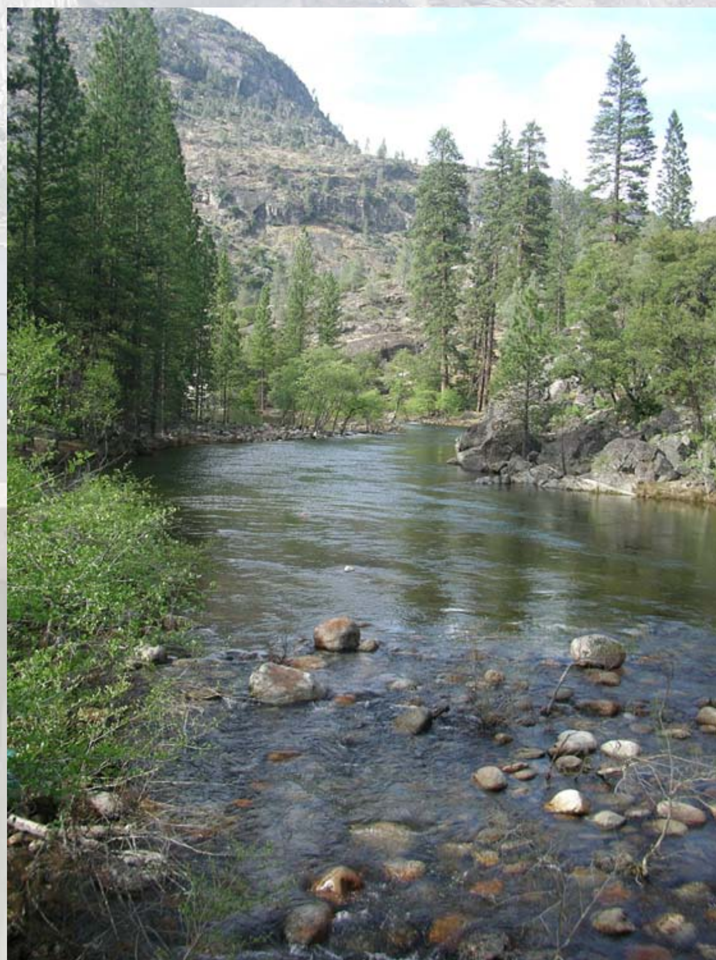
Upper Tuolumne River:

Description of River Ecosystem and Recommended Monitoring Actions

April 2007



SFPUC
Water
Hetch Hetchy
Water & Power
Clean Water

McBain & Trush

RMC

Upper Tuolumne River: Description of River Ecosystem and Recommended Monitoring Actions Final Report

Prepared by:

RMC Water and Environment

and

McBain & Trush, Inc.

April 2007

Table of Contents

List of Tables

List of Figures

Appendices

Appendix A: Daily average hydrographs for Tuolumne River near Hetch Hetchy below O'Shaughnessy Dam (USGS 11-276500) for Water Years 1911-2005.

Appendix B: Daily average hydrographs for Eleanor Creek near Hetch Hetchy below Lake Eleanor Dam (USGS 11-278000) for Water Years 1910-2005.

Appendix C: Daily average hydrographs for Cherry Creek near Hetch Hetchy below Cherry Valley Dam (USGS 11-277000) for Water Years 1910-2005.

Appendix D: 15-minute stage and discharge plots for each month in Water Year 2004 (DRY) and 2005 (WET) for Cherry Creek near Early Intake above Holm Powerhouse (USGS 11-278300) and Cherry Creek below Holm Powerhouse (USGS 11-278400). Simulated 15-minute discharge plots for each month in Water Year 2004 and 2005 for Tuolumne River below Cherry Creek confluence.

Appendix E: Daily average streamflows and water temperatures for Tuolumne River near Hetch Hetchy (USGS 11-276500) and above Early Intake (USGS 11-276600).

Appendix F: Daily average streamflows and water temperatures for Cherry Creek below Valley Dam (USGS 11-277300).

Appendix G: Daily average streamflows and water temperatures for Cherry Creek below Valley Dam (McBain & Trush thermograph UCD2).

Appendix H: Daily average streamflows and water temperatures for Cherry Creek below Dion R Holm Powerhouse (USGS 11-278400).

Appendix I: Daily average streamflows and water temperatures for Eleanor Creek near Hetch Hetchy (USGS 11-278000).

Appendix J: Daily average streamflows and water temperatures for Tuolumne River at the Grand Canyon of the Tuolumne above Hetch Hetchy (USGS 11-274790).

Appendix K: Daily average streamflows and water temperatures for Clavey River at 1N01 Bridge (McBain and Trush gage).

Appendix L: Hypotheses of Potential Project Effects on Geomorphic and Ecological Conditions in the Study Reaches.

Appendix M: Summary of Reach-Scale Study Plan Recommendations for Eleanor Creek, Cherry Creek, and Tuolumne River to Evaluate Hypotheses of Project Induced/Influenced Negative Impacts and Provide Recommendations on Improved Operations to Reduce Negative Impacts.

List of Abbreviations

ac	acres
cfs	cubic feet per second
DEM	Digital Elevation Model
FERC	Federal Energy Regulatory Commission
ft	feet
gpd	gallons per day
gpm	gallons per minute
IFIM	Instream Flow Incremental Methodology
in	inches
m	meters
mgd	million gallons per day
mi	miles
NGVD	National Geodetic Vertical Datum
NPS	National Park Service
RM	River Mile
s	seconds
SFPUC	San Francisco Public Utilities Commision
SL	standard length
stn	station
TRPT	Tuolumne River Preservation Trust
USFS	U. S. Forest Service
USFWS	U. S. Fish and Wildlife Service
USGS	U. S. Geological Survey
WY	water year

Chapter 1 Introduction

The San Francisco Public Utilities Commission (SFPUC) owns and operates Hetch Hetchy Water and Power Project (Hetch Hetchy Project). 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), Eleanor Creek (a tributary to Cherry Creek), and Moccasin Creek (tributary to New Don Pedro Reservoir). As part of establishing a common foundation of environmental information for the river and stream reaches affected by the Hetch Hetchy Project, the SFPUC Natural Resources and Hetch Hetchy Water and Power Divisions funded a 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 Valley Dam, and Eleanor Creek downstream of Eleanor Dam. Study plans and reports were 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. In particular, the Yosemite National Park Service and U.S. Fish and Wildlife Service have provided valuable technical expertise to this study.

This one-year effort included four tasks:

1. Identify and compile existing information, identify key information gaps, and develop a reconnaissance-level field plan to begin gathering additional information in 2006 (completed in October 2006);
2. Implement the 2006 field plan (completed from January 2006 to September 2006);
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 (completed in October 2006); and
4. Identify short- and long-term future monitoring activities necessary to build on this foundation (purpose of this report).

Tasks 1-3 were completed by October 2006, and are summarized in the "Upper Tuolumne River: Available Data Sources, Field Work Plan, and Initial Hydrology Analysis" report. This report summarizes information in Tasks 1-3 to describe current ecologic and geomorphic conditions in each reach, and recommends short- and long-term monitoring needed to improve understanding of the effects of the Hetch Hetchy Project on river and riparian ecosystem function, and identify measures to reduce these effects (Task 4). The objectives of this report are to:

1. Begin informing 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 historical 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.

An additional product of this effort includes a database of available information compiled during the development of these two reports. This database and other supporting information compiled or generated by this effort will be made available to the Tuolumne River Stakeholder Group and other interested parties.

Chapter 2 Project Setting

The Tuolumne River, which drains a 1,960-square-mile watershed on the western slope of the Sierra Nevada range, is the largest of three major tributaries to the San Joaquin River. The river originates in Yosemite National Park and flows southwest to its confluence with the San Joaquin River, approximately 10 miles west of Modesto. At higher elevations, the watershed is exposed granitic bedrock that was scoured by glaciers during the Tioga and earlier glacial periods down to the O'Shaughnessy Dam location, resulting in mountainous terrain, patchy forests, and a variety of steep canyons and mountain meadows. The middle portion of the watershed from New Don Pedro Reservoir to above Hetch Hetchy Reservoir is characterized by deep canyons and forested terrain. Near the town of La Grange, the river exits the Sierra Nevada foothills and flows through a gently sloping alluvial valley that is incised into Pleistocene alluvial fans. The Hetch Hetchy Project regulates flows and sediment on Cherry Creek, Eleanor Creek, and the mainstem Tuolumne River. The study area is delineated into six reaches based on Project operations and tributary boundaries as follows (Figure 2-1):

- 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);
- Lumsden Reach – Tuolumne River from Cherry Creek confluence (RM 103.8) to New Don Pedro Reservoir (RM 78.5).

A brief description of each stream is provided below.

2.1 Tuolumne River

Upstream of Don Pedro Reservoir, the Tuolumne River and its tributaries flow through steep narrow valleys that confine the river channel. In most of this reach, the river channel is steep and alternates between bedrock chutes, boulder cascades, and pools. With the exception of the Poopenaut Valley and the Tuolumne River downstream of the Clavey River confluence, alluvial deposits tend to be limited to small or medium-sized patches associated with flow obstructions (such as boulders and bedrock outcrops). From O'Shaughnessy Dam to Early Intake, the Tuolumne River flows for about 12 miles through a U-shaped glaciated valley. While the average channel gradient in this reach (almost 2%) is steep (Figure 2-2), subreach-scale variation in channel gradient and valley confinement provides very diverse channel morphology, ranging from the low-gradient, sand/gravel-bedded channel and broad meadow of the Poopenaut Valley (Figure 2-3) to the steep, bedrock-confined Tuolumne River gorge (Table 2-1).

From Early Intake, the river flows about 10 miles to the South Fork of the Tuolumne River. Cherry Creek enters the Tuolumne River approximately one mile downstream of Early Intake, where the scale (channel width, valley width, grain size) of the channel begins to increase dramatically downstream of the confluence (Figure 2-4). The river is confined in a deeply incised, V-shaped bedrock canyon with steep, competent side slopes. Channel gradient in this reach also averages about 2%, but is locally as steep as 4% through the "Miracle Mile," popular with rafters. For most of its length, the channel consists of a series of pools separated by steep cascades over transverse boulder bars (Figure 2-5). Alluvial bars and side-channels occur throughout the reach where the valley widens or where bedrock constraints reduce channel gradient.

Figure 2-1: Study Reaches

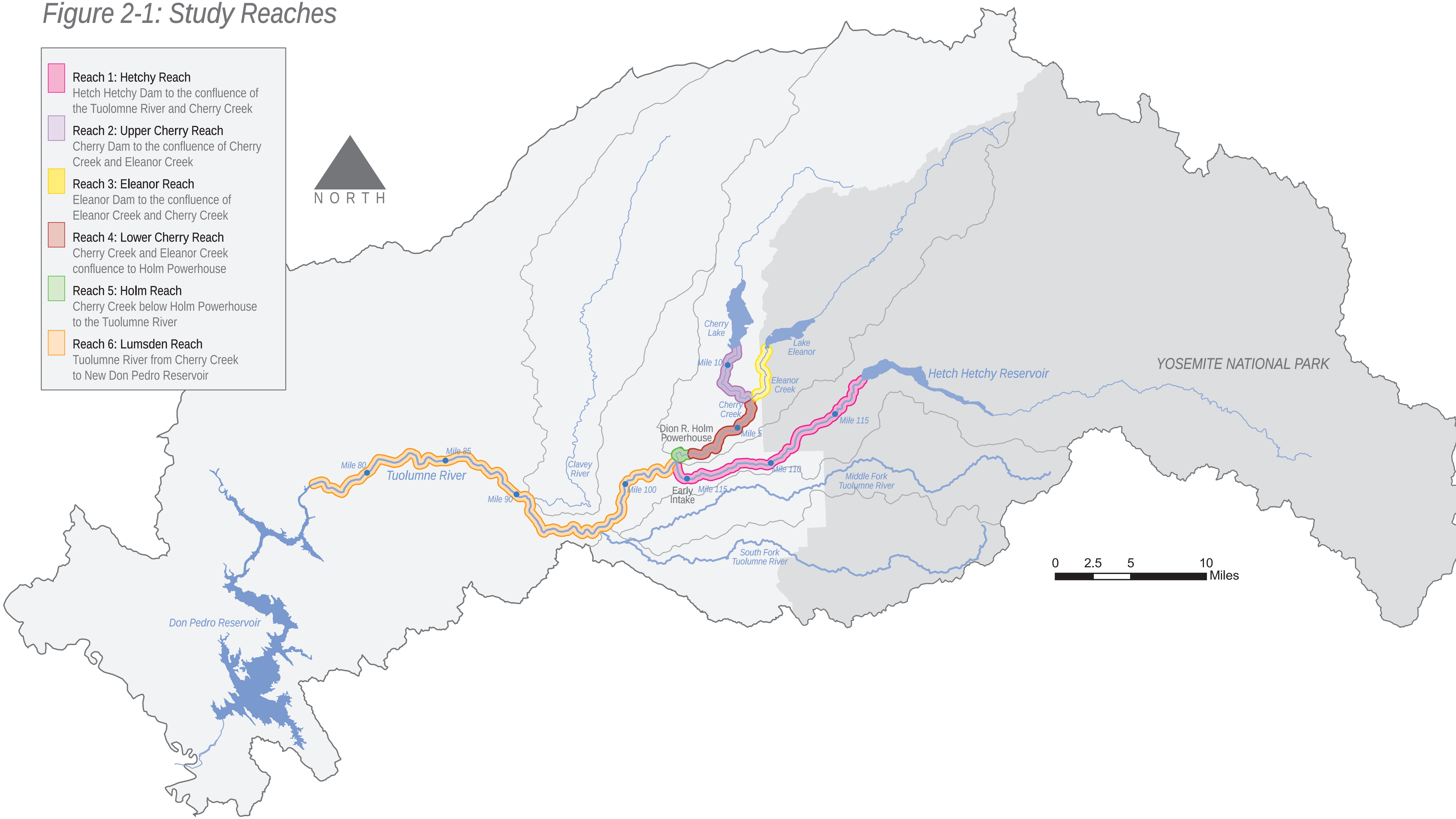


Figure 2-2: Longitudinal Profiles of the Tuolumne River, Cherry Creek, and Eleanor Creek based on 10-meter USGS Digital Elevation Model.

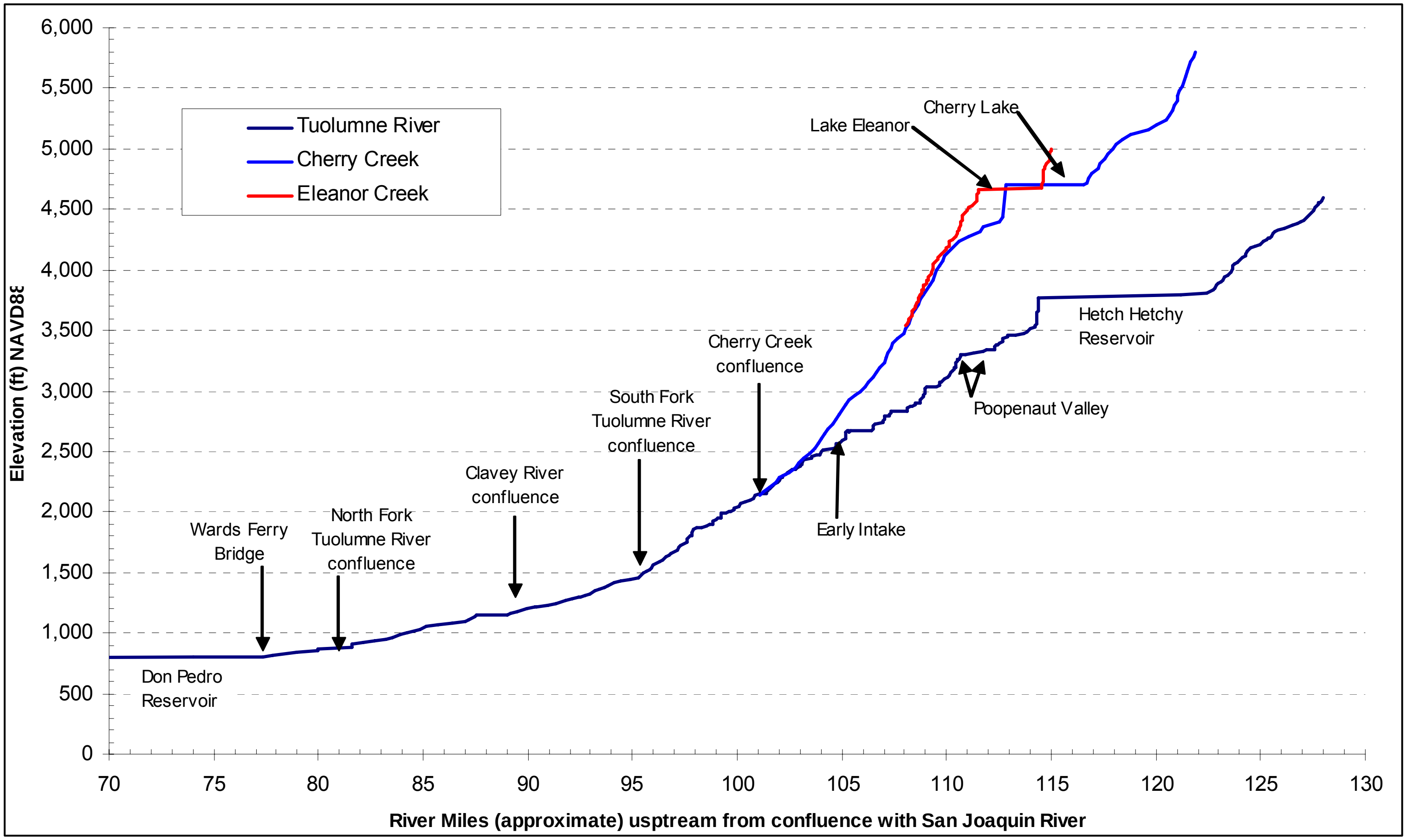


Table 2-1: Channel Gradient and Morphology

Subreach	River Mile	Length (miles)	Channel gradient (%)	Description
O'Shaughnessy Dam to Poopenaut Valley	114.9 - 117.5	2.6	1.4	Deep pools separated by cobble riffles and boulder cascades.
Poopenaut Valley	114.1 - 114.9	0.8	0.85b	Gravel/sand-bedded channel with alternate bars, runs, and glides; deep pools scoured at bedrock outcrops; wide valley with dense willow thicket, high flow scour channels, and meadow wetland.
Poopenaut Valley to Early Intake	105.1 - 114.1	9.0	2.0	Deep pools separated by boulder cascades; confined by steep, bedrock canyon walls.
Early Intake to South Fork Tuolumne River confluence	95.4 - 105.1	9.7	2.1	Deep pools separated by boulder cascades; confined by steep, bedrock canyon walls; some boulder alternate bars and few side channels.
South Fork Tuolumne River confluence to New Don Pedro Reservoir	78.5 - 95.4	16.9	0.7	Frequent alternating boulder bars within a moderately confined canyon, with periodic side channels.

Footnotes:

a. Based on USGS 10-meter Digital Elevation Model (DEM)

b. Actual slope probably lower due to imprecision in USGS DEM.

From the South Fork Tuolumne River confluence to the upper end of New Don Pedro Reservoir, the average channel gradient decreases to 0.7%. In the upper section of this reach, from the confluence with the South Fork to the confluence with the Clavey River, the river channel consists of boulder cascades separated by medium-length pools. Downstream of the Clavey River confluence, the channel gradient decreases, and the channel becomes semi-alluvial (Figure 2-5). Large boulder bars and side channels are more common here than in the upstream reaches.

Figure 2-3: Tuolumne River at Poopenaut Valley Approximately 3 Miles Downstream of O'Shaughnessy Dam Showing Low Slope, Low Valley and Channel Confinement, and Small Gravel/Sand Substrate.

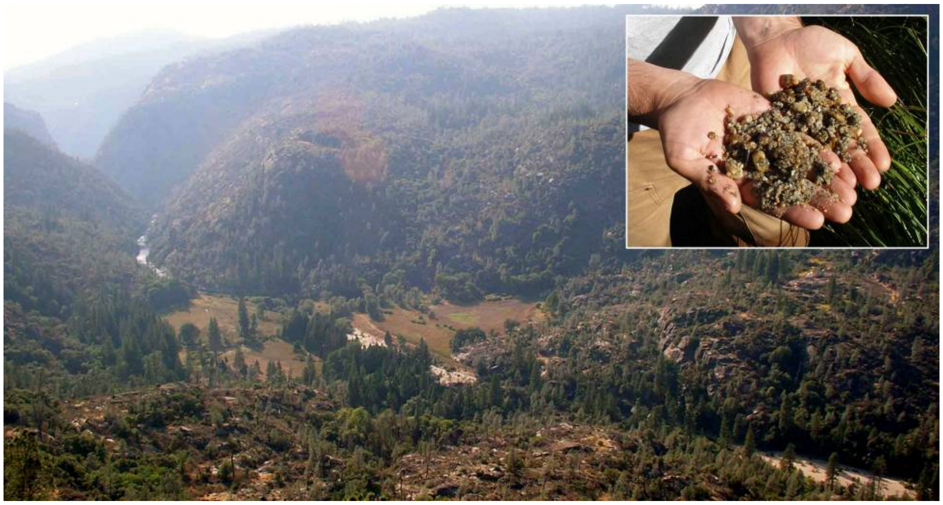
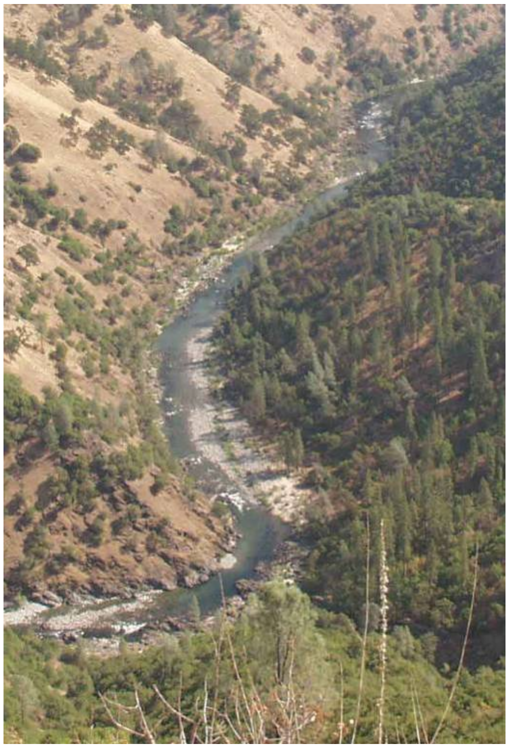
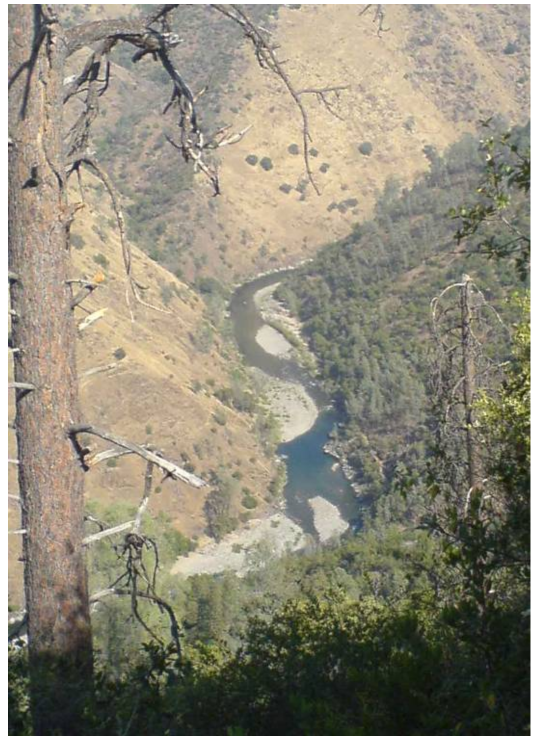


Figure 2-4: Tuolumne River Immediately Upstream (Left Photo) and Downstream (Right Photo) of Cherry Creek Confluence Showing the Increase in Channel Width due to Contributions of Flow and Sediment from Cherry and Eleanor Creeks.

Figure 2-5: Tuolumne River Downstream of the South Fork Tuolumne River Confluence (Left Photo) and Downstream of the Clavey River Confluence (Right) Showing Formation of Alternate Bars with Increasing Valley Width and Decreasing Valley Slope.



Looking upstream



Looking upstream

2.2 Cherry Creek

Cherry Creek is the largest tributary to the Tuolumne River and drains higher elevations to the north of the mainstem Tuolumne River. From Cherry Valley Dam, Cherry Creek flows about 12 miles to its confluence with the Tuolumne River (1.3 miles downstream of Early Intake). For the first two miles immediately downstream of Cherry Valley Dam, the river is less confined with a more gradual gradient (1.8%) before diving into a more confined canyon. Upstream of the confined canyon, the river alternates between low-gradient cobble-bedded reaches separated by steep bedrock chutes. Riparian and upland vegetation has encroached onto formerly active depositional features (point bars and lateral bars) since completion of Cherry Valley Dam (Figure 2-6). However, this low gradient reach immediately downstream of the dam is unusual. For most of its length, Cherry Creek is confined within a steep (4.7%) bedrock canyon, before flattening out to some degree downstream of Holm Powerhouse (2.7%). The bed consists primarily of very large boulders and bedrock (Figure 2-7), though sand, gravel, and cobbles are stored in pools, along channel margins, and in the lee of boulder and bedrock obstructions.

Figure 2-6: Cherry Creek Looking Upstream from the USGS Gaging Station 1 Mile Downstream of Cherry Valley Dam Showing the Low Gradient, Semi-Alluvial Channel Morphology in this Reach. Note Extensive Riparian and Upland Vegetation Encroachment onto Lateral Bars.

Figure 2-7: Cherry Creek Canyon Looking Downstream from Cherry Lake Road Bridge (5 Miles Downstream of Eleanor Creek Confluence). Note Less Riparian Vegetation Encroachment, Boulder Substrate with Gravel/Cobble Pockets, and Steeper Channel Gradient.

2.3 Eleanor Creek

Eleanor Creek flows into Cherry Creek 3.4 miles downstream of Eleanor Dam and seven miles upstream of the Tuolumne River. In the 0.65 mile reach downstream of Eleanor Dam, the channel is moderately confined and steep (3.3%) as it flows across bedrock and boulders (Figure 2-8). For the remainder of its 2.75 mile length, Eleanor Creek flows through a very steep (6.1%) bedrock canyon, where the channel is a series of deep pools, cascades, and falls (Figure 2-9).

Figure 2-8: Eleanor Creek 0.5 Mile Downstream of Eleanor Dam (Looking Downstream) Showing Moderately Confined but Steep Boulder-Bed Morphology. Note Minimal Riparian Vegetation Encroachment.

Figure 2-9: Eleanor Creek 1.5 Miles Downstream of Eleanor Dam (Looking Downstream) Showing Very Confined, Steep, Bedrock and Boulder-Bed Morphology. Note Sparse Riparian Vegetation.

