area (mi^2)	Winter Baseflow (cfs)	Winter Peak[a] (cfs)	Spring Peak[a] (cfs)	Summer Baseflow (cfs)
Eleanor C nr Hetch Hetchy CA (11278000)	4,500	78	80	430	1,470 (1,580)	2
Cherry C nr Hetch Hetchy CA (11277000)	4,500	111	90	755	2,920 (3,800)	4
Tuolumne R nr Hetch Hetchy CA (11276500)	3,480	457	200	1,130	9,170 (10,000)	72

Streamflow Gage	Elevation (ft NGVD)	Drainage Area (mi^2)	Winter Baseflow (cfs)	Winter Peak[a] (cfs)	Spring Peak[a] (cfs)	Summer Baseflow (cfs)
Tuolumne R nr Buck Meadows CA (11283000)	1,420	924	500	5,190	15,200 (17,700)	98
Tuolumne R ab La Grange Dam nr La Grange CA (11288000)	330	1,532	700	23,000 (36,500)	17,100	150

Footnote:

a. Daily average flow. Instantaneous peak shown in parentheses ().

3.3 Effects of Flow Regulation on Annual Hydrograph Components

The effects of dams and flow diversion on downstream flow regime (and thus on channel morphology and aquatic and riparian habitat) are functions of facility size, facility location in the watershed, and the manner in which the project is operated. Large dams typically have greater capacity to alter flow regimes (including reducing flood flows, altering seasonal flow patterns, and shifting water yield between years), trap bedload and suspended sediment load, capture large wood, and reduce wood recruitment downstream. Smaller diversion dams have less of an effect on downstream flows, sediment supply, and large wood. The Hetch Hetchy Project dams vary in size relative to their watersheds and thus the magnitude of their impacts on downstream flows varies (Table 3-3). Eleanor Dam is the smallest dam in the system and has capacity to store only 14% of its watershed's unimpaired runoff. Hetch Hetchy Dam can store 46% of its watershed's unimpaired runoff. Cherry Valley Dam can store 103% of the watershed's unimpaired runoff.

Table 3-3: Tuolumne River Dams, Drainage Areas, and Reservoir Capacities

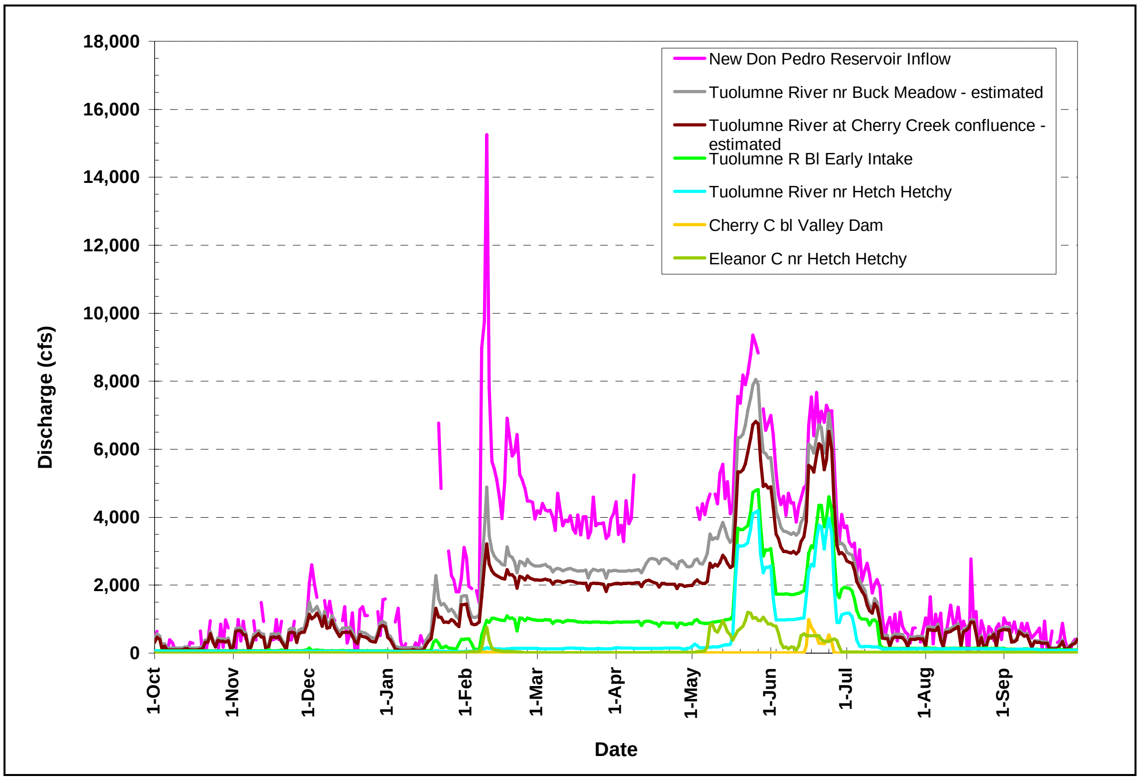
Dam	Year Completed	Drainage Area (mi^2)	Reservoir Capacity (acre-feet)	Unimpaired Annual Runoff (acre-feet)	Reservoir Capacity: Unimpaired Runoff
Eleanor	1918	78	27,100	187,300 (1910–1917)	14%
Cherry Valley	1956	117	274,300	267,003 (1911–1955)	103%
Hetch Hetchy	1923, enlarged 1938	459	360,360	780,230 (1911–1922)	46%
Don Pedro	1923, enlarged 1971	1,532	2,030,000	1,870,859 (1918–2005)	109%