2.4 Project Facilities and Operation

In the Tuolumne River watershed, Hetch Hetchy 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 2-10). The Hetch Hetchy Project was constructed in phases beginning in 1917 and continues to evolve as facilities and operations are modified to meet current project needs and objectives. Hetch Hetchy Project facilities and key dates in its development relevant to its effects on the stream ecosystem in the study reaches are:

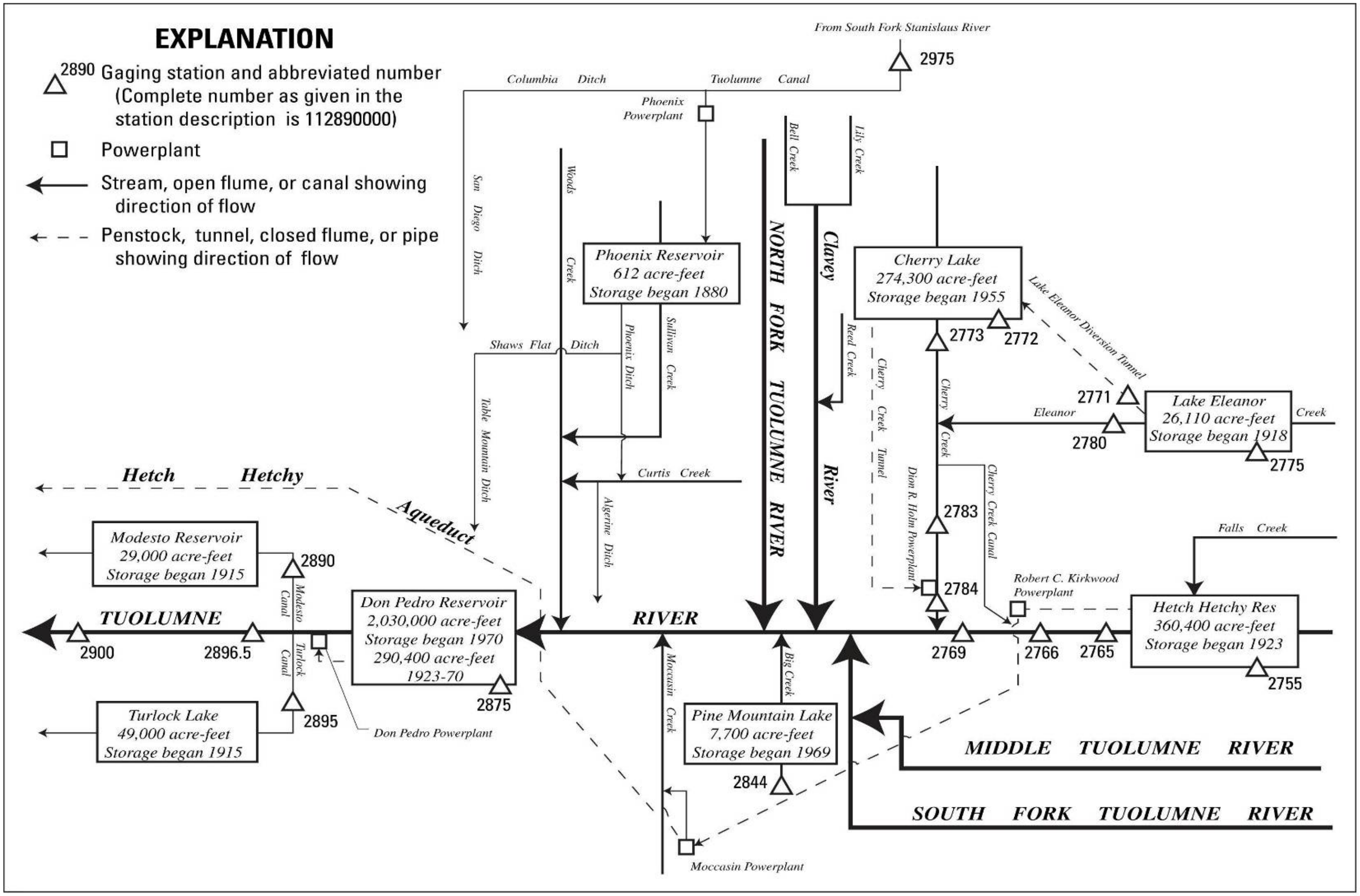
- 1918: Lake Eleanor is enlarged with the completion of Eleanor Dam, creating a reservoir with 27,100 acre-ft of storage beginning in June 1918. Construction of a diversion dam, a tunnel, and the Lower Cherry Creek Aqueduct allows the diversion of Cherry Creek and releases from Lake Eleanor flows to Early Intake Powerhouse in 1918. Approximately 160-200 cfs of flow from lower Cherry Creek is diverted to Early Intake Powerhouse on the Tuolumne River at Early Intake, 12 miles below Hetch Hetchy. Powerhouse outflow is released to the Tuolumne River (i.e., it is not diverted to the Hetch Hetchy Aqueduct).
- 1923: O'Shaughnessy Dam (Hetch Hetchy Reservoir [260,000 acre-feet]) begins storing runoff from the upper 459 mi^2 of the Tuolumne River watershed in April 1923.
- 1925: Early Intake Diversion Dam and Mountain Tunnel begin diverting water from the Tuolumne River. Water released from Hetch Hetchy Reservoir is diverted at Early Intake Diversion Dam to Mountain Tunnel, which conveys up to 670-800 cfs to Moccasin Powerhouse.
- 1934: Hetch Hetchy Aqueduct connection to the Bay Area was completed.
- 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.
- 1950: Department of the Interior and SFPUC agree to minimum flow schedule for Cherry Creek downstream of Cherry Valley Dam, and construction starts in 1953.
- 1955: Cherry Valley Dam begins storing runoff from the upper 117 mi^2 of the Cherry Creek watershed in December 1955. 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 Lake and Hetch Hetchy are operated to reduce flood inflow to Don Pedro Reservoir.
- 1956: Department of the Interior and SFPUC agree to minimum flow schedule for Eleanor Creek downstream of Eleanor Dam.
- 1960: Diversion from Lake Eleanor to Cherry Lake begins in March 1960, and diversion from Cherry Lake to Holm Powerhouse begins in August 1960. Water from Lake Eleanor is periodically diverted to Cherry Lake via the Cherry-Eleanor Diversion Tunnel by gravity through 1981. Diversion is limited by stipulation to certain times of the year and to 1000 AF/day, and that can only be accomplished when Cherry Lake is drawn down below 4651 feet. The Cherry-Eleanor Pump Station is completed in 1982 and has a capacity of 500 AF/day.. Cherry Creek inflow and water from Lake Eleanor are diverted from Cherry Lake to Holm Powerhouse via Cherry Power Tunnel. Cherry Power Tunnel, which can divert 810 cfs (with Cherry Lake empty) to 1,000 cfs (with Cherry Lake full), bypasses flows around the Upper Cherry, Eleanor, and Lower Cherry reaches. Outflow from Holm Powerhouse discharges to Cherry Creek 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 Early Intake and into the Hetch Hetchy Aqueduct during critical drought years.

- 1961: Department of the Interior and SFPUC agree to an interim minimum flow schedule for the Tuolumne River downstream of O'Shaughnessy Dam.
- 1967: Kirkwood Powerhouse is completed and Canyon Power Tunnel begins diverting water to Kirkwood in April 1967. Canyon Power Tunnel shifts the SFPUC point of diversion from Early Intake to O'Shaughnessy Dam, ,removing the need for releases for water supply through the Hetchy Reach. Water from Hetch Hetchy Reservoir can be released via O'Shaughnessy Dam through fourteen outlet conduits, three of which connect to the Canyon Tunnel and 11 of which release water to the river. The river outlets have a maximum capacity of approximately 10,000 cfs. Water stored in Hetch Hetchy Reservoir is diverted to Kirkwood and then either entirely diverted to Moccasin powerhouse and into the SFPUC watery delivery system, or part of the water is released downstream to New Don Pedro Reservoir from either Kirkwood Powerhouse or Moccasin Reservoir, or both.

  After passing through Kirkwood Powerhouse, up to 670 cfs of the flow diverted from Hetch Hetchy can currently be routed directly to Mountain Tunnel and Moccasin Powerhouse without returning to the Tuolumne River. When originally constructed, diversion capacity may have been as high as 800 cfs, but capacity has declined over time. Powerhouse outflows exceeding 670 cfs are discharged to the Tuolumne River at Early Intake Reservoir. Moccasin Powerhouse outflow in excess of SFPUC water delivery is discharged to New Don Pedro Reservoir, and this may occur 3-4 months annually, depending on water-year magnitude. While the Canyon Power Tunnel diversion capacity is 1,400 cfs, the generation capacity limit at Kirkwood Powerhouse is 920 cfs. Until the additional generator is added in 1988, the Canyon Power Tunnel diversion was 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.
- 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 operational change is instituted to increase the firm yield of the Hetch Hetchy Water and Power system. Cherry Lake operations are revised to increase carry-over storage. Before 1993, Cherry Lake storage was drawn down to between 50,000 and 100,000 acre-feet each year. Revised operations increase minimum storage at Cherry Lake to between 200,000 and 250,000 acre-feet, increasing spill frequency and volume to the Upper Cherry and Lower Cherry reaches, and reducing summer outflow from Holm Powerhouse.
- Increased carry-over storage at the three project reservoirs increases frequency, magnitude, and duration of spills to all reaches in the study area.

Figure 2-10: Schematic Diagram Showing Reservoirs and Flow Diversions in the Tuolumne River Watershed



Source: USGS (2004)

Chapter 3 Fundamental Concepts of River Ecosystem Function

3.1 Basic Concepts

Given the variability in streams and rivers, understanding natural ecosystem function and the pathways through which dams and diversions affect ecosystem function can seem overwhelmingly complex. Some basic generalities, however, can simplify this task. Four fundamental concepts of river ecological function form the basis of the conceptual model driving the analyses presented in this report.

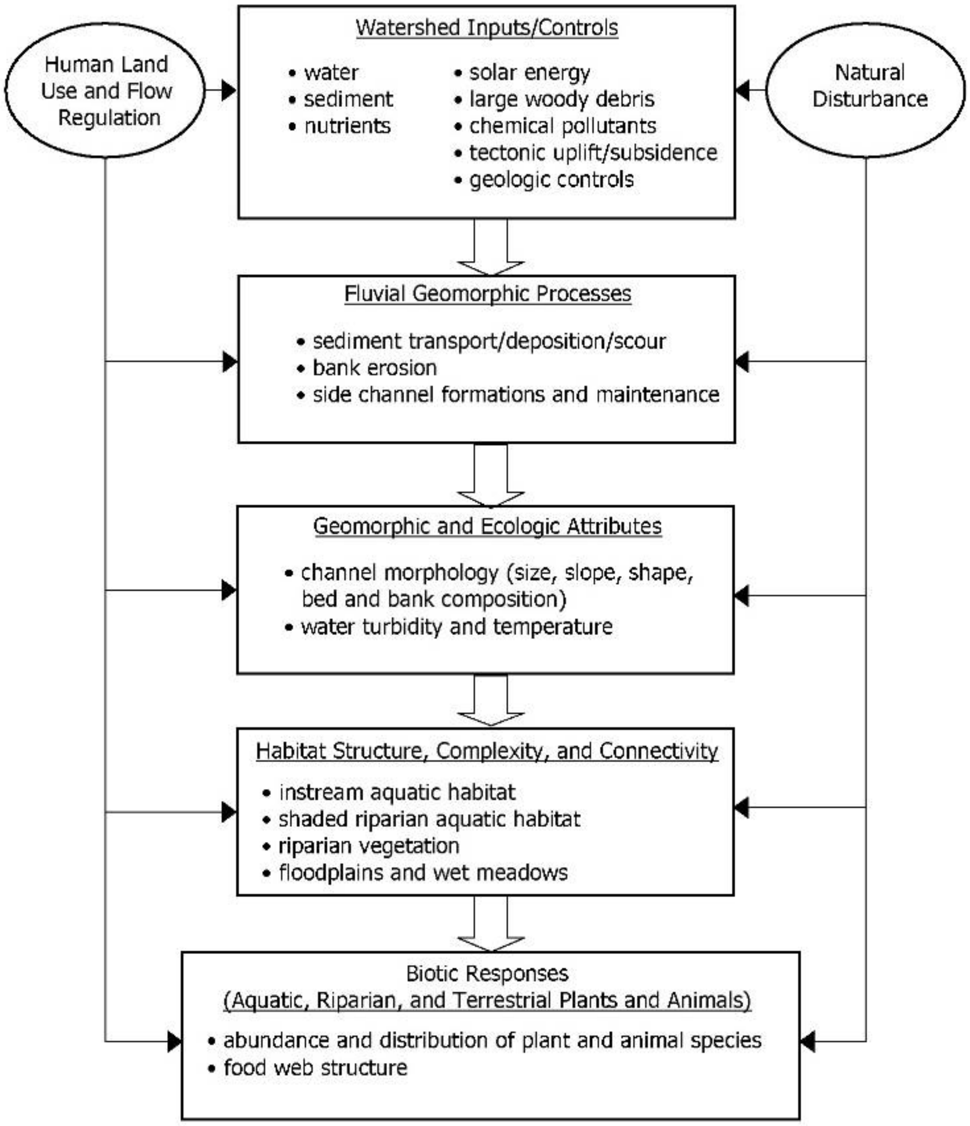
CONCEPT 1: River form (i.e., physical habitat) is created and maintained by complex interactions between flow, sediment supply, large wood, and the underlying geology. These interactions are represented in the simple conceptual model in Figure 3-1, which identifies linkages between *watershed inputs*, *fluvial geomorphic processes*, *geomorphic attributes*, *habitat structure*, and *biological communities*. In this model, watershed inputs (water, sediment, large wood, and nutrients) drive physical processes such as sediment transport and channel migration that, in-turn, determine the geomorphic attributes and physical habitat structure of the river-floodplain ecosystem. These physical habitats support aquatic and terrestrial biological communities and are important determinants of plant and animal species composition, abundance, and distribution. Feedback loops, such as the effects of riparian vegetation on hydraulic roughness, bank stability, and large wood recruitment, also affect geomorphic processes, geomorphic attributes, and habitat structure. Modification of any of these watershed inputs or geomorphic processes (such as through dam operation or flow diversion) can change physical habitat structure and therefore affect distribution and abundance of plant and animal species.

While this conceptual model is very simple and cannot adequately reflect the full range of ecological interactions and complexity in natural river systems, it provides a useful framework for evaluating the effects of flow regulation and diversion on the river ecosystem and identifying measures to restore or improve ecosystem integrity. For instance, a large dam that reduces flood flows (a watershed input) can alter the timing, duration, frequency, and magnitude of floodplain inundation (a geomorphic process) which can, in turn, alter riparian plant species composition and age class structure, thus altering habitat suitability for nesting riparian birds and resulting in a shift in bird species community composition. This framework, however, cannot address all potential effects of dams and diversions on aquatic ecosystems and biota. For example, the model does not address the effects of dams blocking migration of aquatic organisms.

CONCEPT 2: Rivers exhibit predictable flow regimes, and native riverine species are adapted to the "natural flow regime" for their specific river or region. All aspects of this flow regime – flow magnitude, duration, timing, and variability – can have important effects on the sustainability of native animal populations and plant communities. Unregulated rivers exhibit "natural flow regimes" that are controlled by climate, watershed topography, watershed geology, and other regional factors. Flow regime describes the intra-annual variability in flow patterns. A wide variety of flow regimes occurs in nature, including stable regimes, variable regimes lacking seasonal predictability, seasonally predictable snowmelt-dominated streams, and seasonally predictable rainfall-dominated streams (Figure 3-2).

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 landslide materials, 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). Hydrograph components at key gaging stations in the upper Tuolumne River are described in Section 5.

Figure 3-1: Simplified Conceptual Model of Physical and Ecological Linkages in the Upper Tuolumne River Ecosystem (adapted from Stillwater Sciences 2002).



Native plants and animals that inhabit rivers and their floodplains are adapted to the flow patterns of the natural flow regime. Life history strategies are synchronized with predictable, long-term flow patterns, and physical characteristics that take advantage of or avoid harm from extreme flood or drought events (Naiman et al. 2002, Lytle and Poff 2004). Figure 3-3 illustrates the natural flow regime for the Trinity River relative to timing of life history events and stages for fall-run Chinook salmon (*Oncorhynchus tshawytshca*), narrowleaf willow (*Salix exigua*), and black cottonwood (*Populus balsamifera*). In addition to the physical habitat structure created and maintained by interactions between watershed inputs and geomorphic processes, these species depend on a specific temporal flow pattern for reproductive success. For example, Chinook salmon require high spring flows to support floodplain rearing and spring outmigration; black cottonwoods require high flows during their narrow seed release window, followed by a flow recession limb that is gradual enough to support seedling root development and avoid seedling mortality caused by desiccation.

Figure 3-2: Examples of Stable and Variable Streamflow Regimes, with Differing Seasonal Predictability. (A) Example of Stable Flow Regime and High Predictability Using Augusta Creek near Augusta, MI; (B) Example of Variable Flow Regime with Low Seasonal Predictability (Rainfall Hydrograph) at Satilla River near Atkinson, GA; and (C) Example of Variable Flow Regime with High Seasonal Predictability (Snowmelt Hydrograph) at Colorado River at Windy Gap near Granby, CO.

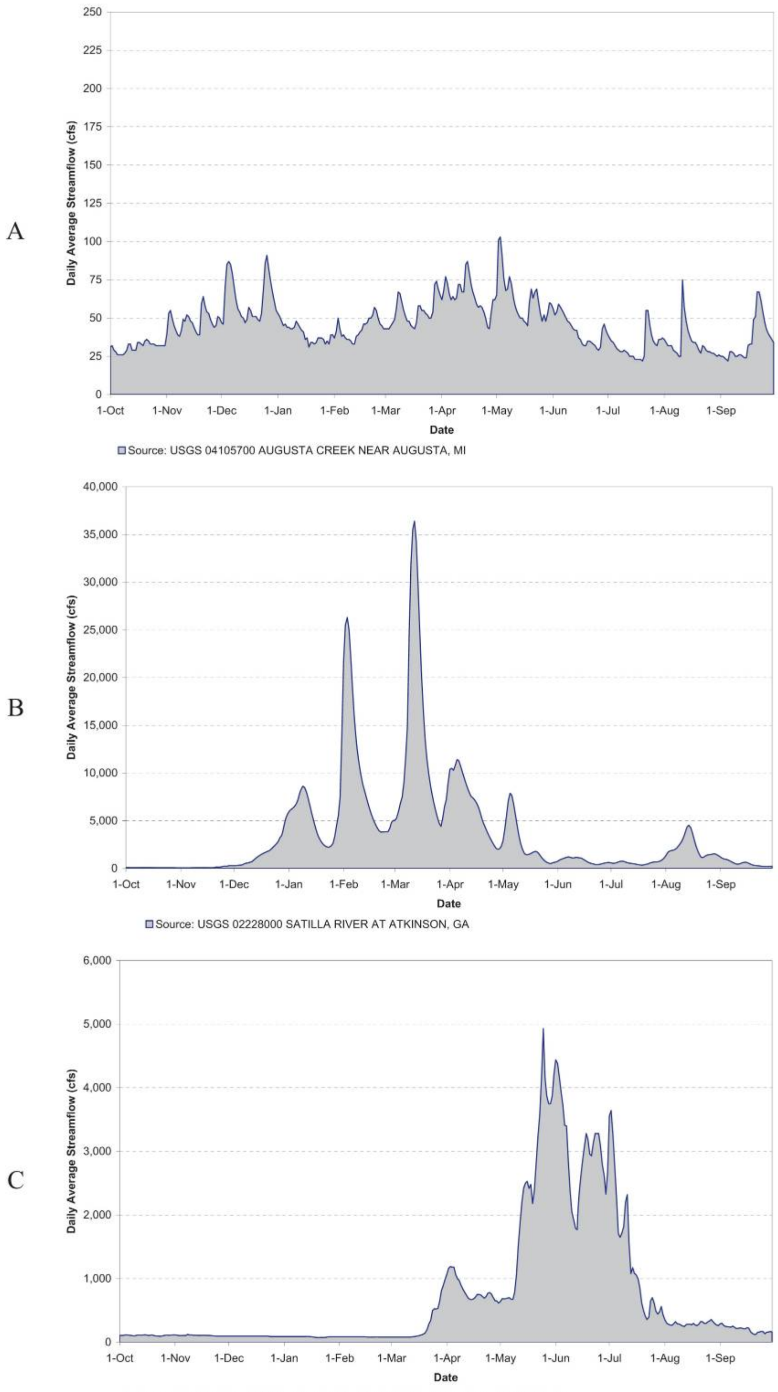
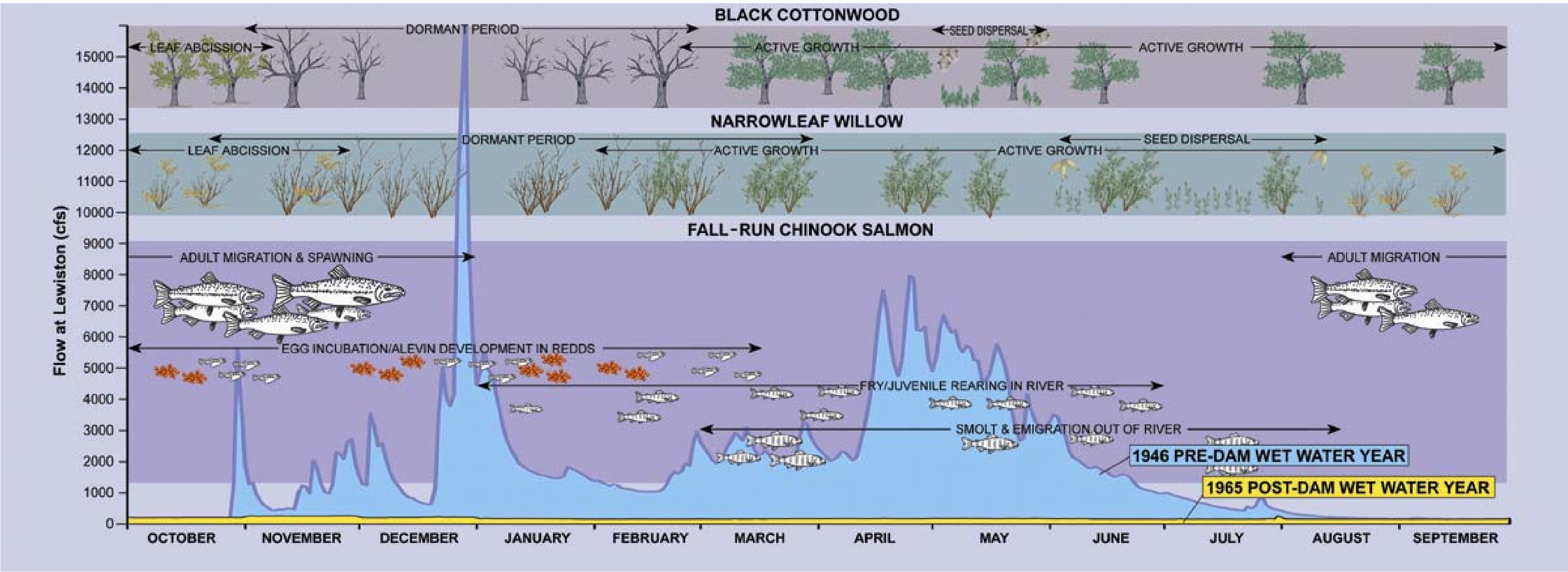


Figure 3-3: Example of Life History Timing Relative to Natural and Regulated Flow Conditions for Fall-Run Chinook Salmon, Black Cottonwood, and Narrow-Leaf Willow on the Trinity River, California.



CONCEPT 3: "Normal" conditions are not normal. Climatic conditions are highly variable from year to year, ranging from critically dry to extremely wet. Geomorphic and ecological processes differ between wet and dry years. Some examples of hydrologic, geomorphic, and ecological processes occurring during critically dry, normal, and extremely wet years are shown in Table 3-1. During critically dry years, flows do not mobilize the channel bed, initiate bank erosion or large wood recruitment, or inundate floodplains. During these years, fish and other aquatic organisms may be stressed or experience reproductive failure due to limited habitat area and high water temperatures. Riparian vegetation can initiate on channel bars and encroach into the active channel. Flows are not sufficient to scour this vegetation from the channel. During normal years, flows mobilize the bed, scour and remove encroaching riparian vegetation, and initiate channel migration and large wood recruitment. Flows also inundate the floodplain for brief periods and deposit fine sediment. Limited riparian vegetation recruitment can occur on floodplains, supported by floodplain inundation and the slow recession of snowmelt flows. During extremely wet years, flows can be high enough to cause significant bed scour, channel avulsion, channel migration, and recruitment of large wood to the channel. Prolonged and extensive floodplain inundation and high flow velocities on the floodplain can remove mature riparian trees and support establishment of significant riparian cohorts. Prolonged floodplain inundation may also benefit aquatic species that spawn or rear on the floodplain, but high flows may also scour redds constructed in the channel.

Riverine species, therefore, are adapted to cope with extremes (i.e., drought and flood). While populations may survive brief periods of extreme conditions (on the order of one or a few years depending on their life history), they may not persist through prolonged extreme conditions that exceed the range of natural variability under which they evolved (such as continuous drier conditions caused by flow management).

Table 3-1: Hydrologic, Geomorphic, and Ecological Processes Supported by Critically Dry, Normal, and Extremely Wet Year Flow Conditions on an Example Alluvial River with Anadromous Salmonids.

Water Year Type	Hydrologic Processes	Geomorphic Processes	Ecological Processes
Critically Dry	• Small winter floods (less than bankfull) • Minor snowmelt runoff peak • Short-duration snowmelt recession limb that ends early in the season (April or May) • Very low winter and summer baseflows • Higher water temperatures	• No channel migration • No gravel bedload transport • Some sand bedload transport • No bed scour, alluvial deposits not mobilized.	• Riparian vegetation initiation on active alluvial bars • No scour of vegetation at the channel margin • No recruitment of riparian vegetation on floodplains • Limited salmonid access to upstream habitats • Low rearing success for cold-water fish species • Low recruitment rates of amphibians
Normal	• Moderate winter floods (approx. bankfull) • Moderate snowmelt runoff peak • Moderate summer and winter baseflows	• Initiate channel migration • Initiate bedload transport • Short-duration floodplain inundation • Small amount of fine sediment deposition on floodplains • Alluvial deposits mobilized	• Riparian vegetation seedlings scoured along the low flow channel margin • Minor woody debris recruitment to the channel • Moderate salmonid access to upstream habitats • Successful rearing of cold water fish species • Successful amphibian recruitment

Water Year Type	Hydrologic Processes	Geomorphic Processes	Ecological Processes
Extremely Wet	• Large winter floods (greatly exceeding bankfull) • Large snowmelt runoff peak • Long-duration snowmelt recession limb that extends into late summer • Higher summer and winter baseflows • Lower water temperatures	• Channel avulsion and/or migration • High bedload transport rates • Bed scour and floodplain scour • Prolonged floodplain inundation • Alluvial deposits scoured and new alluvial deposits formed	• Seedlings along low flow channelbed scoured • Mature riparian vegetation removed • Large wood recruited to the channel • Carbon and nutrient exchange between channel and floodplain • New riparian vegetation cohorts recruited • Increased salmonid access to upstream habitats • Potential redd scour and mortality • Improved fish rearing conditions on floodplains and higher rearing success • Successful amphibian recruitment

CONCEPT 4: While river ecosystems vary across watersheds and regions, basic attributes can describe healthy river ecosystems. The science of bedrock rivers tends to focus on landscape-scale processes at geological timescales, which are usually too large and too long than most contemporary river management issues. A common perception is that bedrock channel morphology is static compared to alluvial channels and, therefore, relatively insensitive to flow and sediment supply changes. Bedrock channels, however, are often highly dynamic depositional environments, with frequent deposition occurring within a confining, rigid bedrock boundary. This bedrock template functions as an intricate complex of hydraulic controls that creates diverse nested depositional features ranging from aggregates of large boulders to fine sand deposits. These depositional features provide habitat that supports native aquatic species.

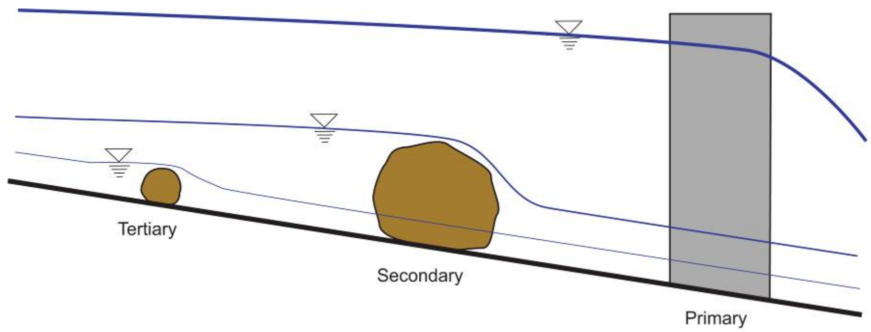
3.2 Bedrock River Attributes

McBain and Trush (2004) describe "attributes" of healthy bedrock river systems. These attributes, by necessity, simplify the range of rivers and streams that occur in nature and cannot represent all hydrogeomorphic processes that drive ecosystem function. However, they provide a basic conceptual model (or starting point) for considering natural river conditions, identifying the effects of dams and diversions on ecosystem health, and identifying measures to avoid or reduce those effects.

Attribute 1. *Bedrock rivers exhibit nested depositional features. Bedrock channels, though principally erosional, exhibit abundant depositional features (e.g., Whipple et al. 2000). Large geomorphically derived hydraulic controls, such as valley width constrictions or expansions and resistant bedrock outcrops, define an overall limit for coarse sediment deposition in each segment of the bedrock channel. These geomorphic controls induce coarse depositional features that in turn perform as smaller hydraulic controls inducing finer secondary depositional features. Transverse boulder "ribs" are prominent depositional alluvial features (i.e., self-formed) and function as hydraulic controls for diverse secondary, and even tertiary, depositional features. The occurrence of smaller hydraulic controls within larger hydraulic controls gives rise to a complex, nested depositional channel morphology that provides diverse aquatic and riparian habitats.*

At first glance, a boulder-bedrock Sierra river appears to be a chaotic collection of large and small boulders with an occasional bedrock pool. Attribute No. 1 asserts that something orderly underlies the chaos: nested hydraulic controls. A hydraulic control is a prominent roughness element (e.g., a large boulder or bedrock outcrop) or channel characteristic capable of modifying the local water surface slope and inducing scour or deposition. During rising flows of a large flood, a cluster of basketball-sized boulders functioning as a hydraulic control for a small sandy lee deposit can be drowned-out by a larger hydraulic control, such as downstream rib of 7-ft-diameter boulders. Hydraulic controls, therefore, are typically nested (Figure 3-4).

Figure 3-4: An Idealized Segment of a Boulder-Bedrock Channel with Three Levels of Nested Hydraulic Controls and Associated Depositional Features (McBain and Trush 2006).



Primary hydraulic controls (such as constricting bedrock valley walls) are capable of influencing the water surface slope and hydraulics of major floods. Secondary hydraulic controls may be drowned-out during a major flood, but are capable of influencing water surface slopes and hydraulics of smaller floods. These secondary hydraulic controls, and even smaller tertiary hydraulic controls, lie within the influence of larger hydraulic controls and are therefore nested.

Nested hydraulic controls create nested depositional features. The end result, the geomorphic chaos seen in the channel, is a hydraulically complex channel sustaining a diversity of depositional features (Figure 3-5). Large-scale depositional features (boulder ribs, forced point bars comprised of boulders) are shaped by primary and secondary hydraulic controls during infrequent, large floods, while smaller-scale depositional features (gravel and cobble deposits in the lee of boulders) associated with small secondary and tertiary hydraulic controls are scoured and reshaped by frequent small floods. Large scale depositional features, such as a rib of car-sized boulders deposited upstream of a valley constriction during a 150-yr flood, can act as secondary hydraulic control inducing formation of a cobble point bar upstream.

Attribute 2. *Bedrock river ecosystems require variable annual hydrographs. Annual hydrographs can be partitioned into discrete hydrograph components. Each is a discrete, repeatable portion of the annual hydrograph that varies in magnitude, duration, frequency, and timing within and among different types of water years. Annual hydrograph components uniquely (a) contribute to geomorphic processes that shape and maintain depositional features, (b) sustain varied life history and habitat requirements for plant and animal species native to a particular bedrock river ecosystem, and (c) perpetuate early-successional woody riparian communities. Seasonally-dependent life history requirements, such as the short time-span when riparian plants disperse viable seeds (often as short as two weeks), have evolved to the natural timing and frequency of annual hydrograph components.*

A hydrological description of streamflows in Sierra Nevada river ecosystems must: (1) faithfully describe natural variation in flow magnitude, duration, frequency, and timing within and among different types of water years, (2) relate directly to geomorphic flow thresholds and life history requirements of native species and communities, and (3) encourage manageable flow prescriptions in regulated rivers (McBain and Trush 2004). Using annual hydrograph components to describe annual flows, while not perfect, meets these criteria. Hydrograph components for a rainfall-snowmelt hydrologic regime typical of Sierra

Nevada rivers includes winter storm peaks, winter and summer baseflows, snowmelt peaks, and snowmelt rising and recession limbs (Figure 3-6).

Attribute 3. *Episodic sediment delivery enhances spatial complexity. Hillslope mass wasting, such as rock falls and bedrock shearing from canyon walls, episodically deliver colluvium of sufficient volume and/or caliber that creates large depositional features in the channel or functions as large-scale hydraulic controls capable of generating other prominent depositional features.*

Episodic events can leave geomorphic signatures on channel morphology. They can impose hydraulic controls anywhere. The high transport capacity of highly confined bedrock channels has tremendous power to modify a huge debris slide blocking or constraining the mainstem channel (as occurs in the lower mainstem Clavey River). The intervening period while the slide feature remains may be brief geologically but extended biologically, supplying a unique depositional environment. Attribute No.3 stresses the need for continued (unimpeded) episodic events to promote their somewhat rare brand of geomorphology that contributes disproportionately to complex channels and ultimately diverse river ecosystems.

Attribute 4. *Bedrock channel maintenance requires multiple flow thresholds. Multiple flow thresholds are required to initiate diverse depositional and erosional processes essential to maintaining the erosional and depositional features of bedrock channels. Infrequent large "re-setting" floods (approximately 25-yr annual maximum floods and greater) are needed to: (a) significantly scour and redeposit large depositional features such as entire lateral bars, (b) reposition and aggregate large boulders into depositional features such as transverse boulder ribs, (c) periodically remove mature woody vegetation from bars and along channel margins, (d) encourage avulsions in broader channel reaches, (e) prevent steepening of riffles due to excessive boulder accumulation, and (f) sweep-out boulders accumulating in bedrock pools. More frequent, lower magnitude floods (10-yr to 20-yr annual maximum floods) are needed to (g) significantly mobilize surface layers of large coarse-grained bars in part to minimize woody riparian encroachment, (h) deposit smaller coarse depositional features associated with transverse boulder ribs and/or individual large boulders and bedrock outcrops, and (i) deposit silt and sand on floodplains and low terraces. Frequent snowmelt flood hydrographs (up to 5-yr annual maximum floods having relatively small peak discharges) are needed to (j) maintain a high turnover of fine-grained depositional features (composed of small cobbles and finer particles) often associated with secondary hydraulic controls of bars and transverse boulder ribs, but also in gravel deposits of bedrock pool tails (e.g., spawning habitat for salmonids), and (k) build few and highly localized floodplains.*

Russell (1902) notes for steep bedrock Sierra Nevada rivers that: *"One of the most important principles connected with stream transportation is that flowing water assorts the debris delivered to it."* The first three attributes, which set the stage for how flowing water sorts sediment (debris) in bedrock channels, are integrated by Attribute No.4. It takes the nested hydraulic controls and depositional/scour features of Attribute No.1, submits these controls and features to variable hydrograph components through Attribute No.2, and supplies the unpredictable (but certain to occur) wild-card of Attribute No.3. All three are needed to meet the physical demands of a complex boulder/bedrock channel morphology. Attribute No.4 makes intuitive sense: no single pulse flow could be expected to maintain the morphologically diverse erosional and depositional environment of boulder-bedrock Sierra Nevada rivers.

Figure 3-5: Stylized Aerial Photograph of Nested Hydraulic Controls and Depositional Features in the Clavey River (McBain and Trush 2006).

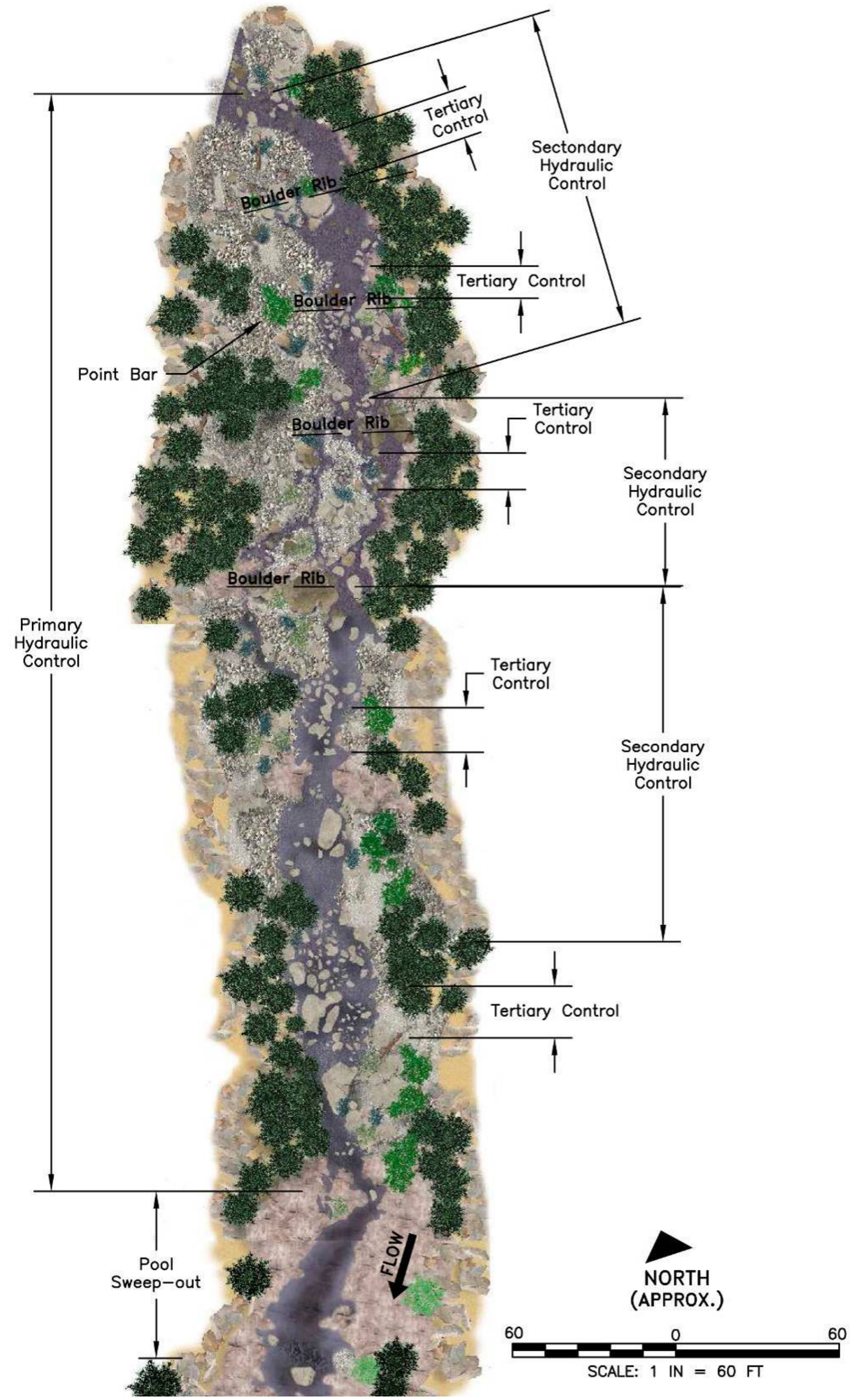
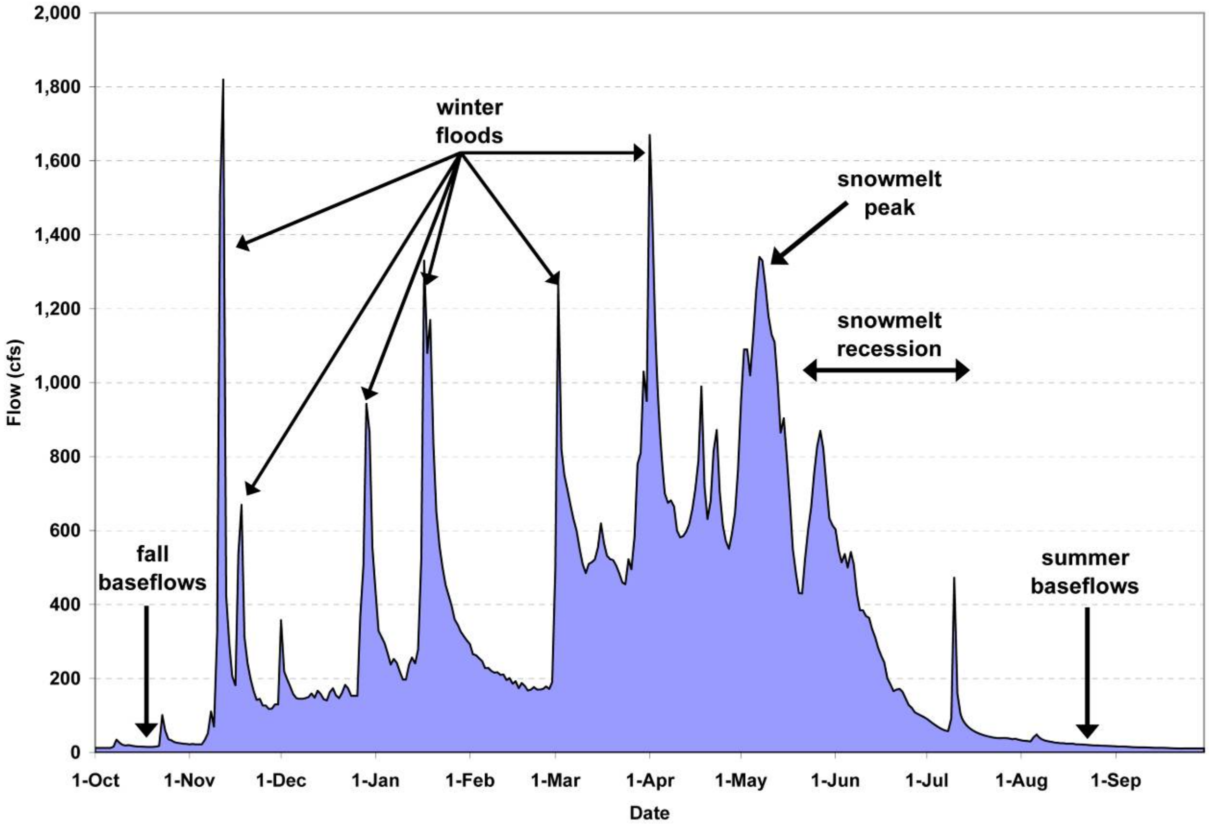


Figure 3-6: Annual Hydrograph Components for WY 1979 for the Clavey River at Buck Meadows (McBain and Trush 2006).



Attribute 5. *Maintenance of depositional features is partially independent of the coarse bedload transport capacity. Bedrock rivers have a large, and generally unfulfilled, potential transport capacity for coarse sediment, but a low temporary storage capacity of coarse and fine sediment. Hydraulic complexity and channel form, expressed as nested hydraulic controls in a variable flow regime, exert the greatest control on storage capacity. The annual coarse bedload transported may fluctuate significantly without significantly affecting the volume of coarse sediment stored in a channel segment. Although storage capacity is low, the ecological implications for maintaining limited depositional features can be great.*

Boulder-bedrock channels can transport coarse sediment well in excess of the actual sediment supplied. As Russell (1902) observed: *"Not only do they [Sierra Nevada rivers] bear away all of the fine material that reaches them, but in times of high water roll along large boulders, and yet their capacity to transport is not satisfied."* Complex hydraulics and channel morphology, expressed as nested hydraulic controls in a variable flow regime, establish the storage capacity for coarse sediment. Thus the annual coarse bed material supplied to a channel segment may fluctuate significantly without seriously affecting the volume of coarse sediment stored in that channel segment.

Attribute 6. *Biological hotspots occur at highly depositional channel reaches. Biological hotspots, short channel segments supporting unique and/or more diverse aquatic and riparian communities, typically occur where the local river corridor or major episodic geomorphic events exert large-scale hydraulic control over deposition. These atypical channel segments exhibit prominent depositional features, and even alluvial tendencies such as a meandering channel morphology and limited floodplains that are highly dependent on snowmelt flood and recession annual hydrograph components. This alluvial tendency promotes smaller particle size, abundant riparian habitat, off-channel amphibian habitat, and* *higher overall biological diversity. Biological hotspots are the offspring of other attributes and are reminders that nature is attracted to novelty.*

Attribute No. 6 may be the most compelling reason for wanting to manage boulder-bedrock river ecosystems ecologically. These atypical channel segments, relatively mellow places in a harsh environment, exhibit many prominent depositional features, including aggradational floodplains. This depositional tendency promotes smaller particle sizes, abundant riparian habitat, off-channel amphibian habitat, early life history habitat for fish, and higher overall biological diversity.

Attribute 7. *Hydraulic pathways in the river corridor fluctuate seasonally and annually. Variable hydrograph components, particularly the snowmelt recession limb and baseflows, sustain surface and subsurface hydraulic pathways throughout the river corridor.*

The magnitude, duration, and timing of the annual snowmelt pulse flow can greatly influence water availability in prominent depositional features.

3.3 Summary

These concepts guide our view of how "healthy" river ecosystems function and serve as a foundation for evaluating project-induced changes to that function, and developing strategies to adjust project operations and management in ways that stand the best chance of improving ecosystem "health." This approach deliberately avoids single-species management, yet uses key components of ecosystem function as the means for improving conditions for key species. This more holistic approach is supported by recent science in salmonid recovery in the Pacific Northwest and the Sierra Nevada Ecosystem Project.

Chapter 4 Study Approach

The study approach proposed to assess existing conditions, project-induced ecosystem changes, and opportunities for modifying operations to improve riverine ecosystem function downstream of Hetch Hetchy project facilities departs from "standard methodologies" by attempting to prioritize information needs that drive the information gathering and analysis, rather than allowing "cookbook methods" to drive information gathering and analysis. The scientific method plays an important role, encouraging the practitioner to use logic and science in a structured, iterative process to define issues, identify and prioritize information needs, select analysis methods, and develop management actions that best remediate diversion impacts to aquatic ecosystems.

This study approach applies the basic scientific method of hypothesis development, prioritization, and testing to discern: (1) how physical processes functioned to support the river ecosystem under unregulated conditions, (2) how flow regulation and diversion have altered the unregulated condition, and (3) what operational changes, if implemented, could improve river ecosystem function. The study approach uses existing information and targeted studies to develop and refine conceptual models and develop and test hypotheses, with the goal of developing potential changes in operations that would improve the river ecosystem (Figure 4-1).

Data collection and assessment will, to the extent feasible, identify and quantify linkages between hydrograph components (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 (Section 7), and also provide information needed to evaluate trade-offs between potential flow management adjustments and ecosystem outcomes.

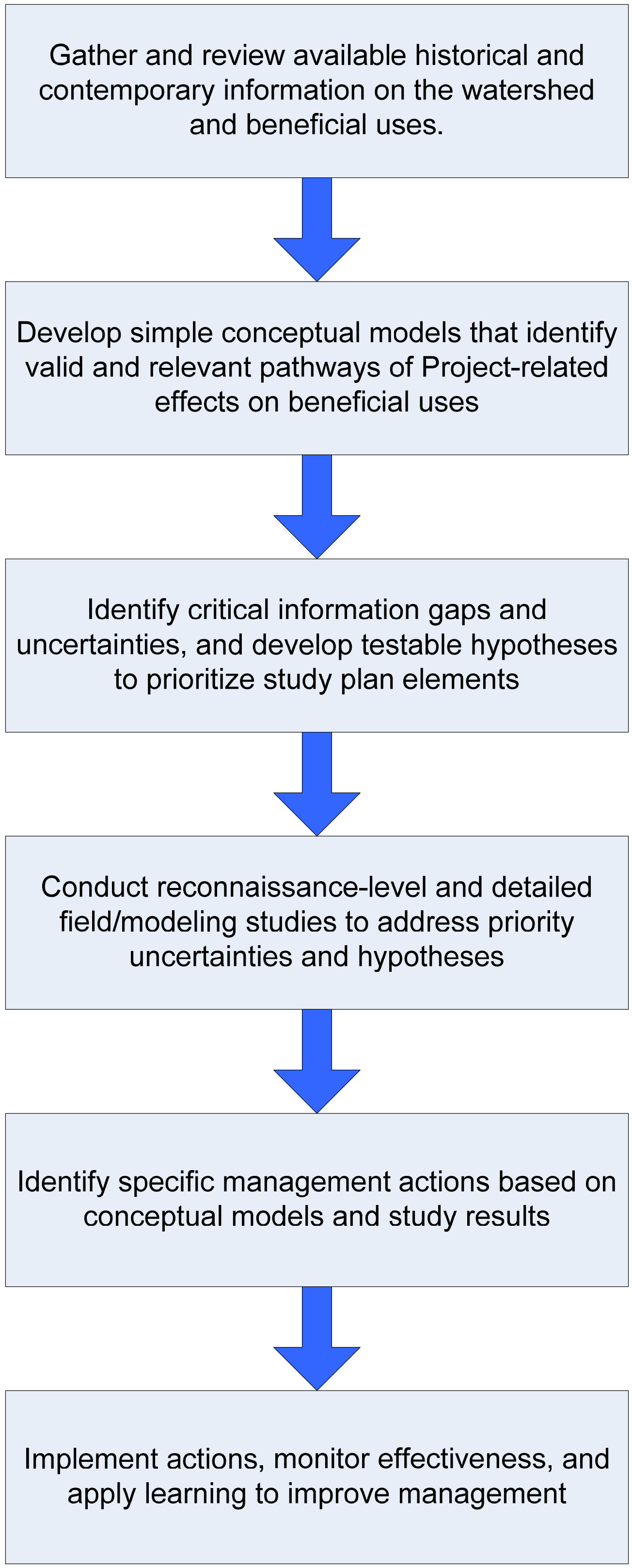
4.1 The Scientific Method

Traditional application of the scientific method is two-stepped (Platt 1964). The first step *defines observed phenomena;* the second step *formulates and tests plausible explanations for each carefully described phenomenon*. Too often, instream flow assessments focus on the first step, using inventories to describe in great detail existing vegetation conditions, fish numbers, fish habitat, and other environmental variables, but fail to implement the second step. By failing to identify and quantify causal pathways through which flow regulation and diversion are expected to affect the river ecosystem, these inventories are not adequate for developing quantitative management objectives or linking impacts to testable management actions.

The second step – *formulating and testing plausible explanations for each carefully described phenomenon* – is fundamental to the scientific investigation needed to support resource management decisions. Webster's Dictionary defines a hypothesis as an unproven theory, proposition, or supposition tentatively accepted to explain certain facts or to provide a basis for further investigation. Our use of hypotheses to evaluate instream flow needs is highlighted in the following excerpt from Quine and Ullian (1988):

"Constructing a hypothesis is guesswork; but it can be enlightened guesswork. Having accepted the fact that our observations and our self-evident truths [e.g., more fish habitat is better for fish] do not together suffice to predict the future, we frame hypotheses to make up the shortage. Hypotheses, where successful, are two-way streets extending back to explain the past and forward to predict the future. What we try to do in framing hypotheses is to explain some otherwise unexplained happenings by inventing plausible stories."

Figure 4-1: Conceptual Study Approach for Science-Based River Ecosystem Assessment.



To develop testable hypotheses, one must first identify and describe the pathways, or causal mechanisms, through which flow regulation or diversion are expected to affect ecosystem function and beneficial uses provided by the ecosystem. This description is accomplished through the development of simple conceptual models. This qualitative description, however, does not provide sufficient detail for developing and testing management actions. To provide this detail, the linkages that comprise these pathways should be quantified if possible. Through this iterative refinement of descriptive concepts and quantitative analyses, testable hypotheses can be developed and critical uncertainties can be identified. Targeted studies can then be conducted to resolve or reduce uncertainties. Using the results of these studies, detailed and testable management improvements can be defined. By focusing on the critical uncertainties with clear relevance to flow and sediment management, study resources are directed toward critical issues, thus improving efficiency and cost-effectiveness of the assessment process.

4.2 Identifying Critical Pathways of Effects

Developing plausible stories begins with sketching-out conceptual models that attempt to explain how the river ecosystem works and identify pathways, or causal mechanisms, through which flow regulation or diversion is expected to affect ecosystem function and beneficial uses provided by the ecosystem. Conceptual models are diagrams illustrating cause-and-effect linkages between driving ecosystem variables (e.g., flow, water, land use) and beneficial uses (e.g., fish populations, riparian vegetation). Conceptual models can be used to illustrate different scales of ecosystem linkages, ranging from system-wide (Figure 4-2), to species specific (Figure 4-3), to life-stage specific (Figure 4-4). Conceptual models are useful tools to develop a common understanding of how the ecosystem functions, how water or land use changes may have impacted the ecosystem, and hypotheses of how changes in management may alter the ecosystem. Conceptual models are manifested in a variety of ways: as box-arrow diagrams, as hypotheses, or as narratives. Conceptual models of how steep, bedrock and boulder-bed streams in the Tuolumne River basin function are implicit in recent publications (e.g., McBain and Trush 2004), which are quite different than on alluvial rivers. Several narrative conceptual models and hypotheses have been developed in previous research on the Clavey River and Cherry Creek (McBain & Trush 2006), and if desired, can be adjusted to more typical box-arrow diagrams.

An initial conceptual model typically includes numerous hypothetical pathways, usually too numerous to test or address in instream flow assessment. Moreover, some pathways in the initial model, while interesting, will have little bearing on potential management actions. Scientists, therefore, must consider available information and professional experience to establish the *validity* and *relevance* of each pathway. A valid pathway must be logical and supported (or at least not refuted) by available lines of evidence. A relevant pathway must directly link flow diversion or regulation to beneficial uses and must be responsive to feasible management action. While simplistic, the resulting conceptual models present a structured articulation of complex interactions through which uncertainties or gaps in knowledge can be identified and complex scientific issues can be simplified and communicated. Moreover, when these models are collaboratively developed, they can provide common understanding of ecosystem function among stakeholders in the analysis process.

4.3 Quantifying Linkages in Relevant Pathways

Conceptual models, such as those in Figure 4-2, Figure 4-3, and Figure 4-4, are useful for identifying and gaining agreement on the pathways through which a Project is expected to affect priority species (e.g., rainbow trout). By themselves, they do not present testable hypotheses that can lead to implementable management improvements. Hypotheses applied to management actions cannot be mere general descriptions, such as “high spring flows increase invertebrate production.” To be useful, these hypotheses must provide details on causal mechanisms (i.e., how does spring flow increase invertebrate production) and the relationships driving these mechanisms. This requires quantifying relationships between each causal mechanism (or linkage) in relevant pathways represented in the conceptual model.