Regulated hydrographs for WY1999 for all study reaches are shown in Figure 3-3. Relative to the wetter-than-median year pre-project hydrograph (WY1917) (see Figure 3-2), project effects on hydrograph shape and magnitude include:

- Reduced winter and spring flow in the downstream of project dams (Hetchy, Upper Cherry, Lower Cherry, and Eleanor reaches);

- Increased late-winter baseflow downstream of Early Intake and Holm Powerhouse (Lumsden Reach and downstream end of Hetchy Reach);
- Later onset of the snowmelt hydrograph and reduced snowmelt peak in all reaches;
- Shorter snowmelt recession in the channel below project dams (Hetchy, Upper Cherry, Lower Cherry, and Eleanor reaches);
- Large flow fluctuations throughout summer and fall downstream of Holm Powerhouse (Lumsden Reach); and
- Increased summer baseflow in the Hetchy and Lumsden reaches.

Figure 3-3. Regulated Tuolumne River Hydrograph WY1999



Footnotes:

a. Computed estimate (source: http://cdec.water.ca.gov/cgi-progs/)
b. See equation 2
c. See equation 1
d. USGS gage Tuolumne River nr Hetch Hetchy, CA (11276500)
e. USGS gage Cherry Creek below Valley Dam, CA (11277300)
f. USGS gage Eleanor C nr Hetch Hetchy CA (11278000)