Figure 4-2: Broad Scale Conceptual Model of Physical and Ecological Linkage in an Alluvial River Ecosystem (Developed for the Trinity River, California). Many of the linkages and components are applicable to the Tuolumne River watershed, yet would require refinement for the bedrock and boulder-bed channels of the Tuolumne River watershed.

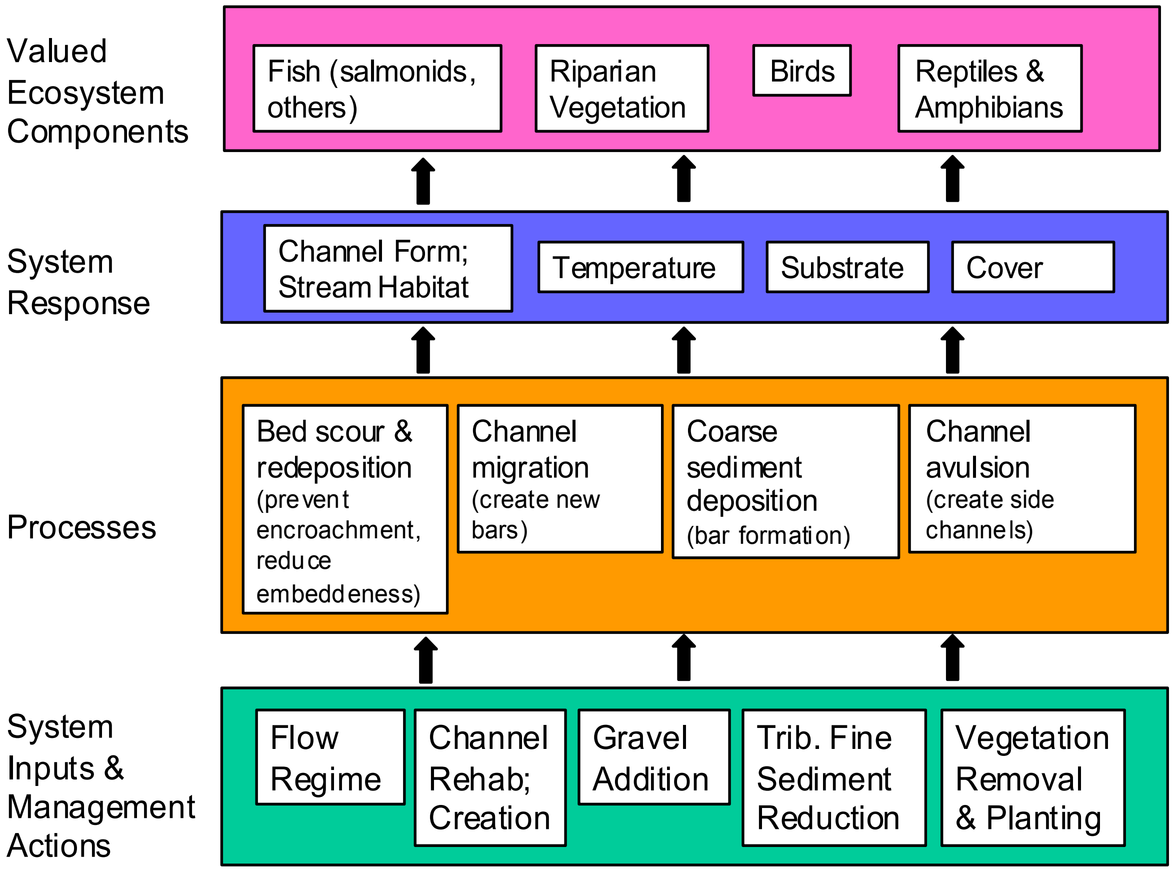


Figure 4-3: Example of More Detailed Conceptual Model Linking Effects of Flow Regulation on Fall-run Chinook Salmon in the Trinity River, California.

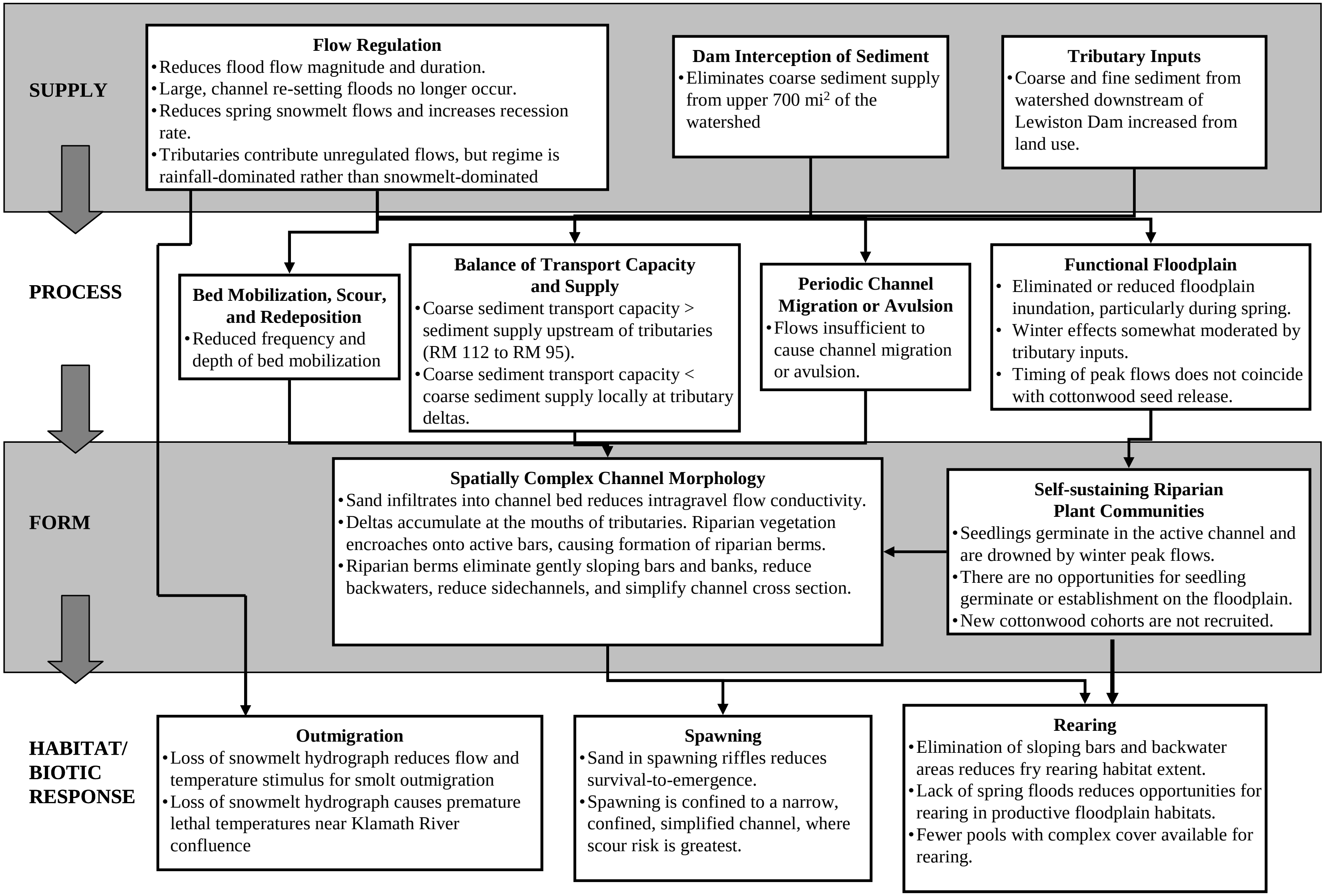
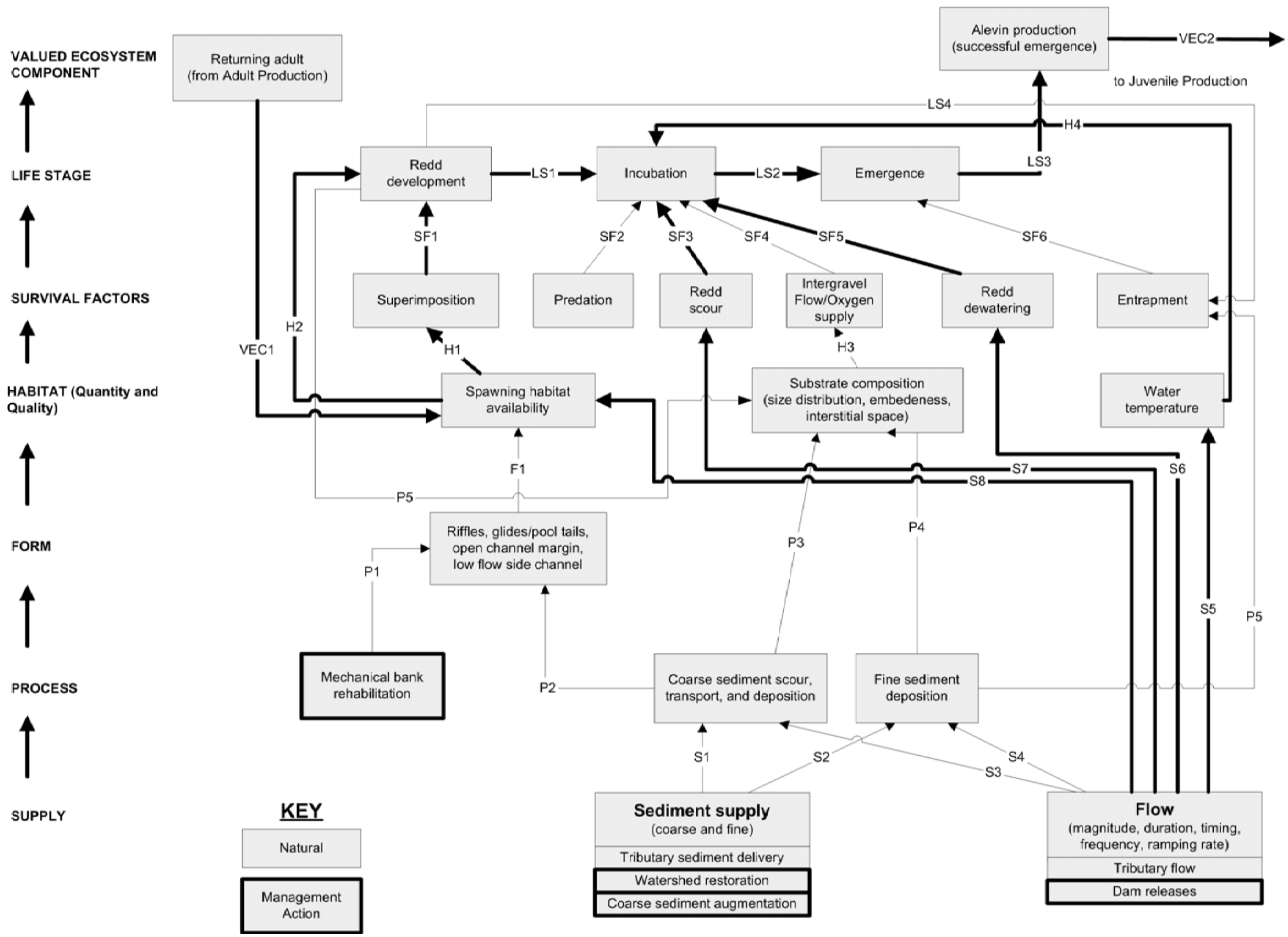
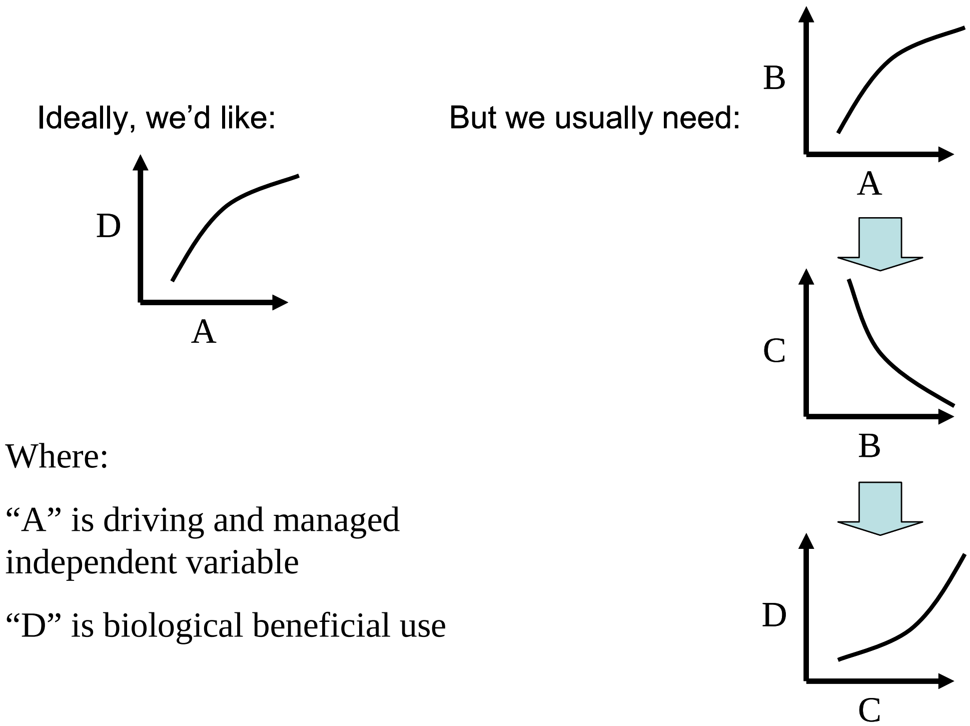


Figure 4-4: Example of Finer-Scaled, Life-Stage Specific Conceptual Model for Chinook Salmon Fry Production in the Trinity River, California.



Numerous procedures can be applied to structure quantitative relationships between linkages for each pathway. One approach, a simple "X-Y analyses," is shown in Figure 4-5. Beginning with flow as the driving independent variable (Y), this analysis moves through a step-wise progression in which the dependent variable (X) in one step becomes the independent variable (Y) in the next step until the target dependent variable (e.g., fall Chinook salmon escapement) is reached. Through this process, relationships between the parameters described in the conceptual model are quantified (based on the best available information), and data gaps and uncertainties are identified. Once critical data gaps and uncertainties are identified, appropriate measures for addressing them can be developed. Depending on the information needed, such measures might include additional analyses or modeling using available data, reconnaissance-level field studies, small-scale field experiments, or large-scale management experiments.

Figure 4-5: Example "X-Y" Analysis for Describing and/or Quantifying Relationships between Driving Variables (flow, sediment) and a Priority Management Objective (fish, riparian vegetation).



4.4 Applying Hypotheses to Management Actions

The instream flow analysis does not end with targeted studies or conceptual models. The ultimate goal of this process is to apply the knowledge gained from these efforts to formulate management recommendations that improve riverine resources. Management recommendations are themselves hypotheses – plausible stories of how specific actions will result in desired outcomes. Again, these hypotheses (i.e., management recommendations) cannot be mere general descriptions, such as "more spring flow will increase salmon outmigrant survival," but must provide details on "how, how much, and when." Again using the Trinity River as an example, take a draft hypothesis from a recent workshop:

> *"Re-creating and maintaining alternate bar channel morphology (and side channels) through mechanical restoration, coarse sediment augmentation, and high flow management will increase the amount of juvenile rearing habitat resulting in increased juvenile production."*

While this hypothesis presents a plausible story, it only weakly implies that increased juvenile production is expected to result in more adult salmon (the ultimate goal of the project). This hypothesis can be strengthened as follows:

> *"Restoring an alternate bar morphology in the mainstem Trinity River above the North Fork Trinity River confluence will increase adult steelhead runs because more 2+ juvenile steelhead habitat will be available that is now limiting the number of pre-smolts and smolts passing downstream, and ultimately the number of returning adults."*

While more specific about the pathway through which increased rearing habitat is expected to result in more adult salmon, this story still is not much more than a statement of the evident truth that more habitat is generally good. To make this hypothesis more useful for management application, it must provide necessary detail to make the hypothesis both quantitative and predictive, as follows:

> *"A single restored alternate bar provides 150% more 2+ juvenile steelhead habitat over a range of flows than an equivalent length of the present channel, sustaining 900 ft^2 of habitat capable of producing 30 steelhead smolts 14 cm and longer that ultimately generates one adult assuming a 3% smolt-adult survival rate."*

This is a quantitative story, but is it plausible? One must consider whether the numerical assumptions in our story are reasonable, thus confirming or rejecting whether this hypothesis is plausible. For example, 30 2+ steelhead juveniles produced from 900 ft^2 of habitat means a juvenile density of one 2+ juvenile/30 ft^2 of habitat. Data from studies on other rivers indicate that this assumption is indeed reasonable and, thus, supports the plausibility of the story.

Is this hypothesis testable? If a single restoration site restores four alternate bars, will more adult steelhead return to the Trinity River annually? Maybe. But it is extremely unlikely we will be able to implement a monitoring plan that can determine exactly how many returning adult steelhead originated from a specific alternate bar. In most cases, simplistic experimental designs (e.g., where H_0: increased habitat does not produce more salmon and H_1: increased habitat does produce more salmon) will be insufficient to test our management-related hypotheses. Plausibility and testability, therefore, must both be considered when prioritizing hypotheses and prescribed management actions. Once plausible actions are selected, they can be implemented and monitored to evaluate their effectiveness in meeting management objectives.

This report does not represent the end of the study approach; rather, the beginning. Hypotheses formulated at the end of this report address the first three steps in the approach shown in Figure 4-1. As additional information is collected to fill critical information gaps and analyzed to test initial hypotheses, more refined impact hypotheses will be developed, some impact hypotheses will be abandoned, and hypotheses for management improvements will begin to be developed.

4.5 Analysis Species

Because ecosystems are complex and are not completely understood, it is neither feasible nor desirable to analyze the effects of flow management on all species inhabiting the aquatic ecosystem. Rather, analysis species were selected that represent beneficial uses considered important. For this initial analysis, four taxa were chosen to represent food web productivity, as well as fish assemblages and river-dependent amphibians native to the Tuolumne River and its tributaries. This selection was based on agency management objectives, species status, available data, and species' potential as indicators of ecosystem function and integrity. Taxa selected for this initial analysis are: rainbow trout (*Oncorhynchus mykiss*), California roach (*Lavinia symmetricus*), foothill yellow-legged frog (*Rana boylii*), and benthic macroinvertebrates. As this study progresses, it may be appropriate to expand the suite of analysis species. For example, researchers working with the NPS at Yosemite National Park are developing methods to use bats as indicator species for aquatic ecosystems. Also, riparian nesting birds, amphibian species found in Poopenaut Valley, or additional at-risk aquatic species (e.g., California red-legged frog) could be incorporated into the analysis, as needed.

The analysis considers two aspects of flow regulation and management on analysis species: (1) effects on channel morphology and physical habitat structure, and (2) availability of flow to meet species-specific life history needs. This requires historic and current species distribution in the watershed, habitat requirements for each life history stage, and life history timing for each beneficial use species. This biological information, combined with the descriptions of hydrologic and physical processes, will be used to develop initial hypotheses and conceptual models of project effects on river ecosystem function.

4.5.1 Fish Species

Streams draining the western slope of the Sierra Nevada range to the San Joaquin River are typified by four distinct native fish assemblages: the rainbow trout assemblage, California roach assemblage, pikeminnow-hardhead-sucker assemblage, and deep bodied fishes assemblage (Moyle 2002). Distributional overlap among these assemblages in Sierra Nevada streams draining to the San Joaquin River is relatively narrow. In the project area, the rainbow trout assemblage extends from the Tuolumne River headwaters to the North Fork Tuolumne River and transitions to the California roach assemblage near Wards Ferry (Moyle 2002). The California roach assemblage transitions to the pikeminnow-hardhead-sucker assemblage then to the deep bodied fishes assemblage in the vicinity of New Don Pedro Reservoir.

The rainbow trout assemblage occurs in clear streams at high elevations, where channel gradient is steep, water is cold (seldom exceeding 70^{o}F) and well oxygenated, and cover is abundant (Moyle 2002). Rainbow trout are the dominant native fish in this assemblage; other species in this assemblage include riffle sculpin (*Cottus gulosus*), Sacramento sucker (*Catostomus occidentalis)*, speckled dace (*Rhinichthys osculus*), and sometimes California roach. The California roach assemblage is found in small, warm tributaries to larger streams that flow through oak woodlands of the Sierra foothills. These streams can be intermittent during summer, and pools may become stagnant and exceed 86^{o}F during the day. During winter and spring, Sacramento sucker, Sacramento pikeminnow (*Ptychocheilus grandis*), and other native minnows may use these streams for spawning.

Fish are one of the most intensively managed components of the ecosystems of the Sierra Nevada. Before the active manipulation of fisheries, most of the Sierra Nevada above 6,000 feet lacked any fish fauna. Hundreds of miles of streams and almost all of the more than 4,000 natural lakes of the Sierra Nevada were dominated by invertebrates and frogs until widespread trout introductions began in the nineteenth century. Occasional transfer of fish in buckets in the 1800s exploded into hatchery production of millions of fish and mechanized stocking at hundreds of sites throughout the range. As a result of these stocking practices, trout are now present almost everywhere in the range that is capable of supporting them, and trout strains have become highly mixed. In the project area, the California Department of Fish and Game (CDFG) has stocked brown trout (*Salmo trutta*) and rainbow trout at Early Intake; rainbow trout stocking has produced fall and mid-winter spawning trout, as well as spring spawning trout typical of the Sierra Nevada (Lewis 1978). At New Don Pedro Reservoir, CDFG also has stocked brook trout (*Salvelinus fontinalis*), Coho salmon (*O. kisutch*), Chinook salmon (*O. tshawytscha)*, and kokanee (*O. nerka*) (Lewis 1978).

Rainbow Trout Habitat Requirements and Life History

The mainstem Tuolumne River is an important rainbow trout fishery (FERC 1994), and the USFS identifies rainbow trout as an indicator species in the Tuolumne River Wild and Scenic River Management Plan (USFS 1988). Rainbow trout are typically a prominent, if not the only, species considered when instream flow recommendations are being evaluated. Though rarely stated, rainbow trout are often considered indicators of stream health on the assumption that streamflows good for rainbow trout must be good for Sierra Nevada river ecosystems.

Rainbow trout prefer cool, clear, fast flowing, streams and rivers where riffles dominate over pools, cover is provided by riparian vegetation or undercut banks, and the benthic macroinvertebrate prey base is diverse and abundant. Rainbow trout life history timing is closely tied to the spring snowmelt hydrograph (Figure 4-6). In the Upper Tuolumne River, rainbow trout spawn from February[1] through June (Figure 4-6). During spawning, the female excavates a redd (or nest) in gravel deposits in pool and run tails or in gravel lee deposits between boulder ribs. Optimal spawning conditions include substrate that is a mixture of gravel ranging from 0.6 in to 2.4 in diameter, flow velocity of 1 ft/s to 2.3 ft/s, and flow depth of 0.3 ft to 4.9 ft. After the male fertilizes the eggs, the female buries them in the gravel, where they incubate for 3 to 4 weeks (at 50 to 59°F). After hatching, the larvae (called “alevins”) remain in the interstitial spaces in the gravel bed gravel for 2 to 3 weeks. Once their the yolk sak is absorbed, young-of-the-year fry emerge up through the gravel bed and enter the water column, emerging 30 to 50 days (or more) after fertilization, depending on water temperature (Figure 4-6).

Figure 4-6: Life Stage Periodicity for Rainbow Trout in the Upper Tuolumne River (USFWS 1992).

Life Stage	Month											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Spawning												
Fry												
Juvenile												
Adult												

After emergence, fry (< 2 in SL[2]) concentrate in shallow, low velocity water along stream edges where flow depth is < 1.6 ft and velocity is 0.03 ft/s to 0.5 ft/s. As they grow and their swimming ability improves, juveniles (2 in to 5 in SL) move to deeper, swifter water; preferred depth is 1.6 ft to 3.3 ft. Larger juveniles and adults seek out deeper, low-velocity habitats (such as pockets behind rocks, runs, and pools) but generally remain close to swift water that delivers benthic macroinvertebrate drift. Rainbow trout survive the winter in cold regions (such as the upper reaches of the project area) in a state of torpor. Juveniles burrow into interstitial spaces within coarse gravel and small cobble deposits; adults overwinter in deep pools. Cover is essential for all life history stages and can be provided by overhanging vegetation, submerged vegetation, undercut banks, pool depth, surface turbulence, and submerged objects (logs, boulders, etc).

Water temperature exerts more control over fish physiology and behavior than any other abiotic factor (Beitinger and Fitzpatrick 1979, as cited in Moyle and Marchetti 1992). Water temperature affects water chemistry, dissolved oxygen concentration, respiratory efficiency, metabolism, growth rates, and feeding behavior. Water temperature also is an important environmental cue, stimulating reproductive, migration, and overwintering, and other behaviors. Given this importance, extensive research has been conducted on the effects of temperature on trout health and suitable or preferred temperatures for maintaining healthy trout populations. Suitable or preferred temperatures for trout are difficult to define, in part because suitability and preferences vary geographically and among genetic strains and temperature effects vary with acclimation temperature, duration of exposure, and the magnitude and rate of temperature variation. Moyle and Marchetti (1992) summarized available literature on critical temperature thresholds for trout survival, growth, and reproduction, as well as temperature preferences exhibited in laboratory and field conditions (Table 4-1). These temperature criteria are applied to evaluate the effects of flow regulation on rainbow trout in the study reaches (see Section 6).

[1] Early spawning (February – March) is presumably due to introductions of non-native rainbow trout strains to the upper Tuolumne River.
[2] SL = standard length, which is length from the anterior tip of the fish to the posterior tip of the caudal peduncle.

Table 4-1: Temperature Suitability for Rainbow Trout Life Stages (Moyle and Marchetti 1992[a], Raleigh et al. 1984[b]).

Life Stage	Temperature Threshold (°F)		
	Criterion	Lower Limit	Upper Limit
Egg/incubation	Optimal[a] 46		59
	Lethal[a] 39		59
Fry	Optimal[b]	55	66
	Preferred[a] 55		66
Juvenile	Preferred[a] 55		66
	Optimal growth[a] 60		68
Adult	Preferred[a] 55		68
	Lethal[a] 34		77

California Roach Habitat Requirements and Life History

Like rainbow trout, California roach life history timing is closely tuned into the snowmelt hydrograph from April through early-July (Figure 4-7). Adults spawn in large groups from March through early July, when water temperature exceeds 61°F. Prior to spawning, adults move from pools to shallow areas with small-to-medium gravel substrate (1.2-2.0 in diameter), and each female deposits her eggs in interstitial spaces on the channel bed surface. The spawning "swarm" can be very active, and females can use their bodies to disturb the channel bed. Eggs are deposited singly or in small clustered in rock crevices, among coarse gravel, among emergent vegetation (if gravel substrate is unavailable). Eggs adhere to the spawning substrate and hatch in 2-3 days.

After hatching, larvae remain in crevices of gravels at or near the spawning site. When they are large enough to swim, fry move into shallow pools or extremely shallow inshore areas. Juveniles move into deeper pools and the main body of the channel. Adults will use a wide variety of habitats. When other fish species are absent, roach will occupy the open waters of large pools. In the presence of predatory fishes (such as pikeminnow), roach shift to the edges of pools, riffles, and other shallow-water habitats. In complex assemblages, they concentrate in low-velocity (<1.3 ft/s), shallow (<1.6 ft) waters where fine substrates predominate.

Optimal incubation temperature roach temperature is 54°F to 64°F (Moyle and Marchetti 1992). Roach prefer water temperatures of around 77°F to 79°F, but can survive in water was warm as 99°F (depending on acclimation temperature) and are often found in streams where water temperatures exceed 90°F for brief periods (Knight 1985, as cited in Moyle and Marchetti 1992).