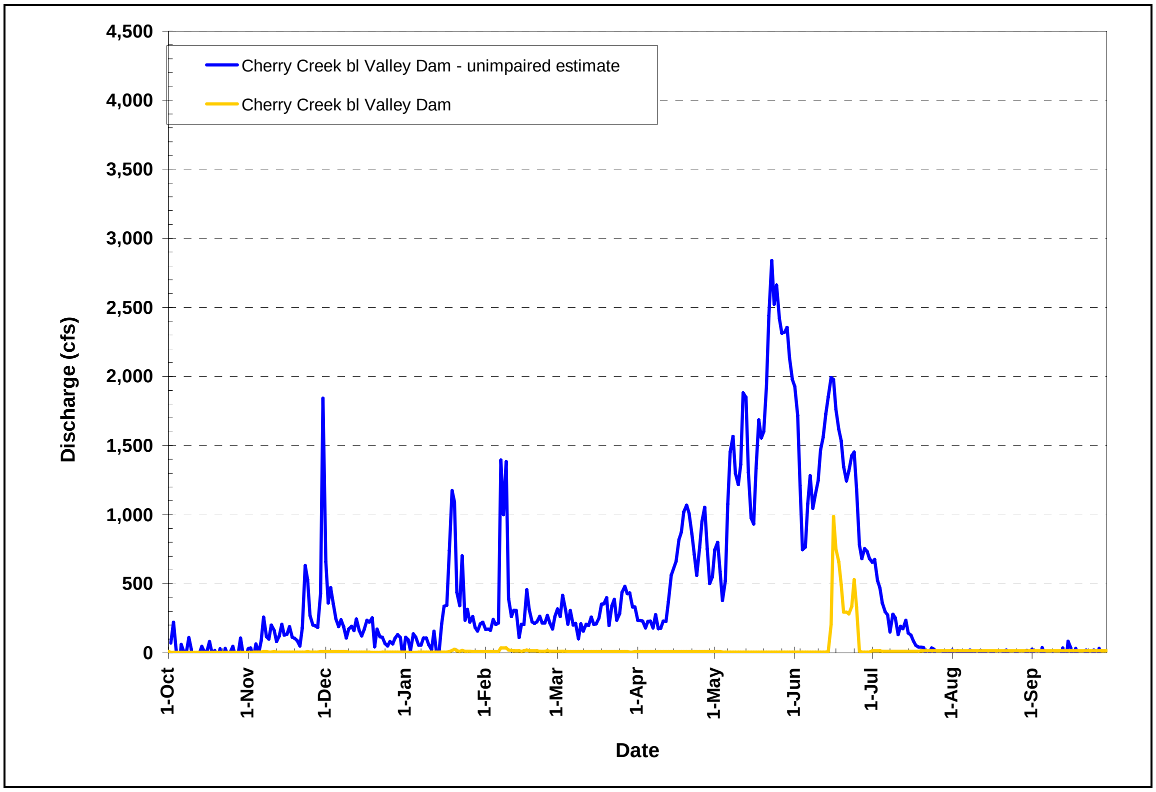
The effects of project operation in each reach, relative to estimated unimpaired flow for WY1999, are discussed below.

3.3.1 Cherry and Eleanor Creeks

Upper Cherry Reach

Required minimum flow releases from Cherry Valley Dam are 5 cfs from October through June and 15.5 cfs from July through September. In most years, flow in the Upper Cherry Reach is maintained at or near minimum flows year-round. WY1999 is shown in Figure 3-4. As