Figure 4-7: Life Stage Periodicity for California Roach (Moyle 2002).

Life Stage	Month											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Spawning						■	■	■	■	■		
Fry						■	■	■	■	■	▌	
Juvenile	■	■	■	■	■	■	■	■	■	■	■	■
Adult	■	■	■	■	■	■	■	■	■	■	■	■

Roach are omnivores and typically feed by browsing bottom substrates. They have also been observed in the Clavey River feeding on drift organisms in fairly fast currents. Depending on habitat conditions and available food supply, filamentous algae, aquatic insects, and small crustaceans can make up important parts of the diet. Gut contents typically reflect availability of benthic and drift prey organisms. Detritus and fine organic debris are also consumed.

4.5.2 Foothill Yellow-Legged Frog

Amphibians have suffered significant declines throughout the Sierra Nevada. Seven of nine frogs and toads are considered at risk of extinction. Most at risk are those that rely on river and riparian habitats: true frogs (*Rana* spp.) and toads (*Bufo* spp.) (Jennings 1996). True frogs (Family Ranidae) have shown the most dramatic declines of all groups of amphibians in the Sierra Nevada (Jennings 1996).

Foothill yellow-legged frogs were once found in most Pacific drainages from the Santiam River in southern Oregon to the San Gabriel River in southern California. In the Sierra Nevada, they occurred west of the Sierra Nevada-Cascade crest up to 6,400 ft elevation (Jennings and Hayes 1994). This species, now eliminated from 66% of its former range, has suffered significant population decline and currently is a California Species of Special Concern and a candidate for Federal listing (Jennings and Hayes 1994). Jennings (1996) identifies eleven location along the mainstem Tuolumne River and its tributaries upstream of New Don Pedro Reservoir where foothill yellow-legged frogs were documented but are now extinct, and three locations along the river or its tributaries where extant populations still existed (as of 1996). Foothill yellow-legged frogs have been observed in Hunter Creek, a tributary to the North Fork Tuolumne River (FERC 1994, USFS unpublished data). Surveys conducted by the USFS in 2001 (unpublished data) recorded foothill yellow-legged frogs in the vicinity of the 1N01 bridge crossing (elevation approximately 2,370 ft NGVD).

The foothill yellow-legged frog is one of the most riverine-dependent ranid (true frog) species, spending most or all its life cycle close to perennial streams or intermittent streams that retain pools. Streams with gradients less than 4% are preferred, but they have been observed in steeper streams (Seltenrich and Pool 2002). Early life history timing is closely linked to the snowmelt hydrograph (Figure 4-8). Several environmental cues, including water temperature, air temperature, day length, and streamflow influence breeding timing in foothill yellow-legged frogs and other amphibian species (Lind 2004). Breeding begins after high winter floods and during the snowmelt hydrograph with egg laying in late-March through early-June (Jennings and Hayes 1994). On the Trinity River (Northern California), egg laying begins May and extends through early-June (Ashton et al. 1997). Eggs are deposited in clusters attached to the sides or undersides of cobbles and boulders. Although cobbles and boulders are preferred, vegetation, woody debris, and gravel are also used. Oviposition sites are typically in sunny areas, often on point bars, lateral bars, side channels, pool tailouts, side-pools, and along the main channel margin. Water depth at oviposition sites is 1.5 to 16 in (Lind 2004); flow velocity ranges from 0 ft/s to 0.7 ft/s (Lind 2004).

Eggs hatch in 5 to 30 days depending on water temperature, with shorter incubation at higher temperatures. Eggs have been observed in water temperatures from 48.2^{o}F to 69.8^{o}F; the critical thermal maximum for eggs is 78.8^{o}F (Zweifel 1955, as cited in Lind 2002). For several days after hatching, tadpoles remain near the oviposition site then disperse as they grow. At least 15 weeks after oviposition are required to reach metamorphosis, which typically occurs between July and September (Jennings and Hayes 1994). Throughout rearing, tadpoles prefer warmer edgewaters along the mainstem channel. The maximum observed water temperature reported for tadpoles is 86.4^{o}F (Zweifel 1955). Juveniles and adults remain strongly associated with cobble bars and slow moving water, preferring sites with shade provided by overhead vegetation.

Figure 4-8: Life Stage Periodicity for Foothill Yellow-legged Frog (Jennings and Hayes 1994, Ashton et al. 1997).

Life Stage	Month											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Courtship												
Breeding												
Egg development												
Larvae (tadpoles)												
Sub-adults												
Overwintering												

4.5.3 Benthic Macroinvertebrates

Aquatic benthic macroinvertebrate communities are a key component of river ecosystems (Erman 1996). Their high species diversity and productivity are often considered ideal integrators and indicators of river ecosystem health. Though not as charismatic as fish, they constitute the critical ecological linkage between primary production and vertebrate species diversity and abundance.

Aquatic macroinvertebrate life histories are incredibly diverse, if for no other reason than there are so many different kinds of aquatic macroinvertebrates. One large cobble can be home to 30 or more taxa, ranging from water mites to predatory stoneflies. Three insect orders, mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera), generally comprise a large portion of the macroinvertebrate species colonizing riffles. Collectively these three orders, called the EPT species, are used as indicators of water quality (e.g., Barbour et al. 1999). Their life histories are highly variable and often strongly seasonal; productivity in temperate climates tends to peak in late-spring when daylight and stream temperatures are increasing (Hynes 1970).

Good macroinvertebrate habitat has a complex physical structure potentially providing abundant and diverse microhabitats. A square foot of channel bed composed of cobbles and small boulders provides much more useable surface area for EPT macroinvertebrates than larger or smaller substrate sizes. The quality of this surface area is better as well, capable of creating a wider range of velocities next to the substrate surface as well as many more crevices of various sizes for filter feeders to construct nets and as refuge for mobile grazers and predators. Ruttner (1963) notes that if "moving water" invertebrate species are left in a slow current, many soon die even though the water is cold and saturated with oxygen. Physical complexity can lead to hydraulic complexity depending on the flow's depth and velocity. Generic habitat preference curves for the EPT species by Gore et al. (2001) specify a high habitat suitability (> 0.5) over a 1 ft/s to 2.6 ft/s velocity range and 0.5 feet to 1.1 feet depth range. Benthic macroinvertebrates can be very sensitive to periodic dewatering (i.e., flow fluctuations such as occur downstream of dams and powerhouse discharges). At experimental sites downstream of Priest Rapids Dam on the Columbia River, Stark (2001) found that periodic dewatering "severely limited" benthic macroinvertebrate density and biomass relative to continually inundated sites at the same location. Periodic dewatering for one to 24 hours reduced total benthic macroinvertebrate density and biomass by 59% and 65%, respectively. For some taxa, as little as one hour of dewatering resulted in 50% mortality.

Water temperature is a dominant environmental factor for aquatic invertebrates. Hynes (1970) notes, "Thus many varied devices have been evolved among the benthic invertebrates which enable them to avoid unfavourable conditions. This is, of course, a commonplace in biology, but what is unusual in running water is that it is the warm period of the year which is avoided by a great number of animals, especially in small streams. This is in considerable contrast to the land habitat where winter-active species are the exception, …". Water temperatures can be too cold and too warm. Highly productive macroinvertebrate habitat therefore requires a range of highly favorable water temperatures. While the scientific literature provides numerous references and studies on upper thermal tolerances, surprisingly few references were found for optimal or highly favorable water temperatures for stream macroinvertebrates. In part, this is due to the wide range in thermal tolerances/preferences exhibited by the wide range of macroinvertebrate orders and families typically living on the streambed. Stoneflies generally are more sensitive to higher water temperatures than mayflies, while mayflies generally are more sensitive than caddisflies, though many exceptions exist. A range of temperatures bounded by upper and lower thresholds is simplistic (i.e., EPT productivity would not cease outside these water temperature thresholds) but useful for exploring this hypothesis. A daily average temperature range of 41^{o}F to 55^{o}F was adopted based on individual species studies and agency guidelines, particularly those by the Washington State Department of Ecology (2002).

4.5.4 Riparian Vegetation

Riparian vegetation is a key component of both alluvial and boulder-bed river ecosystems, influencing channel morphology and flow hydraulics, and providing habitat for aquatic and terrestrial organisms. For example, overhanging vegetation provides critical refuge and food production for fish in the channel. Riparian vegetation also shades the channel and potentially decreases solar warming on smaller streams, especially during summer low-flow periods. On regulated streams where the high flow regime has been impaired and overall variability of annual hydrographs reduced, riparian encroachment is a common response (Pelzman 1973). In extreme cases, riparian encroachment can fossilize bars and channel margins, induce fine sediment deposition as “berms” along the low flow channel edge, and result in channel and habitat simplification (Bair 2004).

The characteristics of riparian vegetation (species composition and abundance, age class, recruitment success) are the net result of the sediment regime, inter- and intra-annual streamflows, and individual plant life history strategies. Each species has its own unique strategies for seed production and dispersal. However, differences between species can be distilled into a general strategy as described below.

General Riparian Life History

Riparian hardwood recruitment usually requires a series of specific hydrologic and physical conditions (Bradley and Smith 1984, Hupp and Osterkamp 1996, Kondolf and Wilcock 1996, Mahoney and Rood 1998). Riparian recruitment is defined as the process of germinating and surviving the first growing season (i.e., initiation), and living through subsequent years of channel bed scouring floods (i.e., establishment) until sexual maturity (Figure 4-9).

Riparian hardwoods (i.e., willows, cottonwoods, and alders) typically have two general seed dispersal strategies (Figure 4-10 and Figure 4-11). Willows and cottonwoods disperse millions of short lived seeds over a small window of time. Seed dispersal periods for willows and cottonwoods are typically about three or four weeks, and the seeds liver for approximately 7-9 days after being dispersed (Young and Young 1992). Alders, maples, and ash have a much broader window of opportunity because they can disperse seeds quickly or over many months, and their seeds remain viable for over a year (Young and Young 1992). Willows and cottonwood seeds are dispersed in the spring and early summer and must arrive at an appropriate nursery site and germinate quickly; these species have developed a complex strategy to take advantage of conditions provided by the snowmelt hydrograph. Alders, maples, and ash seeds are typically dispersed in the fall and sometimes throughout the winter, and are often delivered to nursery sites in debris wracks where they may lie dormant in the deposits until conditions are suitable for germination. These species are less reliant on the conditions created by the snowmelt hydrograph and are often found in greater abundance where it is impaired or regulated (McBain & Trush 2006).

Seed rain from various woody riparian plant species is nearly constant throughout the growing season within riparian corridors (Figure 4-12). Riparian hardwood and conifer initiation is frequent within nested depositional features. Initiation frequency is species-dependent, and along most Sierra streams there is at least one woody riparian species dispersing seeds from the beginning of April through the middle of August (Figure 4-12). This combination of long seed dispersal windows (created by multiple species) with slowly receding or stable streamflows means that for at least one species, initiation occurs annually. The difference between unimpaired and impaired watersheds is the channel bank location where initiation occurs and how frequently successful initiation leads to recruitment. Therefore, regardless of how altered annual streamflow patterns might be, some type of riparian vegetation (as an assemblage of species) will regenerate regardless of inter- and intra-annual flows. The dominant woody species within assemblages, however, might change.

Figure 4-9*: A Generalized Riparian Hardwood Life Cycle, Showing Life Stage, and Mortality Agents that Affect Life Stages.*

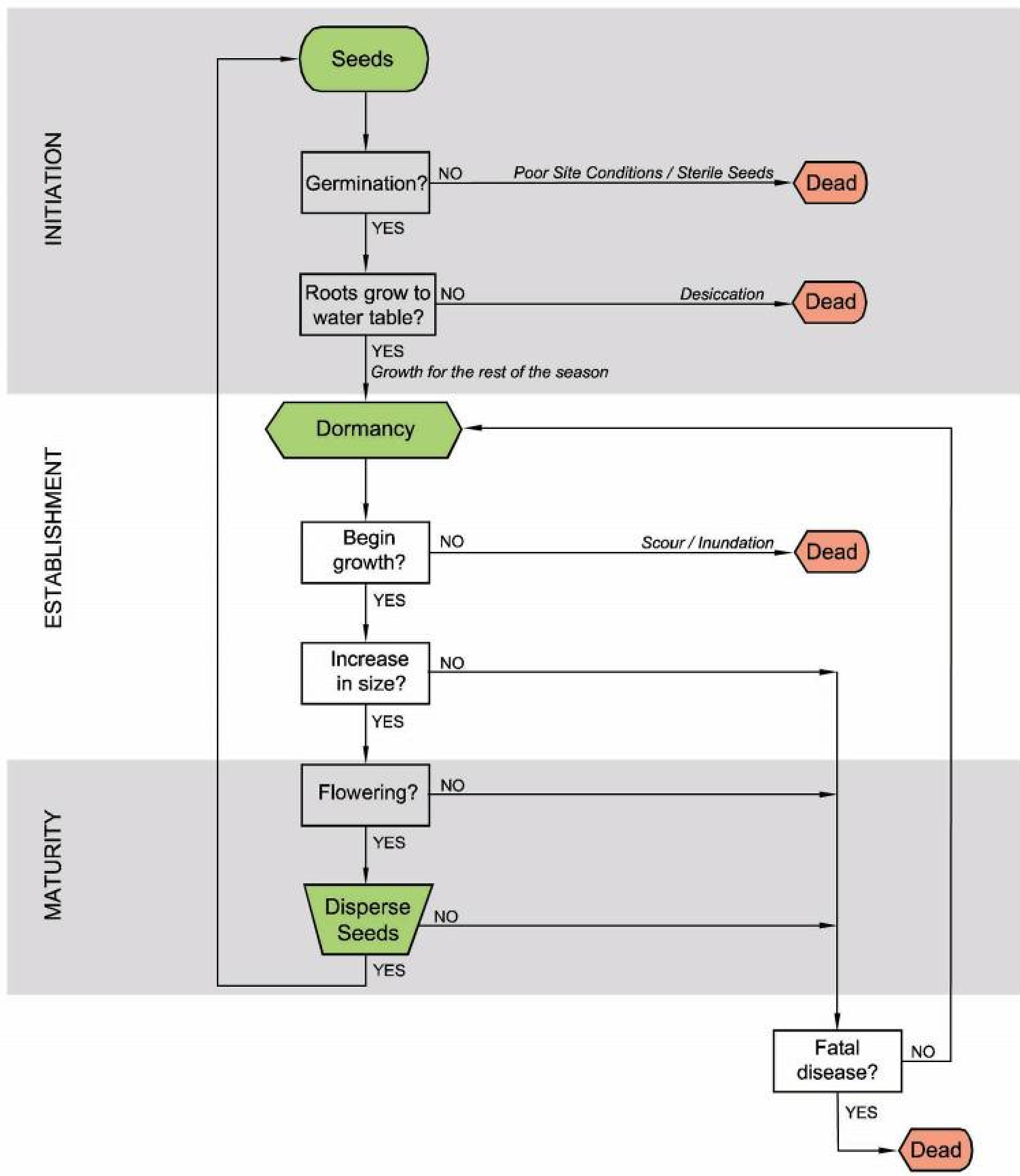
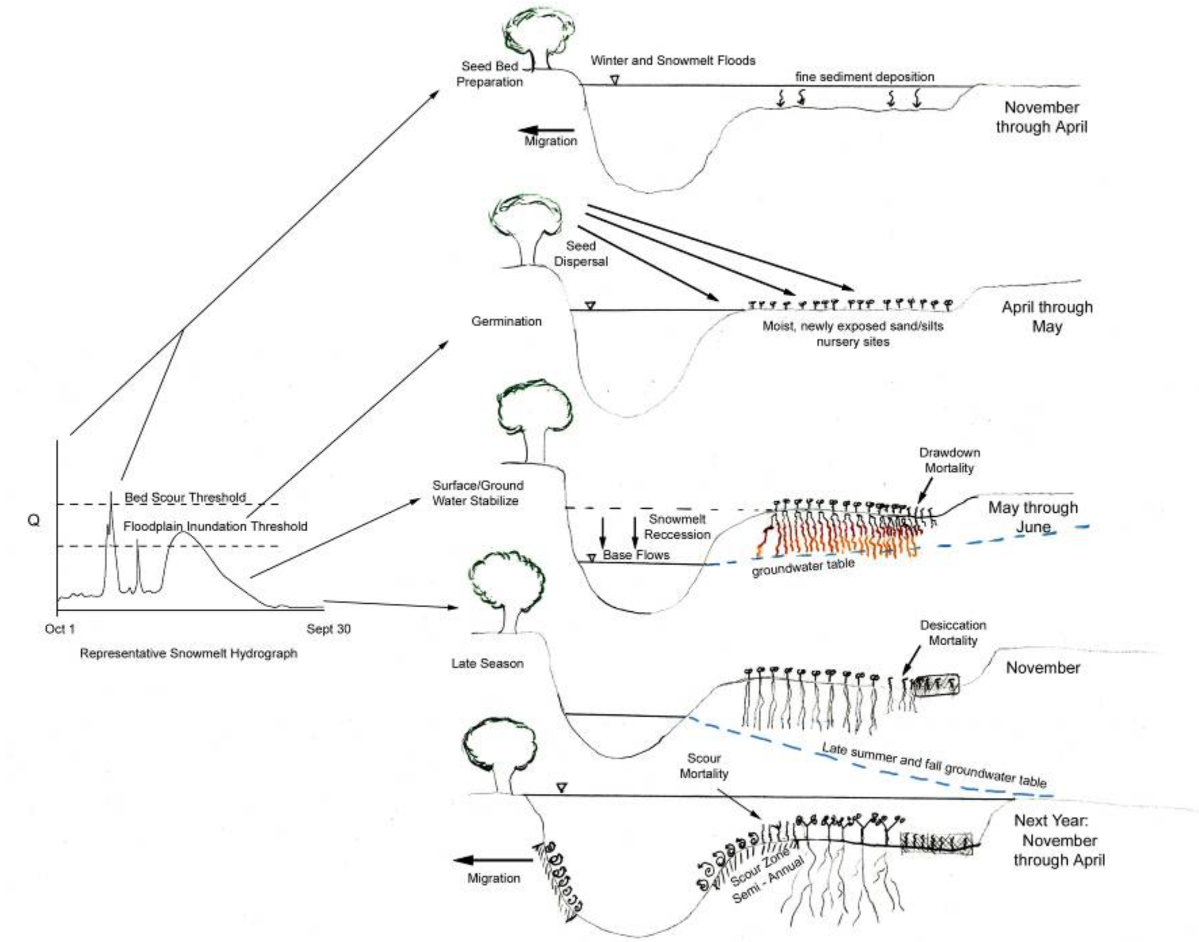


Figure 4-10: Conceptual Model Showing the Relationship of a Spring-Early Summer Seed Disperser with Short Lived Seeds to an Annual Snowmelt Hydrograph on an Alluvial Stream.



Seed rain from various woody riparian plant species is nearly constant throughout the growing season within riparian corridors (Figure 4-12). Riparian hardwood and conifer initiation is frequent within nested depositional features. Initiation frequency is species-dependent, and along most Sierra streams there is at least one woody riparian plant species dispersing seeds from the beginning of April through the middle of August (Figure 4-12). This combination of long seed dispersal windows (created by multiple species) with slowly receding or stable streamflows means that for at least one species, initiation occurs annually.

The "window of opportunity" leading to the successful recruitment of a particular species illustrates the balance between annual desiccation, large channel width maintaining floods, and those smaller floods that annually scour seedlings away from the low water channel margin (Kondolf and Wilcock 1996). The window of opportunity model predicts that the upper limit of the window of seedling establishment is a function of desiccation, and the lower limit is a function of bed scour. Typically during the annual snowmelt hydrograph, seedlings growing along the low water margin are scoured annually or at least biannually (Q2), defining the lower boundary of recruitment. Large floods scour and redeposit nested depositional features and are important in creating seedbeds that in turn facilitate hardwood seedling germination higher and farther away from the low-water edge where they are less susceptible to bed scour from moderate floods (Plant species richness and demographics are associated with discrete areas up the channel bank. Within the active channel to about the 1.5-year flood elevation, riparian vegetation is typically composed of dusky willow, sedges, Indian rhubarb, arroyo willow, and elk clover. Below the 1.5-year flood line, young alders (<10 years old) are often found in association with red willow, shiny willow, and California grape. Where valley width increases, there is enough room for a complex riparian /upland ecotone to develop where riparian plants species gradually transition into upland species. In these riparian-upland transition areas, big leaf maple, mock orange, incense cedar, ponderosa pine and Douglas fir may grow.

Figure 4-13). Seedlings that germinate higher on the bank during years of large floods run the risk of desiccation. With regulation, nearly constant streamflows cause the window of opportunity to shift where riparian hardwoods recruit along the low water margin.

Figure 4-11: Conceptual Model Showing the Relationship of a Late Summer-Fall Seed Disperser with Long Lived Seeds to an Annual Snowmelt Hydrograph on an Alluvial Stream.

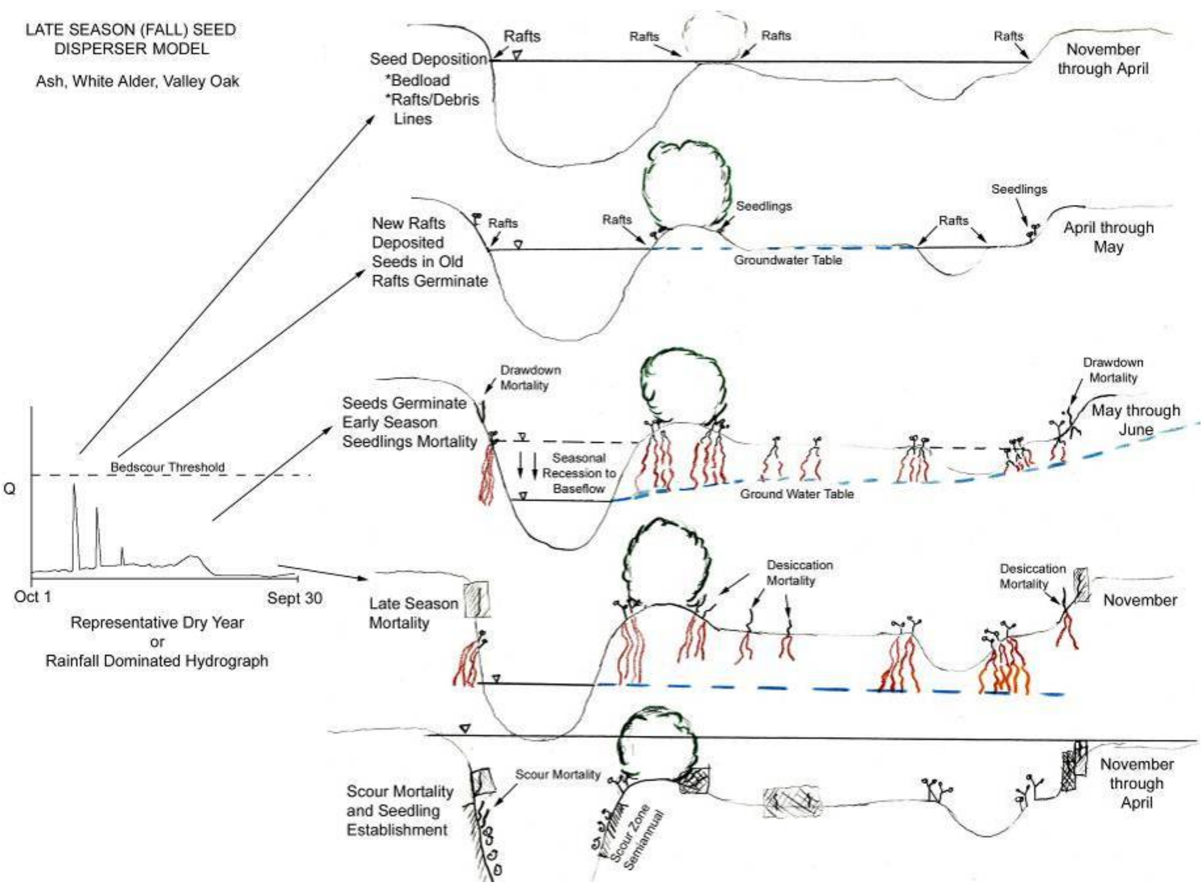
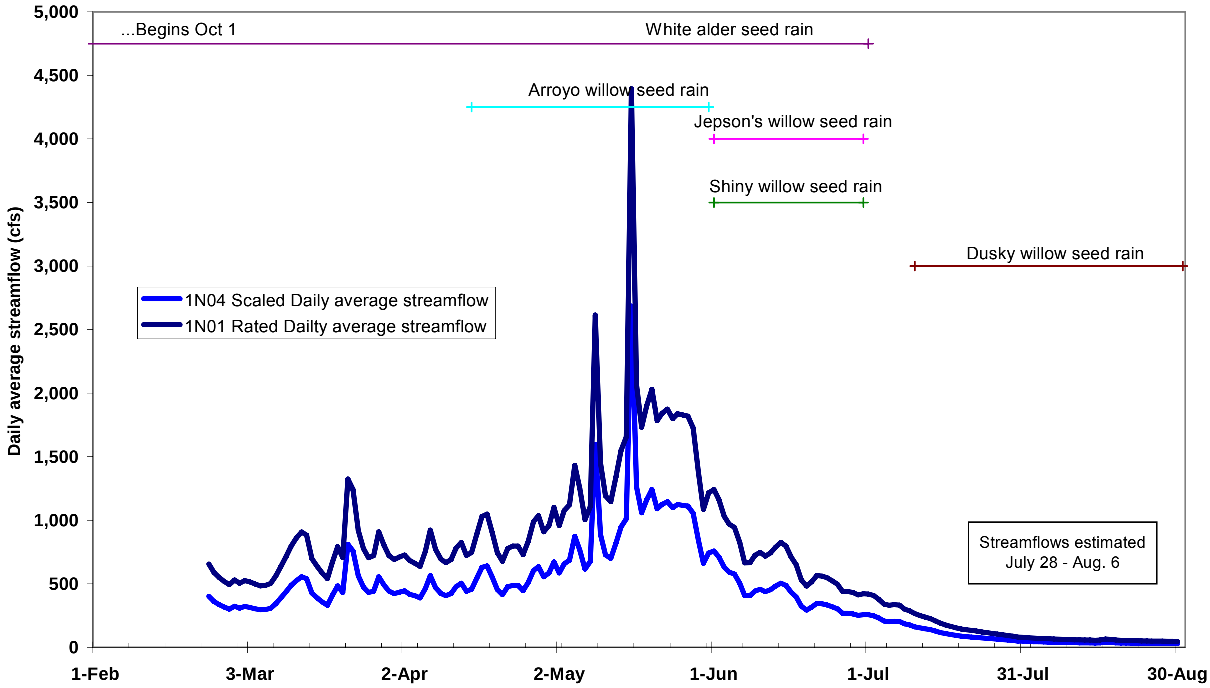
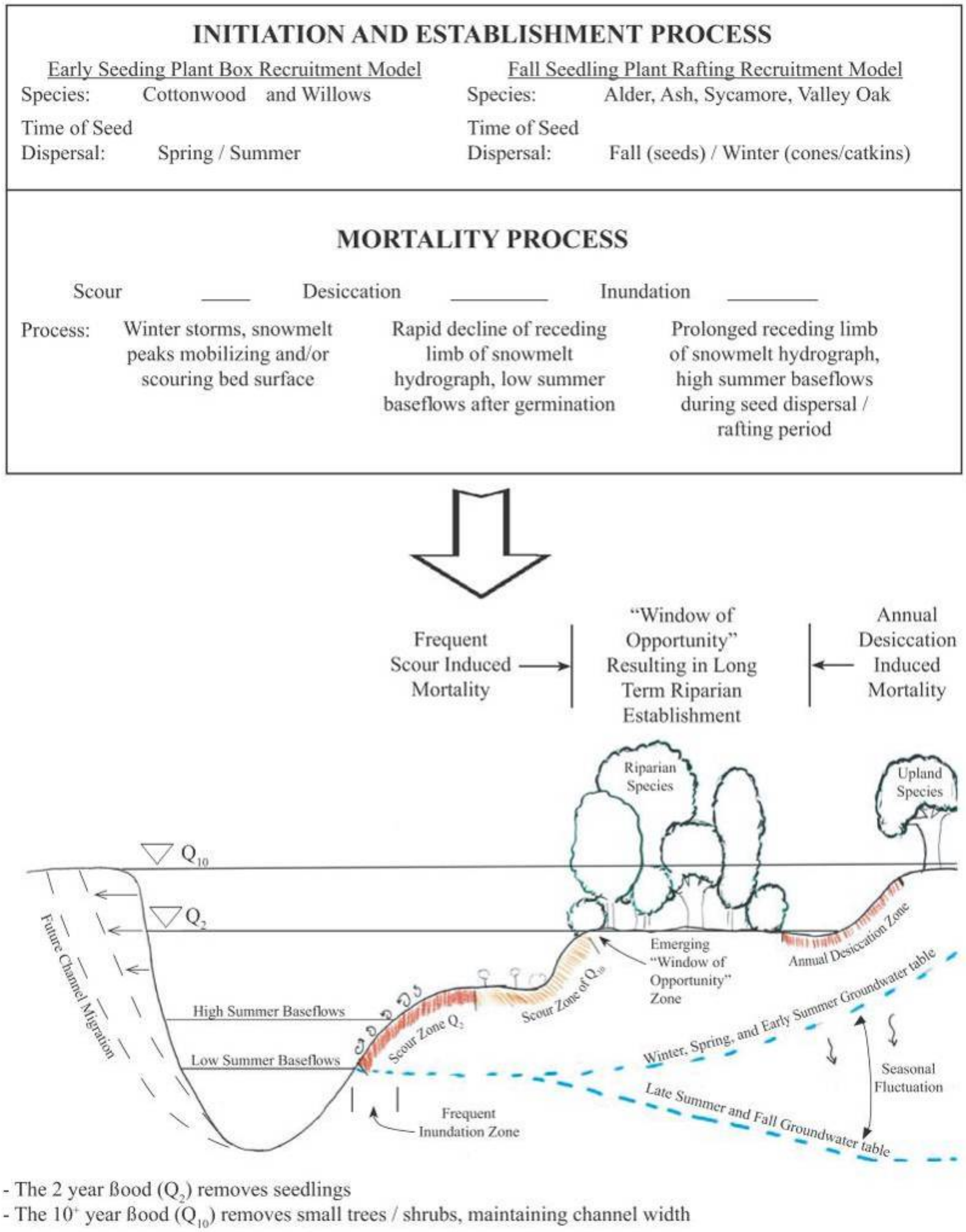


Figure 4-12: Seed Dispersal Periods for Common Riparian Hardwoods Related to the WY2005 Clavey River Hydrographs at the 1N01 Bridge and 1N04 Bridge.