shown, Cherry Valley Dam eliminates virtually all components of the natural hydrograph, except during a brief spring spill. Significant spring spills (May through July) occurred in 7 of 13 years since current operations were instituted in 1993. The only winter spill was in WY1997.

Figure 3-4. Unimpaired and Regulated Upper Cherry Reach Hydrograph WY1999



Footnotes:

a. See equation 5

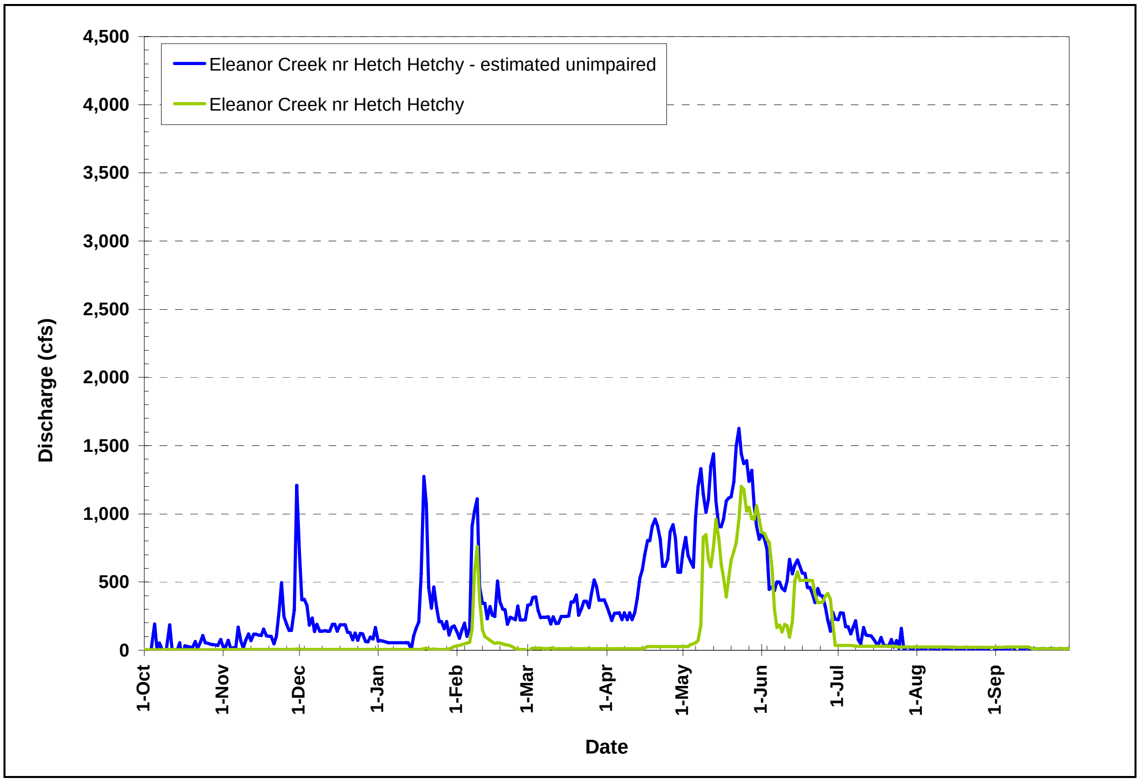
b. USGS gage Cherry Creek below Valley Dam, CA (11277300)

Eleanor Reach

In Eleanor Reach, required minimum flows range from 5 cfs to 20 cfs depending on month and whether the pumping station for the diversion to Cherry Lake is operating. Because the reservoir capacity is small relative to annual runoff from the watershed, spills are frequent. Since 1993, winter spills occurred in 6 of 13 years and spring spills occurred in 11 of 13 years.

For WY1999, project operation (1) reduced winter baseflows; (2) eliminated two winter peaks and reduced a third peak, (3) delayed the onset of spring snowmelt by several weeks to early May, (4) truncated the snowmelt hydrograph by 2 weeks,, (5) reduced snowmelt peak by about 30%, and (6) increased summer baseflows (Figure 3-5).

Figure 3-5. Unimpaired and Regulated Eleanor Reach Hydrograph WY1999

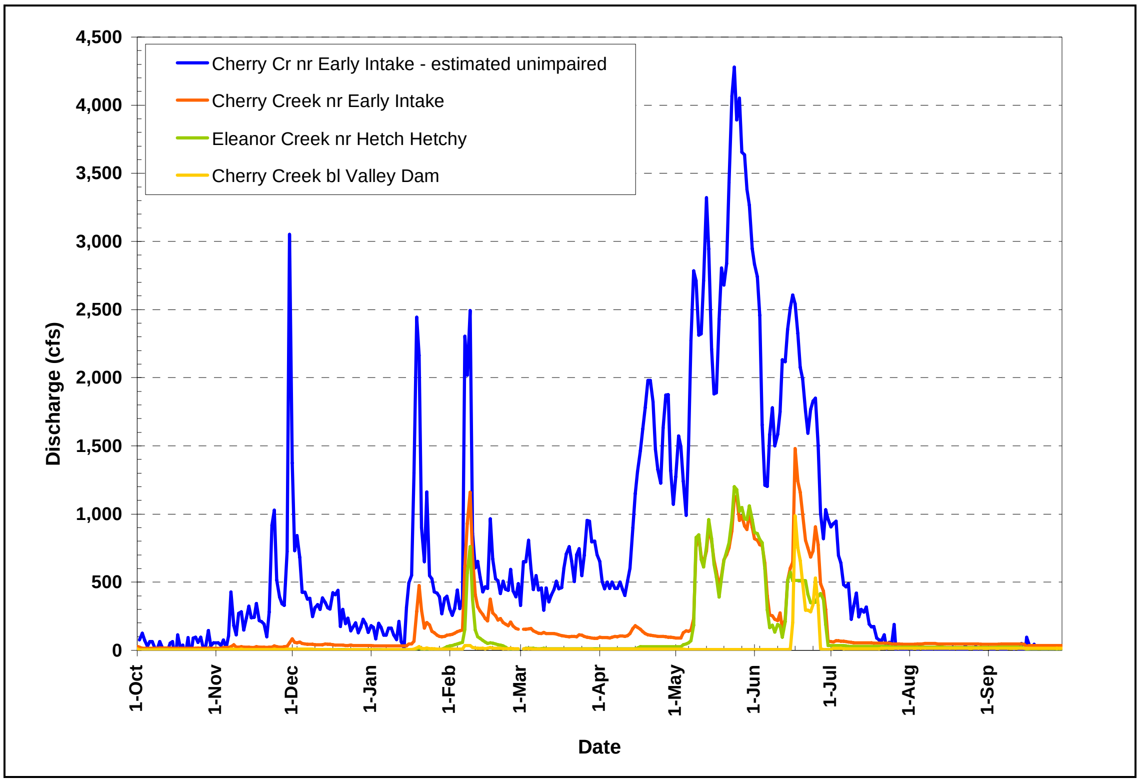


Footnotes:
c. See equation 4
d. USGS gage Eleanor C nr Hetch Hetchy CA (11278000)

Lower Cherry Reach