Plant species richness and demographics are associated with discrete areas up the channel bank. Within the active channel to about the 1.5-year flood elevation, riparian vegetation is typically composed of dusky willow, sedges, Indian rhubarb, arroyo willow, and elk clover. Below the 1.5-year flood line, young alders (<10 years old) are often found in association with red willow, shiny willow, and California grape. Where valley width increases, there is enough room for a complex riparian /upland ecotone to develop where riparian plants species gradually transition into upland species. In these riparian-upland transition areas, big leaf maple, mock orange, incense cedar, ponderosa pine and Douglas fir may grow.

Figure 4-13: Conceptual Model of the "Window of Opportunity" that Results in Long Term Riparian Vegetation Trends along Rivers (Kondolf and Wilcock 1996).



(Adapted from Kondolf and Wilcock 1996)

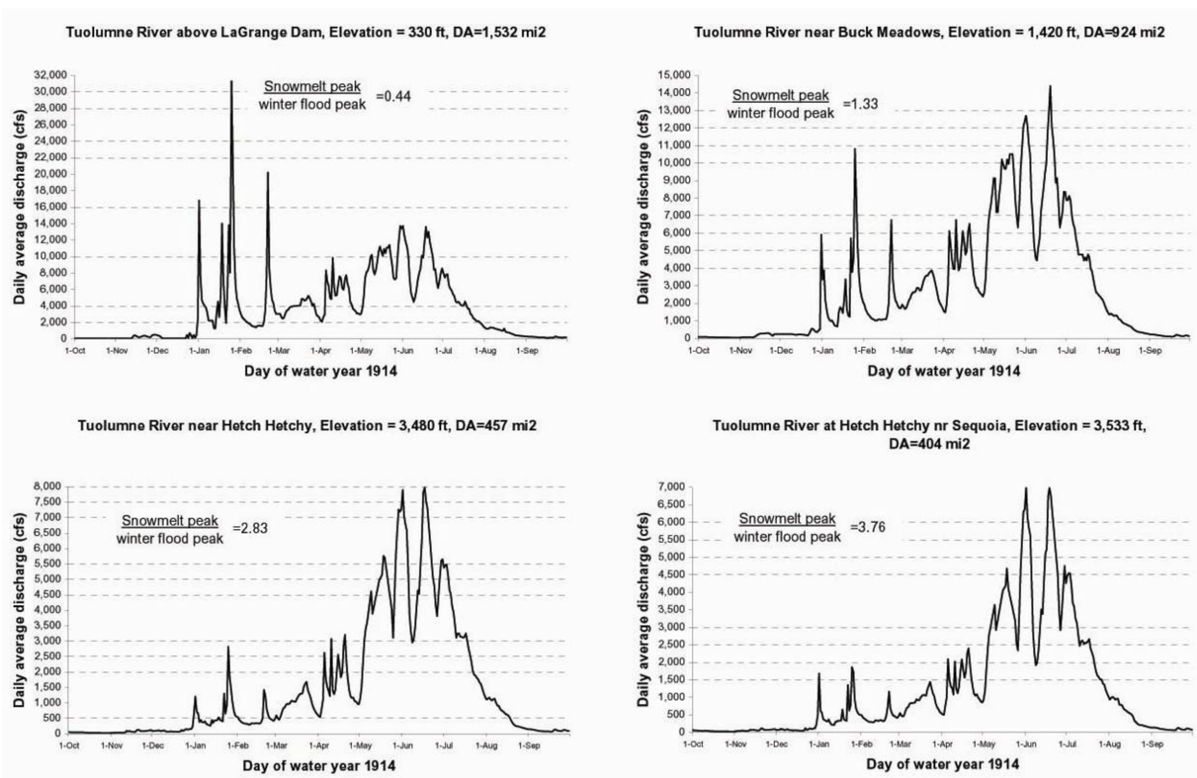
4.6 Summary

The study plan elements recommended in Section 7 applies basic principles of scientific investigation to organize our basic understanding of analysis species above, identify critical information needs, develop efficient study plans to address those needs, and apply the knowledge gained through this process to the formulation of specific and testable operational improvements. The progression of hypothesis development and testing allows the SFPUC and stakeholders to identify and focus on the most important effects of flow regulation and diversion and discard less relevant or non-existent effects, thus better using limited study resources (i.e., staff, time, and funds). By recognizing complex linkages between physical processes and biological communities, this approach can help identify creative improvements to flow management issues and can support hypothesis-driven monitoring, testing, and adaptive management of these actions if desired.

Chapter 5 Streamflow Hydrology Analysis

The natural flow regime (i.e., unregulated) in the Tuolumne River watershed, like any other watershed, is governed by the local climate and underlying geology. The upper Tuolumne River, Eleanor Creek, and Cherry Creek drain the higher elevations of the Sierra Nevada mountains, while downstream tributaries drain mid-elevations and the foothills. The watershed and runoff patterns changes with elevation: higher elevations are characterized by exposed granite bedrock with shallow soils, variable relief, and precipitation primarily as winter snowfall; lower elevations are characterized by steep incised canyons, deeper soils, forested, and precipitation primarily as winter rainfall. These watersheds also exhibit distinct seasonal snowmelt runoff during the spring, occasional rainstorm-generated peak flows, and infrequent, larger rain-on-snow floods. Overall, the hydrology of the Tuolumne River watershed is characteristic of Mediterranean-type streams, with most precipitation and runoff coming in the winter and spring months, followed by a very dry summer and fall period. Winter rainfall or rain-on-snow events are often the largest events of the year, with winter baseflows between these events. Progressing from lower elevations to higher elevations, the high flow regime begins to transition to a snowmelt dominated system (Figure 5-1). Runoff from the snowpack that has accumulated over the winter begins with the spring thaw, and historically extended into mid-summer.

Figure 5-1: Progression of Unimpaired Hydrographs on the Mainstem Tuolumne River in Water Year 1914 Illustrating Increasing Dominance of Snowmelt Hydrograph with Increasing Elevation.



These natural runoff patterns have a strong influence on physical processes within the stream corridor, direct effects on biota (e.g., velocities, depths), as well as indirect effects on biota (flows that create and maintain the channel habitats). Therefore, as a precursor to Section 6, the hydrologic context is provided upon which hydrologic information and available information for geomorphology, riparian vegetation, and biota inhabiting the Tuolumne River ecosystem can be synthesized. This section first summarizes available hydrologic information, then describes the flood frequency information for many gaging station locations, then provides an analysis of hydrograph components at locations immediately downstream of project dams, and lastly provides an overview of flow fluctuations downstream of the Holm Powerhouse on lower Cherry Creek.

5.1 Available Information

To understand and describe the natural hydrology of streams within the project area and how project operations have changed streamflow, McBain and Trush used long-term daily streamflow records collected by the USGS. The USGS operates many streamflow gaging stations in the Tuolumne River basin (Figure 5-2, and Table 5-1). The primary USGS gaging sites used for analyses in this report vary, but there are three that illustrate primary hydrologic alterations due to reservoir storage and diversion: Tuolumne River near Hetch Hetchy (USGS 11-276500, below Hetch Hetchy Reservoir), Cherry Creek below Valley Dam (USGS 11-277300, below Cherry Lake), and Eleanor Creek near Hetch Hetchy (USGS 11-278000, below Lake Eleanor). Annual hydrographs for these three stations are provided for the entire period of record in Appendix A-C.

There are two gaging sites that are used for analyzing the effect of daily flow fluctuations due to power generation and recreational releases: Cherry Creek near Early Intake (USGS 11-278300, above Holm Powerhouse) and Cherry Creek below Holm Powerhouse (USGS 11-278400). There are two SFPUC power generating facilities along the upper Tuolumne River: Kirkwood Powerhouse on the Tuolumne River immediately upstream of Early Intake, and the Holm Powerhouse on lower Cherry Creek. The Holm Powerhouse causes daily flow fluctuations for power peaking and recreational flows, and these fluctuations translate into variable flows in lower Cherry Creek and the Tuolumne River downstream of the Cherry Creek confluence. In contrast, Kirkwood Powerhouse discharges directly into the Hetch Hetchy Aqueduct, and there are no daily fluctuations caused by its operations.

Figure 5-2: Temperature and Streamflow Data Available for the Study Reaches

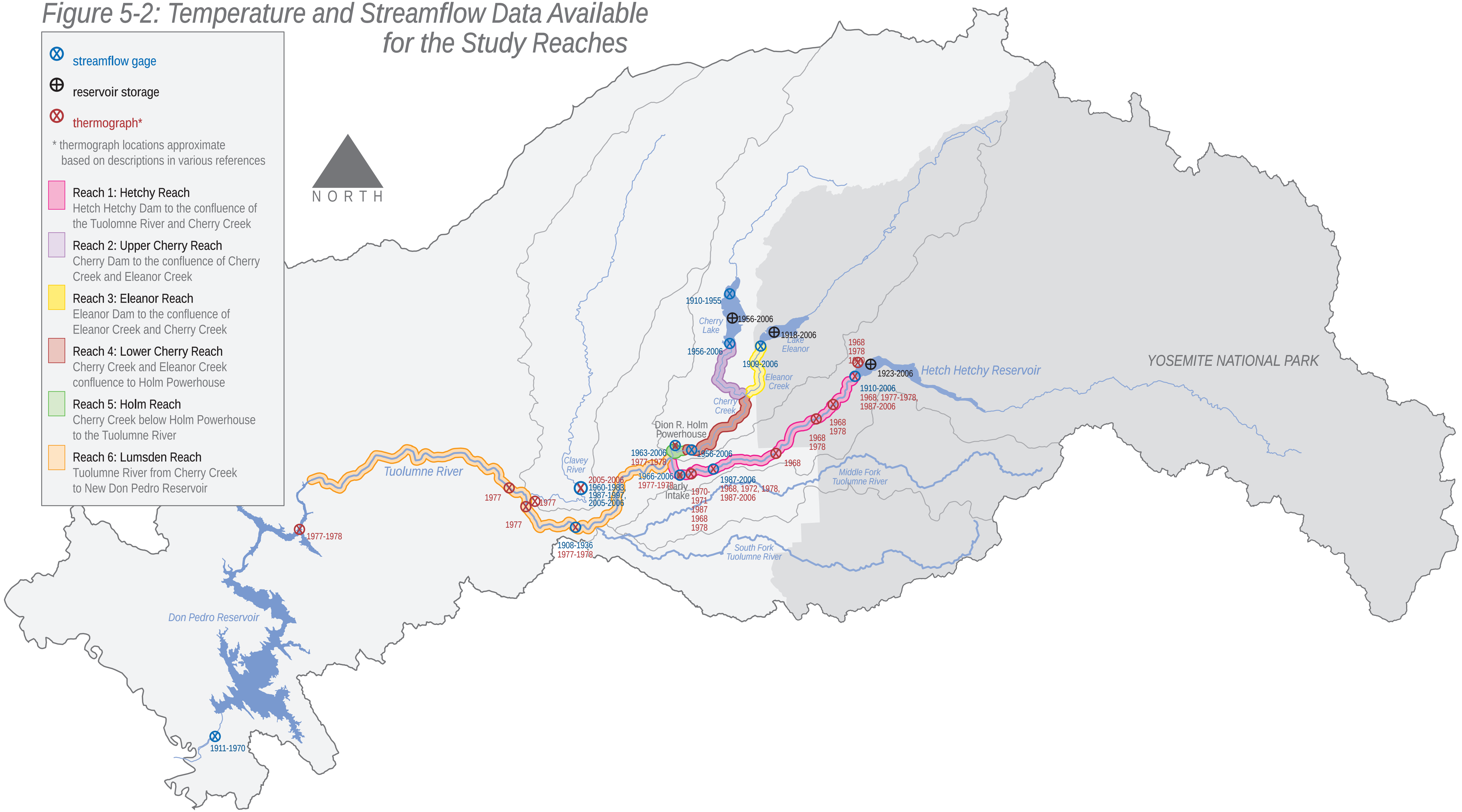


Table 5-1: Summary of Available Daily Average Streamflow Data, Reservoir Storage Data, and Computed Streamflow Estimates.

Station		Elevation (ft NGVD)	Drainage Area (mi^2)			Period of Record of Available Daily Average Data[a]				
ID	Name		Total	Unimpaired	Impaired	Total	Pre-dam	Post-dam, No Diversion	Post-dam, With Diversion	Post-dam, Computed Unimpaired
Eleanor Creek										
11-277500	Lake Eleanor nr Hetch Hetchy CA	4,663	78.1	N/A	78.1	June 1918-present	N/A	1919-present	N/A	N/A
11-277100	Lake Eleanor Diversion to Cherry Lake nr Hetch Hetchy CA	4,670	N/A	N/A	N/A	July 1996-present	N/A	N/A	1997-present	N/A
11-278000	Eleanor C nr Hetch Hetchy CA[b]	4,500	78.4	0.3	78.1	Oct. 1909-present	1910-1918	1919-1959	1960-present	1919-1959, 1997-1999, 2003-present
Cherry Creek										
11-277000	Cherry C nr Hetch Hetchy CA	4,500	111	111	N/A	Apr. 1910-1955	1911-1955	N/A	N/A	N/A
11-277200	Cherry Lake nr Hetch Hetchy CA	4,705	117	N/A	117	Dec. 1956-present	N/A	Dec. 1956-1959	1960-present	N/A
11-277300	Cherry C bl Valley Dam nr Hetch Hetchy CA[b]	4,337	118	1	117	1911-present	1911-1955	Nov. 1956-1959	1960-present	1958-1959, 1997-1999, 2003-present
11-278200	Cherry C Canal nr Early Intake CA	2,700	N/A	N/A	N/A	Apr. 1956-May 1971, June 1987-1996	N/A	Apr. 1956-1960	1961-May 1971, 1988-1996	N/A
11-278300	Cherry C nr Early Intake CA[b]	2,272	226	31	195	May 1956-present	N/A	1957-1959	1960-present	N/A
11-278400	Cherry C bl Dion R Holm PH, nr Mather CA[b]	2,134	234	39	195	Apr. 1963-present	N/A	N/A	Apr. 1963-present	N/A
Tuolumne River Mainstem										
11-274800	Tuolumne R at Hetch Hetchy nr Sequoia CA	3,533	404	404	N/A	1911-1916	1911-1916	N/A	N/A	N/A
11-276500	Tuolumne R nr Hetch Hetchy CA[c]	3,480	457	2	455	1911-present	1911-1923	1924-1967	1968-present	1924-present

Station		Elevation (ft NGVD)	Drainage Area (mi²)			Period of Record of Available Daily Average Data[a]				
ID	Name		Total	Unimpaired	Impaired	Total	Pre-dam	Post-dam, No Diversion	Post-dam, With Diversion	Post-dam, Computed Unimpaired
11-275500	Hetch Hetchy Reservoir at Hetch Hetchy CA	3,810	455	N/A	455	1931-present	N/A	1931-1967	1968-present	N/A
11-276600	Tuolumne R ab Early Intake nr Mather CA[d]	2,420	484	29	455	1971-present	N/A	N/A	1971-present	N/A
11-276900	Tuolumne R bl Early Intake nr Mather CA[b]	2,200	487	32	455	1967-present	N/A	N/A	1967-present	N/A
11-283000	Tuolumne R nr Buck Meadows CA	1,420	924	274	650	1908, 1911, Apr. 1912-1936	1908, 1911, Apr. 1912-1923	1924	1925-1936	N/A
11-287500	Don Pedro Reservoir nr La Grange, CA	830	1,533	N/A	1,533	1924-present	N/A	1924	1925-present	N/A
DNP	Regulated Inflow to New Don Pedro Reservoir (daily)	N/A	~1,533	883	650	Jan. 1994-present	N/A	N/A	Jan. 1994-present	N/A
DNP	Full Natural Flow at Don Pedro Reservoir	N/A	~1,533	883	650	1901-present	N/A	N/A	N/A	N/A
11-288000	Tuolumne R ab La Grange Dam nr La Grange CA	330	1,532	N/A	~1,532	1911-Oct. 1970	1911-1923	1924	1925-Oct. 1970	N/A
--	Unimpaired flow at La Grange (daily)[e]	330	1,532	1,532	N/A	1918-present	1918-1923	1924	1925-present	N/A
11-266500	Merced River at Pohono Bridge nr Yosemite CA[f]	3,862	321	321	N/A	1917-present	N/A	N/A	N/A	N/A
					Lumsden Reach Tributaries					
11-279500	SF Tuolumne R at Italian F nr Sequoia CA	Not available	65	65	NA	1924-1933	N/A	N/A	N/A	N/A
11-280000	SF Tuolumne R nr Sequoia CA	Not available	68	68	NA	1914-1917	N/A	N/A	N/A	N/A
11-281000	SF Tuolumne R nr Oakland Recreation Camp CA	2,800	87	87	N/A	1923-2002	N/A	N/A	N/A	N/A

Station		Elevation (ft NGVD)	Drainage Area (mi^2)			Period of Record of Available Daily Average Data[a]				
ID	Name		Total	Unimpaired	Impaired	Total	Pre-dam	Post-dam, No Diversion	Post-dam, With Diversion	Post-dam, Computed Unimpaired
11-281500	M Tuolumne R nr Mather CA	Not available	52	52	NA	1924-1933	N/A	N/A	N/A	N/A
11-282000	M Tuolumne R at Oakland Recreation Camp CA	2,800 73.5		73.5	N/A	1917-2002	N/A	N/A	N/A	N/A
11-282500	SF Tuolumne R nr Buck Meadows CA	Not available	164	164	NA	1911-1921	N/A	N/A	N/A	N/A
11-283250	Clavey R nr Long Barn CA	5,160 49		49	NA	1986-1994	N/A	N/A	N/A	N/A
11-283500	Clavey R nr Buck Meadows CA	2,374	144	144	NA	1959-1995	N/A	N/A	N/A	N/A
11-284400	Big C ab Whites Gulch nr Groveland CA	2,561 16		16	NA	1969-present	N/A N/A		N/A	N/A
11-284500	Big C nr Groveland CA	2,450	25	25	NA	1931-1974	N/A	N/A	N/A	N/A
11-284700	NF Tuolumne R nr Long Barn CA	4,650 23		23	NA	1962-1966	N/A	N/A	N/A	N/A
11-285000	NF Tuolumne R Ab Dyer C Nr Tuolumne CA	2,200	69	69	NA	1958-1966	N/A	N/A	N/A	N/A
11-278500	Jawbone C nr Tuolumne CA	Not available	19	19	NA	1911	N/A	N/A	N/A	N/A

Footnote:

DNP= California Data Exchange Center code for New Don Pedro Reservoir
a. Dates with months reflect partial water years
b. Temperature monitoring devices added in spring and summer 2006.
c. Temperature data available for Oct. 1971–Sept. 1972, Aug. 1987–present.
d. Temperature data available for Oct. 1971–June 1972, Aug. 1987–present.
e. Computed by Turlock Irrigation District
f. Reference gage on unregulated reach of the Merced River.

There are many tools to analyze changes to streamflow, such as flood frequency analysis, flow duration analysis, water yield analysis, Hydrograph Component Analysis, Indicators of Hydrologic Alteration (Richter et al 1997), and others. Because this effort attempts to describe natural conditions of the Tuolumne River ecosystem, how the project changed it, and potential operational adjustment to improve the ecosystem function, useful analyses are needed to describe the geomorphology of the streams, and allow an ecological assessment. The basis for hydrologic analyses is daily average flow data, annual maximum flood data, and 15-minute flow and stage data, all obtained from United States Geological Survey (USGS) gaging station records. The analyses applied to this data are as follows: (1) annual water yield analysis and water year classification for the entire watershed based on computed unimpaired inflow into New Don Pedro Reservoir, (2) annual maximum flood frequency analysis for key gaging stations downstream of the project infrastructure, (3) analysis of hydrograph components immediately downstream of the three dams using daily average flow data, and 4) analysis of flow fluctuations below Holm Powerhouse using 15-minute flow and stage data. The goal of these analyses is to describe streamflow patterns in the Tuolumne River, Cherry Creek, and Eleanor Creek, describe the unimpaired flow regime, and identify important changes to the flow regime resulting from SFPUC operations.

5.2 Flow Release Stipulations for Cherry Creek, Eleanor Creek, and Tuolumne River

The 1987 Flow Stipulation governs contemporary minimum instream flows below O'Shaughnessy Dam. The 1987 Flow Stipulation arose from the 1985 Flow Stipulation, which required additional consultation with the Department of Interior if the City proposed expansion, alteration or other modification of water or power facilities between O'Shaughnessy Dam and Early Intake. In 1985 the City proposed to add a Third Generator at the Kirkwood Powerhouse, and the City, NGOs and the Department of Interior negotiated the 1987 Flow Stipulation. The 1985 and 1987 Flow Stipulations increased minimum flow releases from O'Shaughnessy Dam (Table 5-2) and included an additional four-year study to assess whether further flow releases within specified limits were needed for resident fishes between O'Shaughnessy Dam and Early Intake. In 1950 flow stipulations were developed for Cherry Creek below Cherry Dam (Table 5-3), and in 1982 flow stipulations were developed for Eleanor Creek below Eleanor Dam (Table 5-4). Where analyses further in this section identify post-dam flows higher than the three Flow Stipulations flows, they are the result of either conservative releases to ensure meeting the Stipulation Flows, additional flows from tributary accretion, or high flow releases or spills during years when the dams are unable to store high runoff flow.

Table 5-2: 1985 Streamflow Stipulation for the Tuolumne River below O'Shaughnessy Dam.

Month	Minimum Flow (cfs)[a]				
	A (60%)	A[b] (60%)	B (32%)	B[b] (32%)	C (8%)
Jan	50	114	40	104	35
Feb	60	124	50	114	35
Mar	60	124	50	114	35
April	75	139	65	129	35
May	100	164	80	144	50
June	125	189	110	174	75
July	125	189	110	174	75
Aug	125	189	110	174	75
Sept 1-15	100	164	80	144	75
Sept 16-30	80	144	65	129	50
Oct	60	124	50	114	35
Nov	60	124	50	114	35
Dec	50	114	40	104	35

Footnotes:

a. Releases for A, B, and C determined each month by cumulative precipitation from October 1 through that particular month, where 8%, 32%, and 60% are exceedence probability boundaries based on the long-term precipitation record.

b. Additional flow (64 cfs) required when flow at Canyon Tunnel exceeds 920 cfs per 1987 Stipulation.

Table 5-3: 1950 Streamflow Stipulation for Cherry Creek below Cherry Valley Dam.

Month	Minimum Flow (cfs)
January	5
February	5
March	5
April	5
May	5
June	5
July	15.5
August	15.5
September	15.5
October	5
November	5
December	5

Table 5-4: 1982 Streamflow Stipulation for Eleanor Creek below Lake Eleanor Dam.

Month	Minimum Flow (cfs) [a]	
	Pumping	Not Pumping
January	5	5
February	5	5
March	10	5
April 1-14	10	5
April 15-30	20	5
May	20	5
June	20	5
July	20	15.5
August	20	15.5
September 1-15	20	15.5
September 16-30	10	15.5
October	-[b]	5
November	5	5
December	5	5

Footnotes:

a. "Pumping" is defined as when water is pumped from Cherry Lake to Lake Eleanor through the Cherry-Eleanor Tunnel.

b. The 1982 Stipulation does not specify minimum flow releases for October in years when pumping occurs. The SFPUC operational practice in pumping years has been to continue the September 16-30 release (10 cfs) through October 31.

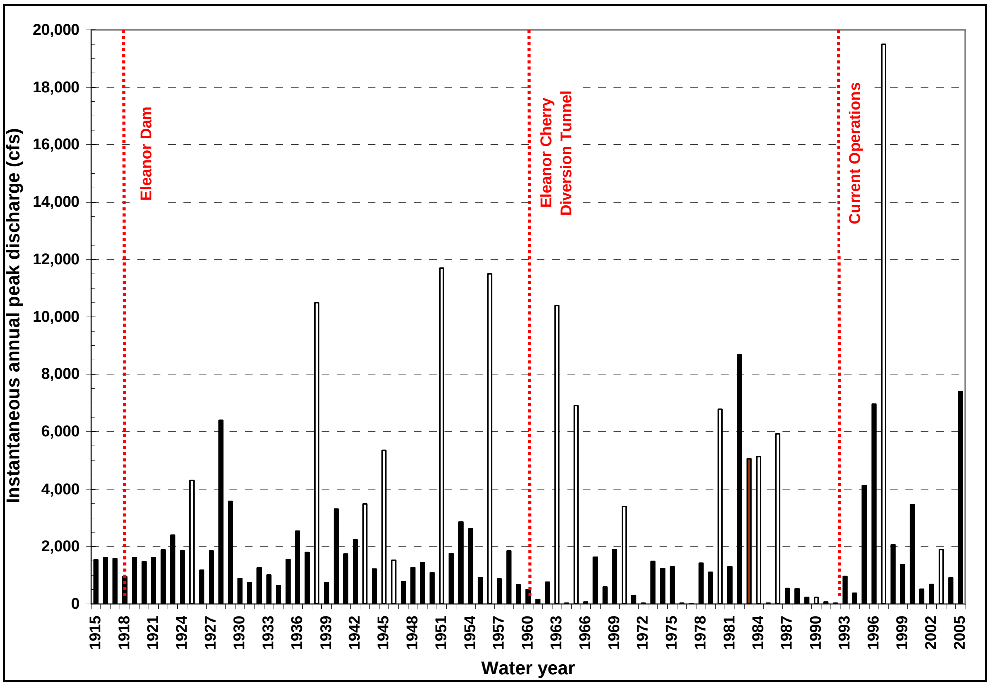
5.3 Annual Peak Flows and Flood Frequency Analysis

Annual peak floods within the Tuolumne River watershed typically occurs in the winter months or spring months, and as shown in Figure 5-1, the peaks tend to shift towards the spring snowmelt period with increasing elevation. The two "hydrograph components" (see Section 5.5) that nearly always contain the annual peak flood are the winter flood component and the snowmelt peak component. These two hydrograph components are partially described using a flood frequency analysis. The flood frequency analysis is based on the annual maximum instantaneous discharge and follows standard procedures established by the USGS (1982). A flood frequency analysis provides important information about the magnitude and frequency of annual maximum floods, and is useful because correlations have been established between flood recurrences and specific thresholds of geomorphic work (e.g., sediment transport, bank erosion, scour of riparian vegetation). A flood frequency analysis, based on the annual maximum flood series, was performed for the following USGS gaging stations: Eleanor Creek near Hetch Hetchy, Cherry Creek below Cherry Valley Dam, Tuolumne River near Hetch Hetchy, and Tuolumne River near Buck Meadows. With the exception of Cherry Creek, the pre-dam period of record is too short to accurately predict flood magnitude for floods greater than a 5 or 10-year recurrence. In addition, the standard application of the Log-Pearson III distribution usually provided a poor fit to the measured data. More work may be needed to better fit the measured data to an appropriate distribution; meanwhile, flood frequency estimates are presented for the plotted data rather than the Log-Pearson II distribution predictions.

5.3.1 Eleanor Creek near Hetch Hetchy below Eleanor Dam

The pre-dam annual flood period of record for Eleanor Creek nr Hetch Hetchy is only three years (WY1915–WY1917), which is too short to compute the pre-dam flood frequency (Figure 5-3). While operation of the reservoir and diversion likely reduces the magnitude of small, frequent floods, the

Figure 5-3: Eleanor Creek near Hetch Hetchy (USGS 11-278000) Annual Instantaneous Peak Flood History for 1915-2005 Period of Record. White bars Indicate Winter Floods, Black Bars Indicate Snowmelt Peaks.



reservoir has insufficient capacity to capture larger floods, thereby allowing the majority of larger peak flood flows to pass. To provide a rough comparison of pre- and post-dam flood magnitude, pre-dam data from Cherry Creek near Hetch Hetchy, which has a much longer period of record, were scaled to the Eleanor Creek nr Hetch Hetchy drainage area (Figure 5-4). Comparison of pre-dam annual floods from Cherry Creek nr Hetch Hetchy scaled to Eleanor Creek nr Hetch Hetchy by drainage area suggest that the greatest reduction in flood magnitude caused by Eleanor Dam is for floods smaller than the 5-year flood (Table 5-5).

Figure 5-4: Eleanor Creek near Hetch Hetchy (USGS 11-278000) Annual Instantaneous Peak Flood Frequency Plot for 1915-2005 Period of Record (Drainage Area = 78.4 mi^2).

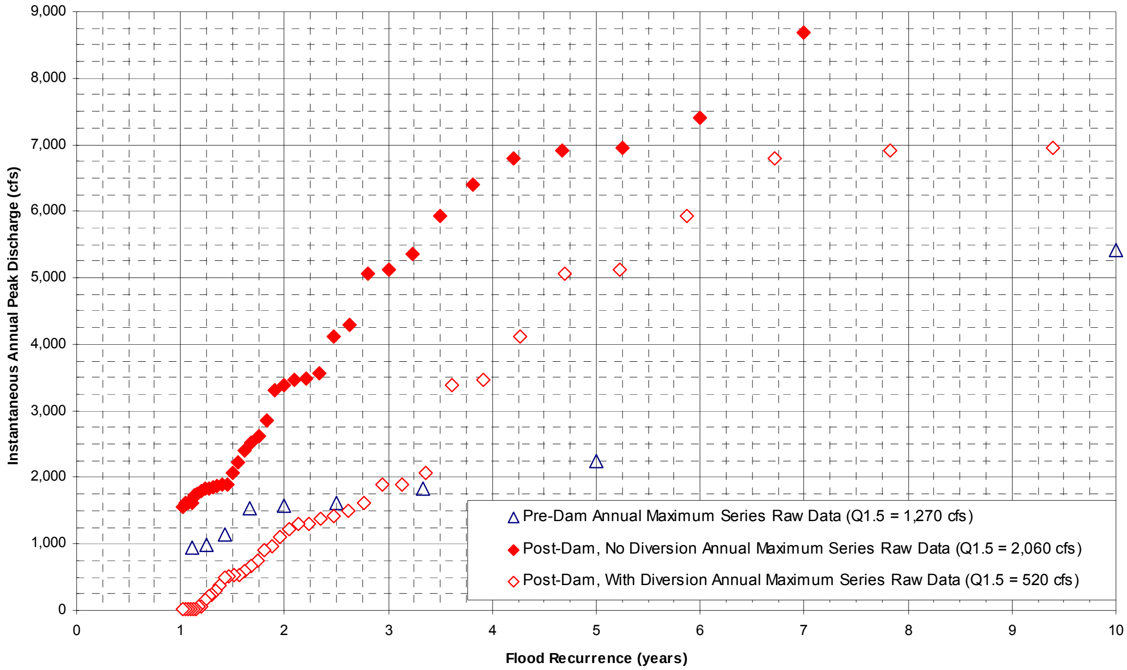


Table 5-5. Summary of Annual Peak Flood Magnitude Estimates from the USGS Gaging Station Eleanor Creek near Hetch Hetchy, CA (USGS 11-278000) for the Pre-dam Period, Post-dam Period with no Diversion to Cherry Lake, and the Post-dam Period with Diversion to Cherry Lake.

Recurrence Interval (years)	Estimated Flood Magnitude (cfs)[a]				
	Pre-dam (1910-1918)[b]	Post-dam, no diversion (1919-1959)	Percent Change from Pre-dam	Post-dam, with diversion (1960-2005)	Percent Change from No Diversion
1.5	1,270	2,060	+63%	520	-75%
2.33	1,600	3,570	+123%	1,350	-62%
5	2,250	6,940	+208%	5,100	-24%
10	N/A[c]	10,500	N/A	7,070	-32%
25	N/A[c]	13,200	N/A	11,000	-17%

Footnotes:

a. All estimates made from interpolations of raw data due to poor curve fitting of Log-Pearson III distribution.

b. Period of record extended from 1915-1918 to 1910-1918 by adjusting 1910-1914 peak daily average flows by 1.083 based on 1915-1918 peak flow-to-daily average flow ratio. Estimates considered very poor due to short period of record and supplemental data.

c. Pre-dam record too short to make reasonable estimate.

5.3.2 Cherry Creek near Hetch Hetchy below Valley Dam

Flood history at Cherry Creek is shown in Figure 5-5. During the 41-year period of record, annual floods were in spring (April-June) in 27 years and winter (October–February) in 11 years. The largest floods were in winter, including seven of the nine largest annual floods of record and all floods exceeding the 9-

year recurrence interval. The largest spring annual flood was 7,750 cfs (an 8.4-year flood). Since Cherry Valley Dam and Cherry Power Tunnel were completed, annual floods have shifted from winter to spring, and winter peaks are no longer significant. The January 1997 flood was the largest winter peak during this period, but this flood peaked at only 2,430 cfs downstream of the dam (a post-dam 5.6 year flood).

Operation of Cherry Valley Dam and the Cherry Power Tunnel has reduced annual flood magnitude for all recurrence intervals evaluated (Table 5-6, Figure 5-5). The maximum controlled release capacity from Cherry Valley Dam is approximately 5,000 cfs, equivalent to a pre-dam 3-year flood and a post-dam 34-year flood. Since Cherry Valley Dam was completed, the annual floods have approached 5,000 cfs in three years – WY1996, WY2004, and WY2006. The largest flood of record since the dam was built was in May 1996. This flood peaked at 5,120 cfs, a post-dam 50-year flood but only a pre-dam 3.2-year flood. The May 2006 peak (provisional peak data = 6,570 cfs) was the largest annual flood in this reach since the dam was completed. The May 2006 peak is equivalent to a pre-dam 6-year flood and exceeds the post-dam 50-year flood.

Figure 5-5: Cherry Creek near Hetch Hetchy (USGS 11-277000) and Cherry Creek below Valley Dam (USGS 11-277300) Annual Instantaneous Peak Flood History for 1915-2005 Period of Record. White Bars Indicate Winter Floods, Black Bars Indicate Snowmelt Peaks.

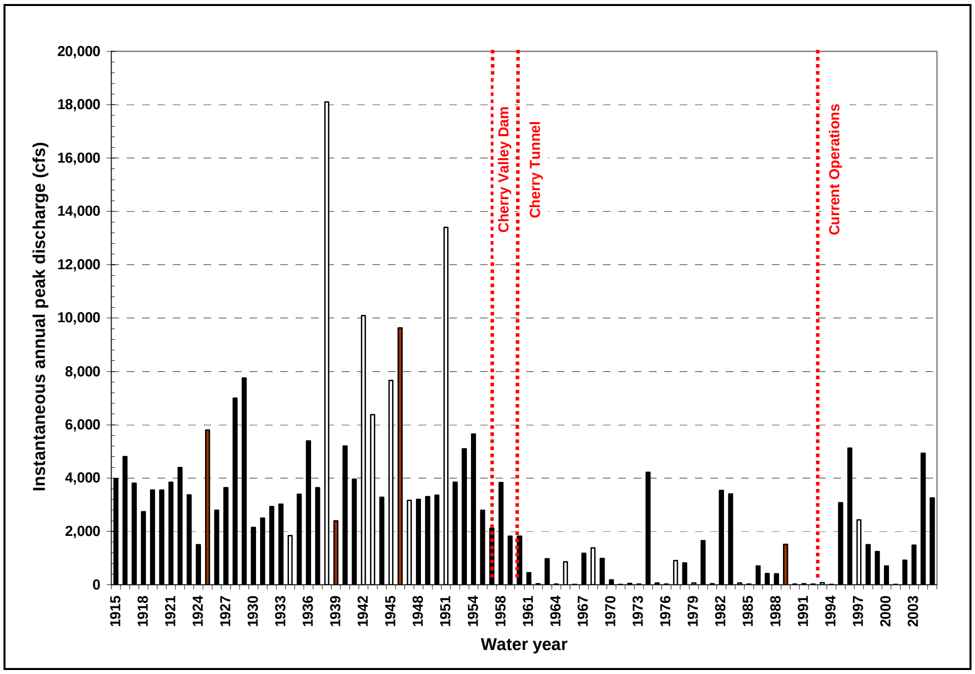


Figure 5-6: Cherry Creek near Hetch Hetchy (USGS 11-277000) and Cherry Creek below Cherry Valley Dam (USGS 11-277300) Annual Instantaneous Peak Flood Frequency Plot for 1915-2005 Period of Record (Drainage Area=118 mi^2).

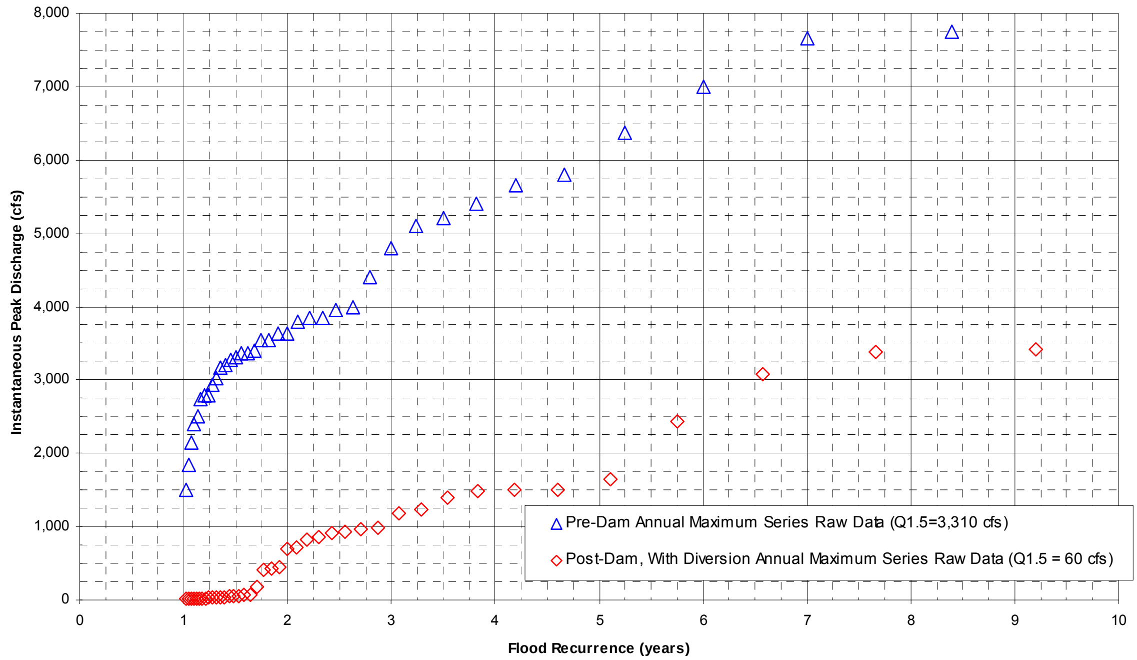


Table 5-6. Summary of Annual Peak Flood Magnitude Estimates from the USGS Gaging Station Cherry Creek near Hetch Hetchy, CA (11-277000) for the Pre-dam Period, Cherry Creek below Valley Dam (USGS 11-277300) for the Post-dam Period with Diversion from Lake Eleanor and to Holm Powerhouse.

Recurrence Interval (years)	Estimated Flood Magnitude (cfs)		
	Pre-dam (1915-1955)	Post-dam, with diversion (1961-2005)	Percent Change
1.5	3,310	60	-98%
2.33	3,850	870	-77%
5	6,130	1,620	-74%
10	9,200	3,450	-62%
25	14,300	4,950	-65%
50	20,000	5,200	-74%

5.3.3 Tuolumne River near Hetch Hetchy below O'Shaughnessy Dam

The pre-dam annual flood period of record at the Tuolumne River near Hetch Hetchy spans only 12 years. To provide a longer-term unimpaired flow record against which to compare managed flows in Technical Memorandum #2 (McBain & Trush and RMC Water and Environment 2006), annual flood data were scaled from the Merced River at Pohono Bridge near Yosemite gage (USGS 11-283500) by drainage area at the Tuolumne River at Hetch Hetchy gage. Because the Merced River gage has a long period of record (WY1917–present), and its elevation and drainage area are similar to the Tuolumne River near Hetch Hetchy gage (see Table 5-1), estimates of the pre-dam flood frequency were created from the Merced River data. For the six pre-dam years during which both gages were in operation, the scaled data underestimated annual peak flow at the Hetch Hetchy by 4% to 33%. The scaled unimpaired record, therefore, underestimates Tuolumne River flood peaks and the effects of project operation on annual flood magnitude. Because of this variability and uncertainty, Merced River data was not used, and flood magnitude predictions were limited to the 10-yr flood recurrence.

For pre-dam and unimpaired conditions, annual peak floods were typically in spring, but the largest and most geomorphically significant floods were winter rain-on-snow events. Pre-dam floods at the Hetch Hetchy gage were all in May and June and ranged from 6,202 cfs (WY 1913) to 11,400 cfs (WY 1919) (Figure 5-7). O'Shaughnessy Dam prior to the Canyon Power Tunnel diversion had moderate impacts to common floods (1.5-year recurrence interval), and minor impacts to larger floods (Figure 5-8, Table 5-7). Small, frequent floods (1.5-year pre-dam recurrence interval) were lowered by 40%, while less frequent floods were only lowered by 5%-20%.

More substantial changes to flood frequency and magnitudes occurred after completion of Canyon Tunnel in 1967 (Figure 5-8). Frequent floods (1.5-year recurrence) were further regulated, reduced by an additional 62% from the post-dam no diversion period (Table 5-7), and 79% from the pre-dam period. The 2.3 year flood was reduced an additional 26% (40% reduction from pre-dam), and the 5-year flood was reduced an additional 16% (21% reduction from pre-dam). However, the larger, less frequent floods were less impacted, with the 10-year flood only being reduced by 5% from pre-dam to the post-dam no diversion period, and only a 10% reduction from pre-dam to the post-dam with diversion period. Compared to the pre-dam record, the 1.5- and 2.33-year floods decreased 58% and 33%, respectively (Table 5-7). Since WY 1939, annual floods exceeded 10,700 cfs in three years (WY 1943, WY 1995, WY 1997). For the same period, annual floods scaled from the Merced gage exceeded 10,700 cfs in 11 years. Six of these floods were winter events. The January 1997 flood peaked at 16,400 cfs (an unimpaired 12-year flood and a post-dam 67-year flood), and was the largest flood of record in the reach for both the pre- and post-dam periods and was the only post-dam winter flood. The estimated unimpaired flow from this event (from the scaled Merced River at Pohono Bridge data) was approximately 35,000 cfs (an unimpaired 89-year flood). Although project operations after 1993 to retain higher reservoir storage through the winter have caused longer spills, spill magnitudes have not greatly changed.

Figure 5-7: Tuolumne River near Hetch Hetchy (USGS 11-276500) Annual Instantaneous Peak Flood History for 1915-2005 Period of Record. White Bars Indicate Winter Floods, Black Bars Indicate Snowmelt Peaks.

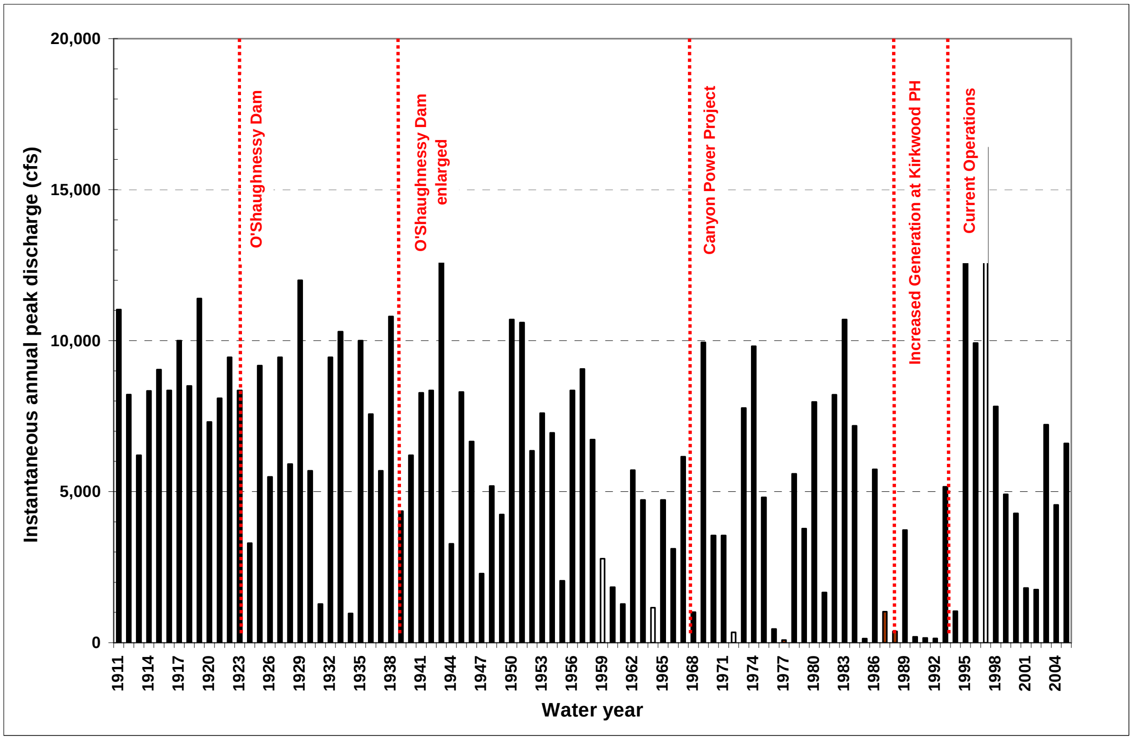


Figure 5-8: Tuolumne River near Hetch Hetchy (USGS 11-276500) Annual Instantaneous Peak Flood Frequency Plot for 1911-2005 Period of Record (Drainage Area = 457 mi^2).

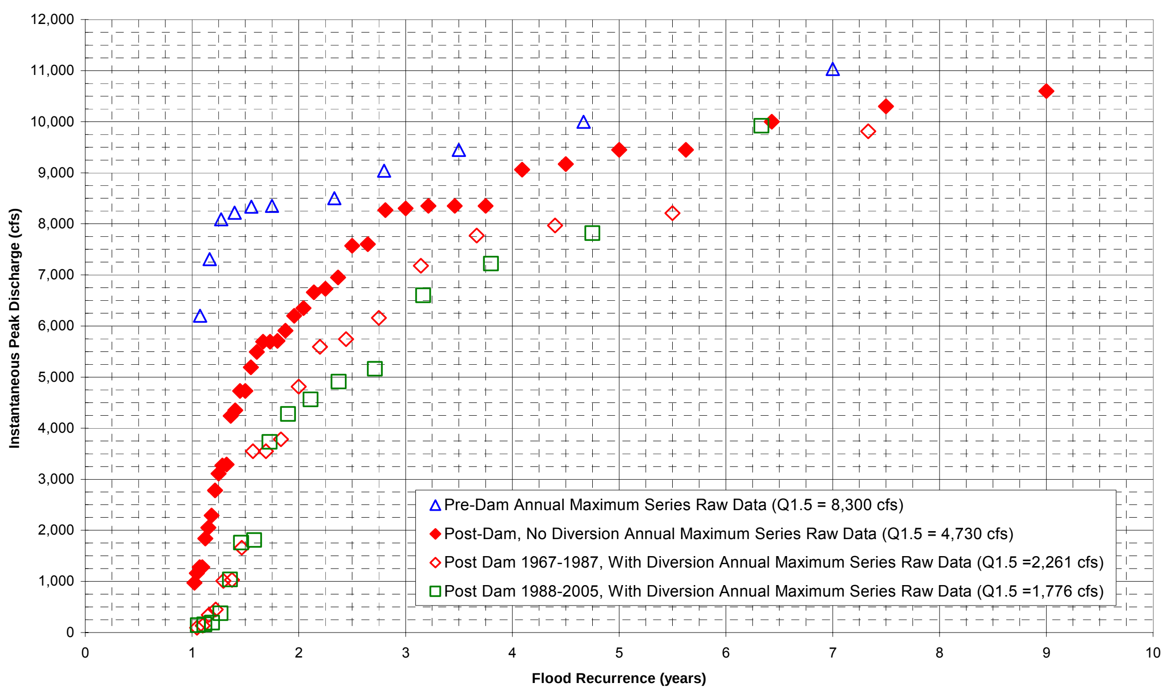


Table 5-7: Summary of Annual Peak Flood Magnitude Estimates from the USGS Gaging Station Tuolumne River near Hetch Hetchy, CA (USGS 11-276500) for the Pre-dam Period, Post-dam Period With No Diversion, and the Post-dam Period With Diversion.

Recurrence Interval (years)	Estimated Flood Magnitude (cfs)[a]					
	Pre-dam (1910-1922)[b]	Post-dam, no diversion (1923-1966)	Percent Change from Pre-dam	Post-dam, with diversion (1967-1987)[d]	Post-dam, with diversion (1988-2005)[d]	Percent Change from No Diversion
1.5	8,300	4,730	-43%	2,260	1,780	-62%
2.33	8,500	6,900	-19%	5,670	4,850	-29%
5	10,150	9,450	-7%	8,100	8,150	-14%
10	11,200	10,600	-5%	9,900	N/A[c]	N/A[c]
25	N/A[c]	12,100	N/A[c]	N/A[c]	N/A[c]	N/A[c]

Footnotes:

a. All estimates made from interpolations of raw data due to poor curve fitting of Log-Pearson III distribution.

b. Period of record extended from 1915-1922 to 1910-1922 by adjusting 1910-1914 annual peak data for Tuolumne River at Hetch Hetchy near Sequoia (11-276800) by 1.19 based on 1915-1916 peak flow-to-peak flow ratio between the two gages for those two overlapping years. Estimates considered poor due to short period of record and supplemental data.

c. Record too short to make reasonable estimate.

d. Diversion capacity increased from 670 cfs to 1,400 cfs in 1988.

Recurrence Interval (years)	Estimated Flood Magnitude (cfs)[a]				
	Pre-dam (1910-1922)[b]	Post-dam, no diversion (1923-1966)	Percent Change from Pre-dam	Post-dam, with diversion (1967-2005)	Percent Change from No Diversion
1.5	8,300	4,730	-43%	1,780	-62%
2.33	8,500	6,900	-19%	5,100	-26%
5	10,150	9,450	-7%	8,000	-16%
10	11,200	10,600	-5%	9,900	-7%
25	N/A[c]	12,100	N/A	14,300	+18%

Footnotes:

e. All estimates made from interpolations of raw data due to poor curve fitting of Log-Pearson III distribution.

f. Period of record extended from 1915-1922 to 1910-1922 by adjusting 1910-1914 annual peak data for Tuolumne River at Hetch Hetchy near Sequoia (11-276800) by 1.19 based on 1915-1916 peak flow-to-peak flow ratio between the two gages for those two overlapping years. Estimates considered poor due to short period of record and supplemental data.

g. Pre-dam record too short to make reasonable estimate.

5.3.4 Tuolumne River near Buck Meadows

The pre-dam annual flood period of record at the Tuolumne River near Buck Meadows gage only spans 11 years and the post-dam period of record only spans 12 years. In addition, water year 1911 (45,000 cfs, pre-dam) appears to be an outlier for the short period of record, which elevates the pre-dam 10-year flood magnitude. Therefore, flood magnitude predictions were limited to the 5-yr flood recurrence for both periods. The post-dam period of record reflects the influence of the following upstream regulation: 1) effect of storage from O'Shaughnessy Dam, 2) effect of diversions at Early Intake to the Hetch Hetchy Aqueduct, and 3) small amounts of regulation from Eleanor Lake. Dam operation has reduced flood magnitude for all flood recurrence intervals up to the 5-year flood (Figure 5-9), ranging between 20% and 37%. Because the gaging station was discontinued in 1936, the post-dam flood frequency data do not capture substantial changes in project operations after 1955 with the completion of Cherry Valley Dam, and the enlargement of O'Shaughnessy Dam in 1937, such that reductions to the pre-dam flood magnitudes are likely greater than that illustrated in Table 5-8.