In the Lower Cherry Reach, inflow from Eleanor Creek reduces the effect of Cherry Valley Dam. Because most inflow to this reach is from Eleanor Creek (except during infrequent releases from Cherry Valley Dam), flow conditions in this reach are similar to those described for Eleanor Creek above. Compared to unimpaired conditions, all hydrograph components remain substantially reduced. The combined effects of Cherry Valley Dam and Eleanor Dam for this example water year include: (1) reduced winter baseflow, (2) elimination or reduction of winter storm peaks, (3) delayed onset and reduced duration of spring snowmelt hydrograph component, (4) reduced spring snowmelt flow magnitude, and (5) increased spring snowmelt recession rate (Figure 3-6). Net effects on summer baseflows appear to be minor in most years, and in some years, project operations may increase summer baseflow above unimpaired conditions.

Figure 3-6. Unimpaired and Regulated Lower Cherry Reach Hydrograph WY1999



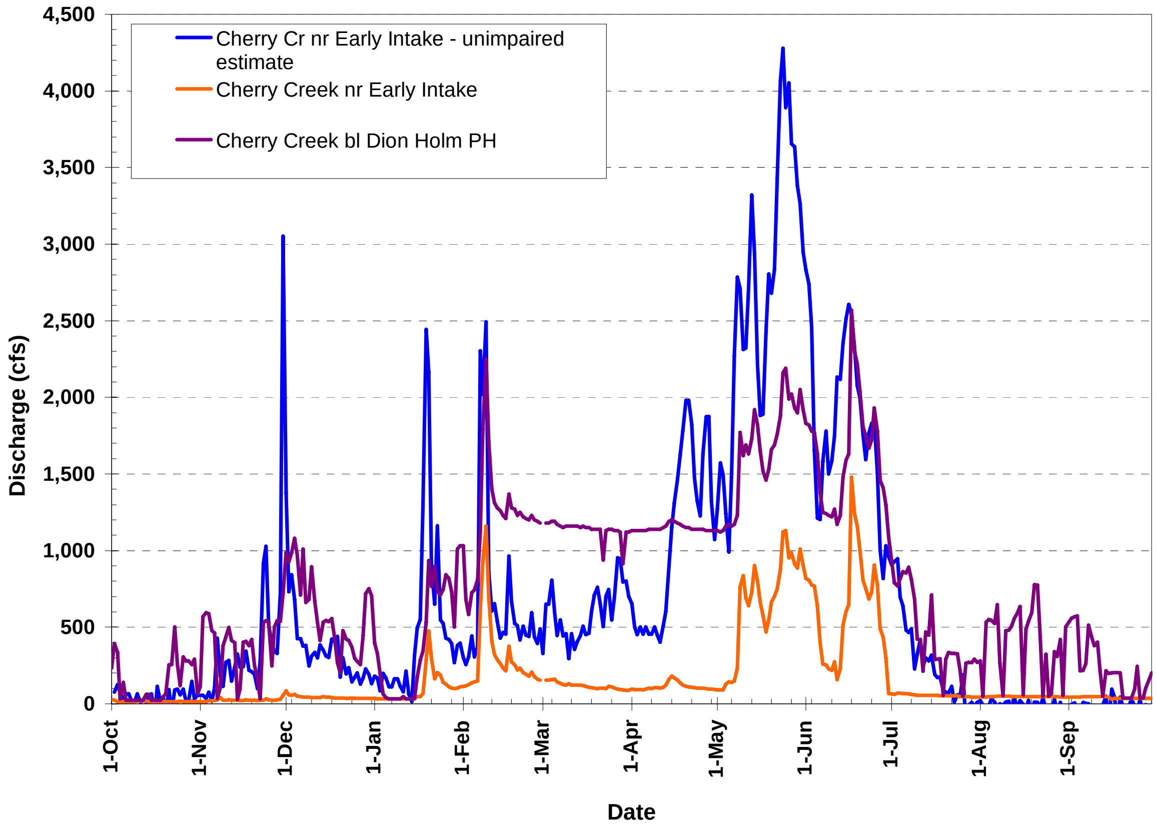
Footnotes:

a. See equation 6
b. USGS gage Cherry C nr Early Intake CA (11278300)
c. USGS gage Eleanor C nr Hetch Hetchy CA (11278000)
d. USGS gage Cherry Creek below Valley Dam, CA (11277300)

Holm Reach

In the Holm Reach, return flow from the Holm Powerhouse increases flow magnitude. For WY1999, project operation: (1) increased winter and summer baseflow by at least an order of magnitude, (2) increased early spring snowmelt flow, (3) slight delay of snowmelt peak, (4) reduced snowmelt peak magnitude, and (5) daily or weekly power production fluctuations (Figure 3-7). Daily fluctuations support recreational needs during summer between Memorial Day and Labor Day (Pers. Communication, B. McGurk).

Figure 3-7. Unimpaired and Regulated Holm Reach Hydrograph WY1999



Footnotes:

a. See equation 6
b. USGS gage Cherry C nr Early Intake CA (11278300)
c. USGS gage Cherry C bl Dion R Holm PH, nr Mather CA (11278400)

3.3.2 Tuolumne River

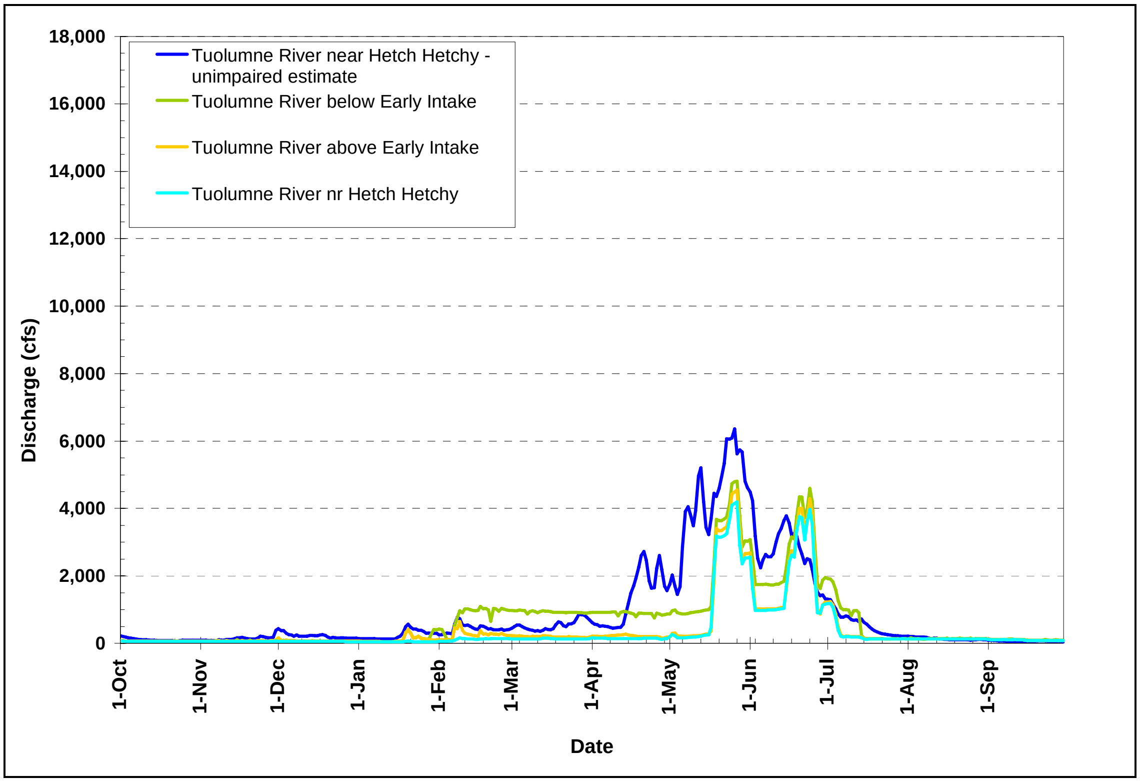
Hetchy Reach

Required minimum flows range from 35 cfs to 125 cfs depending on time of year and water year type. Flow in this reach is typically maintained at or near stipulated minimum flows, except during spring and summer spills (Figure 3-8). Spill releases increase flows well above the minimum flow stipulation. Since current operations were instituted in 1993, spring spills were released in 10 of 13 years. The only winter spill since 1993 was in WY1997.

For WY1999, project operation had the following effects on hydrograph components:

- reduce winter baseflows to 50 cfs upstream of Early Intake and increase winter baseflows to 900 cfs downstream of Early Intake from 400 cfs (umimpaired);
- delay onset of spring snowmelt from late March (WY1917)/mid-April (Pohono Bridge) to mid-May;
- truncate the end of the snowmelt hydrograph at early July upstream of Early Intake and mid-July downstream of Early Intake compare to late July (Pohono Bridge and 1917)
- reduce snowmelt peak by about 2,000 cfs (30%);
- increased snowmelt recession rate; and
- increase summer baseflow from 65 cfs (Pohono Bridge), 72 cfs (HH 1917) to 98 cfs 1999, 65 cfs (Pohono Bridge), 72 cfs (HH 1917).

Figure 3-8. Unimpaired and Regulated Hetchy Reach Hydrograph WY1999



Footnotes:

a. USGS gage Merced R at Pohono Bridge nr Yosemite CA (11266500) scaled by drainage area to Tuolumne River nr Hetch Hetchy

b. USGS gage Tuolumne River nr Hetch Hetchy, CA (11276500)

c. USGS gage Tuolumne River ab Early Intake nr Mather, CA (11276600)

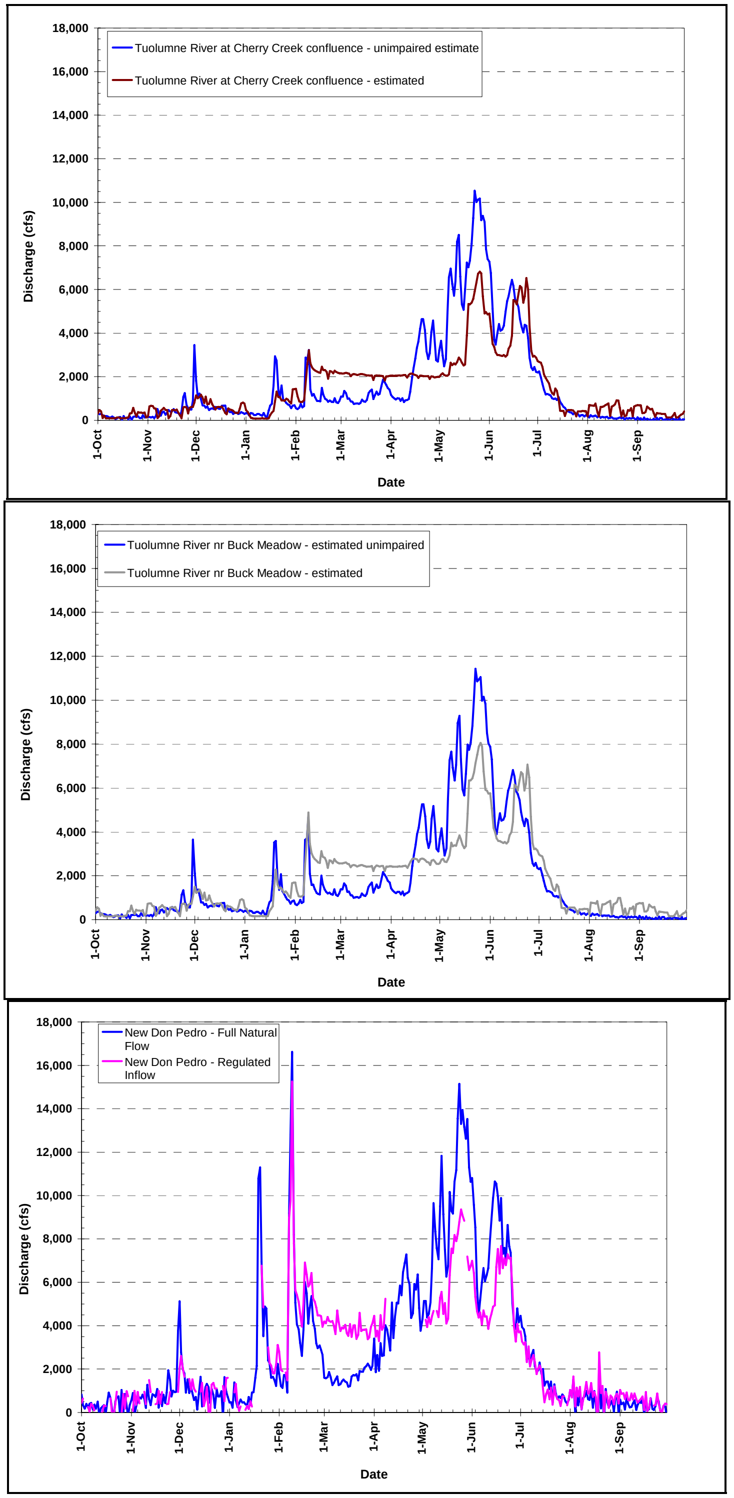
d. USGS gage Tuolumne River bl Early Intake nr Mather, CA (11276900)

Lumsden Reach

This reach receives inflow from the regulated Hetchy and Holm reaches and from several major unregulated tributaries. From upstream to downstream, major tributaries in this reach are Cherry Creek, South Fork Tuolumne River, Clavey River, and North Fork Tuolumne River. Big Creek, a small tributary that flows into the Tuolumne River between the Clavey River and North Fork Tuolumne River confluences, is the only tributary to this reach downstream of Cherry Creek affected by flow regulation or diversion. Big Creek is regulated by Pine Mountain Lake, a 7,700-acre-foot reservoir constructed in 1969. The Tuolumne Utilities District diverts up to 52 cfs from the South Fork Stanislaus River into the Tuolumne River watershed via the Tuolumne Canal for power, irrigation, and domestic supply for Phoenix Lake, East Sonora, Sonora, and Jamestown. After passing through the Phoenix Powerhouse, diverted flow distributed through a systems of canals for irrigation and domestic use.

The Hetch Hetchy Project dams regulate 90% of the drainage area at the upstream end of the reach, 70% at the Tuolumne River nr Buck Meadows (located between South Fork Tuolumne River and Clavey River confluences), and 42% at the New Don Pedro Dam. Project effects are most pronounced at the upstream end of the reach, and include: reduced winter peaks, increased winter baseflows, reduced snowmelt duration and peak (Figures 3-9). Summer and fall baseflows are augmented compared to unimpaired conditions, and fluctuate due to flow releases for whitewater rafting and power generation operations. For 5–7 days each week, flow fluctuates between approximately 175 cfs and 1,100 cfs, then returns to baseflow for the remainder of the week. The rate of spring snowmelt recession is similar to unimpaired conditions.

Figures 3-9 a, b and c. Unimpaired and Regulated Hydrograph at Three Locations in the Lumsden Reach WY1999



Footnotes:

a. at Cherry Creek (top), equations 1 and 7;