Figure 5-9: Tuolumne River near Buck Meadows (USGS 11-283000) Annual Instantaneous Peak Flood Frequency Plot for 1908-1936 Period of Record (Drainage Area = 924 mi^2).

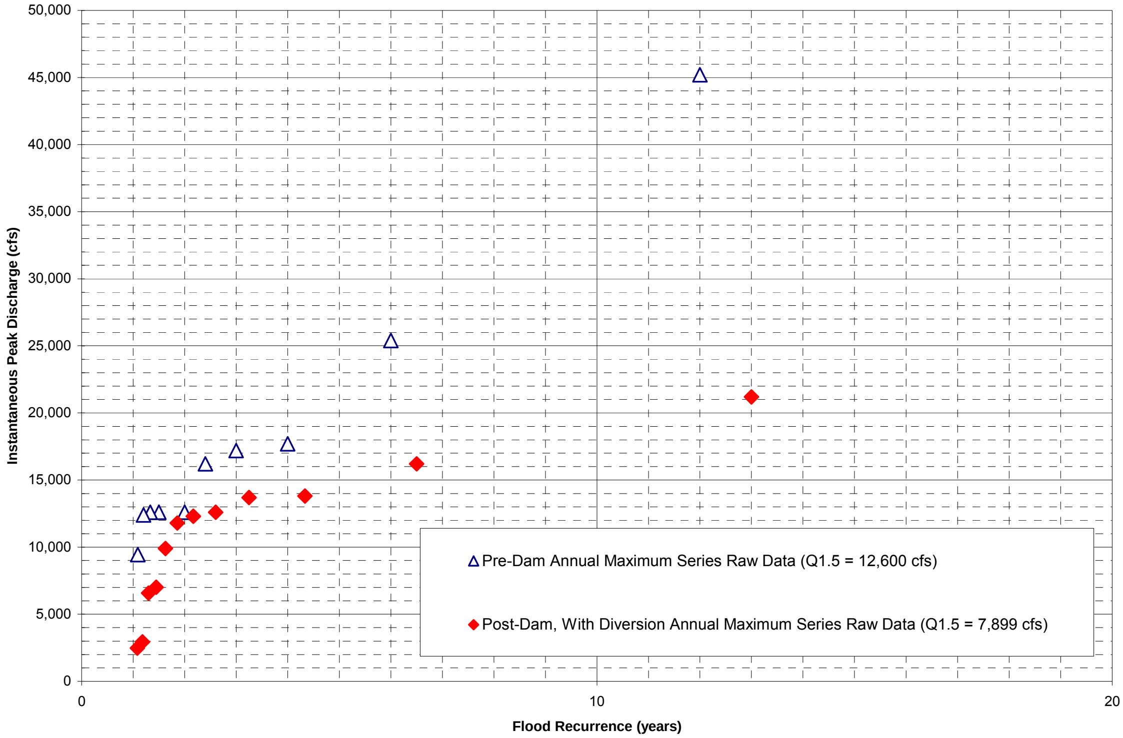


Table 5-8. Summary Of Annual Peak Flood Magnitude Estimates From The USGS Gaging Station Tuolumne River Near Buck Meadows, CA (USGS 11-283000) for the Pre-dam Period and Post-dam Period with Diversion from Lake Eleanor and to Holm Powerhouse.

Recurrence Interval (years)	Estimated Flood Magnitude (cfs)[a]		
	Pre-dam (1911, 1913-1914, 1916-1922)	Post-dam, with diversion (1925-1936)	Percent Change
1.5	12,600	7,900	-37%
2.33	15,570	12,410	-20%
5	21,550	14,540	-32%
10	38,600	18,890	-51%
25	N/A [b]	N/A [b]	[b]
50	N/A [b]	N/A [b]	[b]

Footnotes:

a. All estimates made from interpolations of raw data due to poor curve fitting of Log-Pearson III distribution.

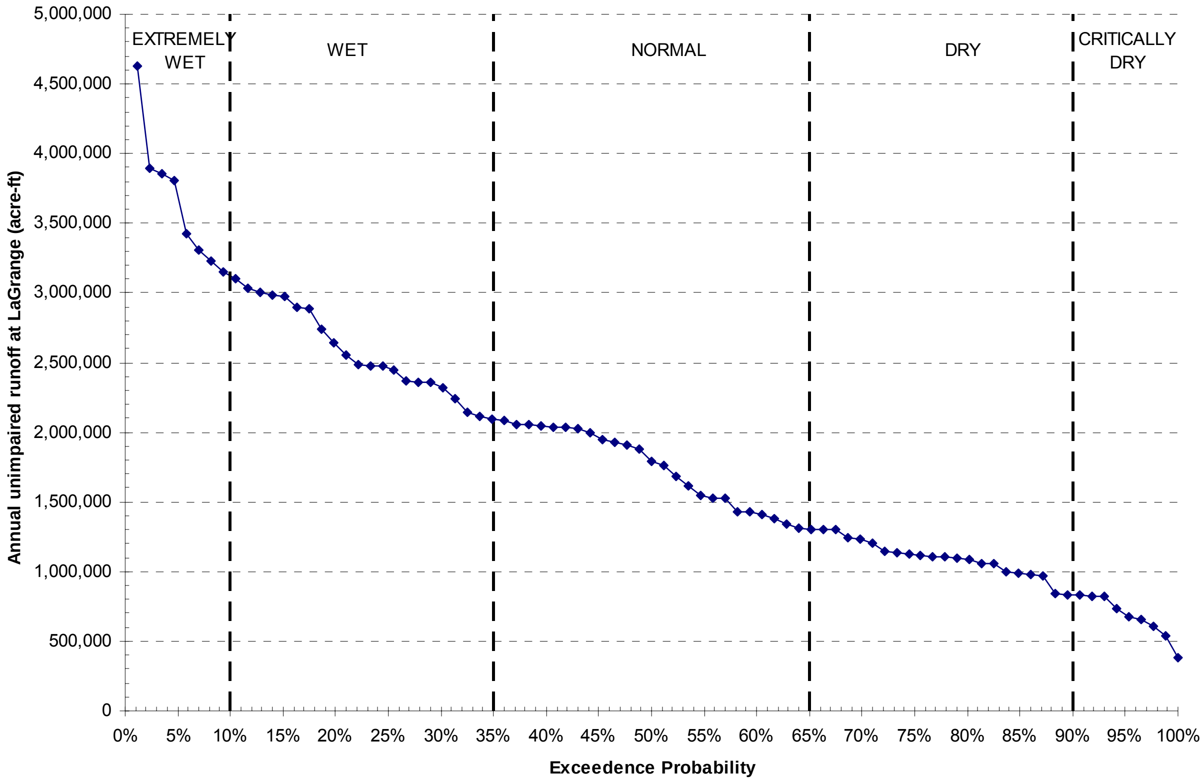
b. Pre-dam record too short to make reasonable estimate.

5.4 Water Year Classification

The annual yield, or total volume of flow from a watershed (e.g., acre-feet per year), is an important hydrologic variable, and is usually computed for the Water Year (WY) from October 1 to September 30. Because the annual water yield varies from year to year, describing both the average yield over a number of years, and the range in annual yield, is informative. This “inter-annual variability” is typically described using a water year classification system, which assigns each water year to a discrete category such as “Extremely Wet” or “Dry”. Following the classification of individual water years, all the water years in each category can be compiled, then flow statistics such as average baseflow and high flow magnitudes can be computed for a water year type (e.g., “Dry”) and compared to values from different water year types (e.g., “Extremely Wet”). This type of analysis thus allows evaluation of inter-annual variability in certain hydrograph components (e.g., typical summer baseflows for Dry water years compared to Extremely Wet water years).

To establish uniform water year designations for different sub-basins within the Tuolumne River watershed, the annual water yield was first estimated using computed unimpaired inflows into New Don Pedro Reservoir for the period 1918-2005. Water yields were ranked and plotted as an exceedance probability, then divided into five asymmetrically weighted classes separated by annual exceedance probabilities (p) of 0.10, 0.35, 0.65, and 0.90 (Figure 5-9). The five classes were named “Extremely Wet” (p = 0 to 0.10), “Wet” (p = 0.10 to 0.35) “Normal” (p = 0.35 to 0.65), “Dry” (p = 0.65 to 0.90), and “Critically Dry” (p = 0.90 to 1.00). From this classification based on water yield for Tuolumne River at New Don Pedro, each water year from 1918 to 2005 was assigned a water year designation, and the same designation for each water year was used in analyses for the USGS gages Tuolumne River near Hetch Hetchy, Eleanor Creek near Hetch Hetchy, and Cherry Creek near Hetch Hetchy. Hydrograph component analyses were then performed for each of those three gaging locations for the five water year types.

Figure 5-10: Water Year Classes Used for Hydrograph Component Analysis Based on Computed Unimpaired Inflows into New Don Pedro Reservoir from 1918-2005 (from TID 2005).



5.5 Hydrograph Component Evaluations

The annual water yield and water year classification are useful for comparing variation between different water year classes (inter-annual variation), but other specific ecological objectives (e.g., flows for fish spawning) require focusing on a specific portion of the year (intra-annual variation). The unregulated annual hydrograph depicts the natural variability of streamflow patterns, and is thus a useful tool for analyzing changes to the natural flow regime that result from streamflow regulation. While the specific <u>magnitude</u>, <u>duration</u>, <u>frequency</u>, and <u>timing</u> of runoff events within the annual hydrograph are variable, there are general trends within this variability that are broadly predictable. For example, extremely wet winters tend to produce a larger snowpack that results in a larger (magnitude and duration) snowmelt flood that typically peaks later in the spring (timing) than do drier years. These trends, which are termed "hydrograph components", are seasonal patterns of daily average flow that recur from year to year and have meaningful geomorphic and biological functions (Trush et al. 2000). Important hydrograph components applicable to the Tuolumne River basin included summer and fall baseflows (magnitude), winter floods (magnitude, frequency, timing), winter baseflows (magnitude), spring snowmelt floods (magnitude, duration, timing), and snowmelt recession (timing, duration) (Figure 5-10).

The fundamental concept underlying the hydrograph component analysis is that each hydrograph component accomplishes specific ecologically significant functions, but those functions may be performed across the range of water year types and not necessarily during every water year. Characterizing the intra-annual variability (hydrograph components) for a range of water year types (inter-annual variability) thus provides a comprehensive assessment of hydrologic changes that may impact ecological functions or species' life histories.

The hydrograph component analysis evaluated three primary locations where gaging data were available and impacts from operations were most pronounced, including the Tuolumne River below

O'Shaughnessy Dam, Eleanor Creek below Lake Eleanor, and Cherry Creek below Cherry Valley Dam (Table 5-9). Impacts likely diminish downstream of these locations due to unregulated tributary and groundwater accretion.

Hydrograph components and the associated variability in magnitude, timing, duration, and frequency were analyzed for each water year class to provide a mean or median value, peak value, and/or minima and maxima representative of each water year class. In summary, the hydrograph component analysis used the following procedure:

- The annual water yield (runoff volume in acre-feet) was computed for Tuolumne River computed unimpaired inflows to New Don Pedro Reservoir, plotted as a cumulative distribution curve by ranking the annual yield, and the distribution was then divided into the five water year classes (Figure 5-10).
- Key hydrograph components were delineated by examining individual annual hydrographs over different water year types and observing seasonal patterns of daily average flow and the range of their occurrence, (Figure 5-11).
- Daily average flow data for each water year were grouped into the appropriate water year class, and statistical parameters (e.g., median, maxima, minima) were computed for each hydrograph component using daily average flow data. Analyses were performed for the unimpaired (pre-dam or computed unimpaired data) period, the post-dam but pre-diversion period, and the post-diversion period of record. These data were then compared in order to describe how each hydrograph component was affected by various stages of regulation.
- Statistical data were compiled into 'hydrograph component summary tables' that report a range of discharge values for each component for Extremely Wet, Wet, Normal, Dry, and Critically Dry water year types for the pre-dam and post-dam periods of record.

The following section describes the hydrograph components analyzed for each gaging station and for each period of record. The start and end dates for each component were chosen to provide a consistent period for the component, but occasionally do not capture the full range of variability.

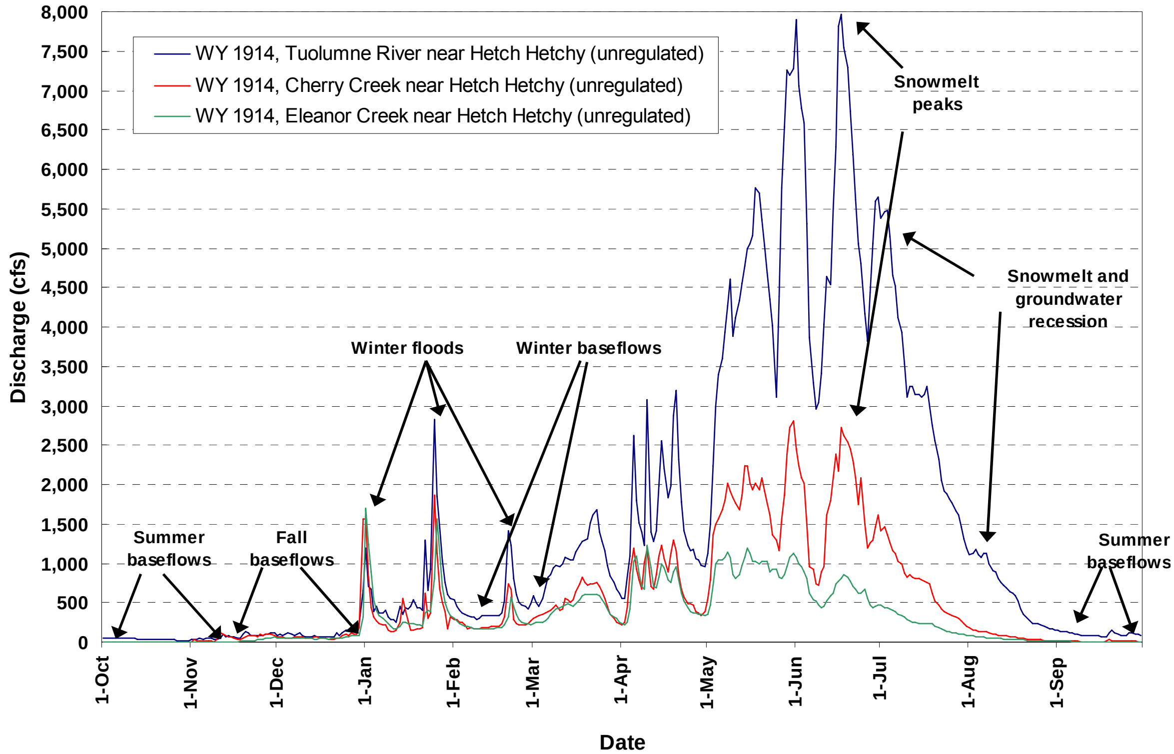
5.5.1 Definitions of Components

Summer and fall baseflows

Following the spring snowmelt runoff period, summer baseflows are low flow periods that extend through summer and into fall. During wetter water years, the snowmelt runoff extends later into the summer season and those years have a shorter summer baseflow period. During most water years, the warmest air and water temperatures correspond to summer baseflows. Summer baseflows were estimated for each water year by computing the median daily average flow for the period August 15 through September 30, then reporting the median, maximum, and minimum values of those individual water year median baseflows for each water year type.

Occurring somewhat variably between October 1 and November 15, fall baseflows are low flows, frequently the lowest daily average flows of the year. Fall baseflows are occasionally punctuated by small rainstorm events. Air and water temperatures during this period are typically cooler, compared to July and August temperatures. Unimpaired and computed fall baseflows were estimated by computing the median daily average flow for the period October 1 to November 15, then reporting the median, maximum and minimum value of those individual water year median baseflows for each water year type.

Figure 5-11: Hydrograph Components Identified for Upper Tuolumne River from Unimpaired Hydrographs, Using Water Year 1914 as Example Year.



Winter floods

Winter floods typically occur between mid-December and late-March, and are generated by rainfall or rain-on-snow storm events. Larger magnitude, short duration floods caused by rainfall and rain-on-snow events typically peak in late December through January, with moderate magnitude events extending through March. Winter floods perform a variety of important ecosystem processes, including the creation and maintenance of alluvial channel morphology, scour and transport of bed sediments, bank erosion and channel migration (where possible), scour of riparian vegetation along channel margins, scour of alternate bars and other habitat features, and floodplain inundation.

A standard flood frequency analysis (see Section 5.2) is a common method for assessing the high flow regime. Flood frequency analysis tabulates the annual *instantaneous* maximum peak flow for each water year, ranks the peak flows across the period of record, and computes the flood recurrence for each flow event. A distribution is then fit to the data to predict flood magnitude for a given recurrence interval. Depending on the dominant flood processes for a given stream, the flood frequency analysis can capture peak flows from the winter flood and/or snowmelt peak flood.

For the hydrograph component analyses, winter floods were estimated by computing the *daily average* maximum peak flow for the period December 10 to March 20 for each water year and reporting the median, maximum, and minimum value for each water year type. The daily average maximum flow is typically lower than the instantaneous peak, but has longer duration, lasting from one to several days. Descriptions below nevertheless use the term "peak" to describe the maximum daily average flow for the winter period.

Winter baseflows

Winter baseflows occur between December 10 and March 20 (and frequently later into the spring) and are low flow periods between winter storms. Winter baseflows, maintained by the receding limbs of storm hydrographs and shallow groundwater discharge, generally increase in magnitude and duration throughout the winter months as soils become saturated and groundwater tables rise. Flow conditions during winter months are naturally highly variable, so determining a single winter baseflow for each water year type is more challenging than for other components. A close succession of storms, for example, would establish relatively high baseflows, whereas a long, dry spell between storms would lead to lower winter baseflows. To help define winter baseflows, daily average flows for the period December 10 to March 20 were sorted and plotted as a cumulative distribution curve. Observation of the cumulative curve showed a strong inflection at a 10% exceedence value, which functionally represents the transition between storm events and winter baseflows. Therefore, winter baseflows were estimated for each water year by computing the median value from the sorted daily average flows below 10% exceedence for the December 10 through March 20 period, then reporting the median, maximum, and minimum value of those individual water year median baseflows for each water year type.

Snowmelt peaks

Spring snowmelt floods typically have lower peak magnitudes and longer durations than winter floods. Prior to regulation and diversion, this component was the largest contributor to the total annual water yield, with large magnitude and long duration floods extending from mid-April to mid-July during wetter years and peaking in May or June. The spring snowmelt flood has important ecological significance, particularly to the native flora and fauna whose life history traits are strongly linked to the seasonal runoff. Native plant species depend on spring floods to inundate higher-elevation gravel bars and floodplain surfaces and to deposit fine sediments that provide seed beds for germinating plants. There is substantial diurnal fluctuation within the snowmelt hydrograph, with magnitudes of diurnal fluctuation increasing (up to 30% of the daily average flow) with increasing ambient air temperatures in the late spring. Recent research by Lundquist et al., (2004) suggests that the timing of the diurnal fluctuations varies with depth of snowpack and drainage areas for smaller watersheds (less than 77 mi2), yet remains fairly constant for larger watersheds (greater than 77 mi2).

Snowmelt floods were computed in a similar manner as winter floods, i.e., the *daily average* maximum flow was computed for the period April 20 to July 20 for each water year and the median, maximum, and minimum value were reported for each water year type. In addition to the peak magnitude, the timing of the peak is also critical, because it signals the beginning of the snowmelt recession. The median, earliest, and latest date of the snowmelt peak were estimated for each water year type.

Snowmelt and Groundwater Recession

The snowmelt recession represents the transition from snowmelt flood to summer baseflows. The recession often extends late into summer, but generally declines to baseflow level by August. Two critical aspects of the snowmelt recession are the rate and duration of the recession. The recession rate describes the daily decrease in river stage height with reduction in flow volume, while duration describes the length of time the recession extends into summer. The snowmelt recession may also transition from steeper recession rates to slower rates, with a visible inflection in the rate. The recession rate, particularly the tail-end of the recession limb, affects survival or mortality-by-desiccation of germinating plant seedlings. The duration of the descending limb primarily influences water temperatures in the river during the hotter summer months of July and August.

A significant portion of the total precipitation within a watershed does not flow directly into streams, tributaries, or mainstem rivers, but instead recharges groundwater basins. Groundwater recharge peaks during the snowmelt period, and recharge rates decline along a gradient from high to low elevation, until a transition occurs from losing (surface flow lost to groundwater) to gaining (groundwater discharged back to streamflow) discharge. As with surface flow, groundwater discharge recedes following the snowmelt peak, but may provide an important flow component to buffer declining streamflow volumes during late summer.

5.5.2 USGS Gaging Stations Used

The hydrograph component analysis used a subset of gaging locations within the Tuolumne River basis (Table 5-9). Locations were selected based on their available period of record and ability to describe important intra-annual hydrologic changes caused by construction of dams and diversion facilities on the Tuolumne River, Eleanor Creek, and Cherry Creek. For each gaging location, computed unimpaired data were developed from reservoir inflow data to extend the available period of unimpaired data. Because of inherent inaccuracies in the computed unimpaired data, those records were not used in baseflow evaluations. The term “pre-dam” is thus often used to refer to pre-dam and computed unimpaired data. All annual hydrographs for the period of record have been included in Appendix A, Appendix B, and Appendix C.

Table 5-9: USGS Gaging Stations Used in the Hydrograph Component Analysis.

Location	Regime	Gage #	Years Used in HCA
Tuolumne River near Hetch Hetchy	Pre-dam 11-2	76500	1911-1923, 1924-2005[a]
	Post-dam, no Diversion	11-276500	1924-1967
	Post-dam w/ Diversion	11-276500	1968-2005
Eleanor Creek near Hetch Hetchy	Pre-dam 11-2	78000	1910-1918, 1919-1959[a], 1997-1999[a], 2003-2005[a]
	Post-dam, no Diversion	11-278000	1919-1959
	Post-dam w/ Diversion	11-278000	1960-2005
Cherry Creek near Hetch Hetchy	Pre-dam 11-2	77700	1910-1955, 1958-1959[a], 1997-1999[a], 2003-2005[a]
	Post-dam w/ Diversion	11-277300	1960-2004

Footnotes:
a. Computed Unimpaired.

5.5.3 Tuolumne River near Hetch Hetchy Hydrograph Components

Quantification of hydrograph components for unimpaired, post-dam with no diversion, and post-dam with diversion are summarized in Table 5-10, Table 5-11, and Table 5-12, respectively, and described below.

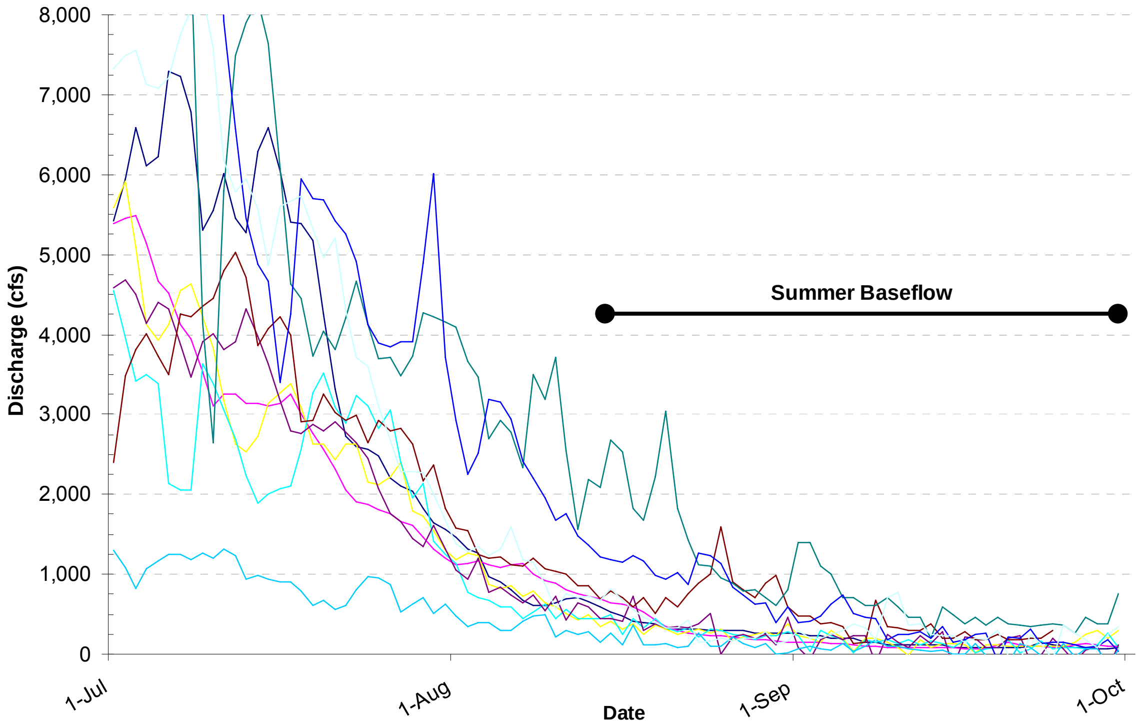
Summer and fall baseflows (August 15 – September 30)

The unimpaired summer and fall baseflows were fairly uniform during most water year types, typically ranging between 50-100 cfs, with wetter years’ baseflows slightly higher than drier years. The main exception to this trend occurred during some Extremely Wet and Wet years when large snowpack caused later snowmelt peak dates (e.g., 1983, 1995), causing the snowmelt recession to bridge summer months and extend into fall (Figure 5-12). Baseflows during these unique years were subsumed by the snowmelt recession.

A major hydrologic impact of O’Shaughnessy Dam occurred prior to construction of the Canyon Power Tunnel (1967) when summer and fall baseflows were elevated to deliver stored water downstream to Early Intake for diversion into the Hetch Hetchy aqueduct. Summer and fall baseflows during post-dam, pre-diversion period were again fairly uniform but ranged between 600-800 cfs, with occasionally higher summer baseflows exceeding 1,200 to 1,300 cfs. Summer periods in which construction activities occurred (1924, 1925, 1932, 1967) had anomalously low baseflows, and were not included in the analysis.

Following construction of the Canyon Power Tunnel, flows were no longer released to this reach for water supply delivery, which decreased summer and fall baseflows to levels which closely resembled unimpaired conditions. Summer and fall baseflows consistently ranged between 50 and 100 cfs. In drier years, baseflows occasionally ranged as low as 30-40 cfs. During water year 1983 (the wettest year on record), summer and fall baseflows still remained below 150 cfs. Minimum baseflows for August and September are now set at 80-125 cfs, 65-110 cfs, or 50-75 cfs based on the three different precipitation year classes used in the 1985 Flow Stipulation (Table 5-6).

Figure 5-12: Plot of Snowmelt Runoff and Summer Baseflows for Unimpaired Extremely Wet Water Years at the Tuolumne River near Hetch Hetchy, CA Gaging Station (USGS 11-276500).



Winter floods

The unimpaired daily average winter floods (in contrast to instantaneous peak floods discussed in Section 5.3) were quite variable overall, but diminished consistently toward drier water year types. Maximum flood peaks ranged as high as 37,000 cfs during Extremely Wet years (the computed unimpaired 1997 flood), and as low as 1,000 cfs in Critically Dry years. As evident from the minimum peak (daily average) values, some years had very little or no winter flood events. The majority (~ 60%) of peak winter floods was between 1,000 and 9,000 cfs, and a large minority of winter peak values (30%) was below 1,000 cfs.

During the post-dam period of record with and without diversions, the winter peak flood component has been eliminated in almost all years. Post-dam winter maximum daily average values are typically only slightly higher than, or often equivalent to, winter baseflows. The post-dam flood of record (the actual measured 1997 flood) produced a peak discharge of 13,800 cfs, far higher than the next highest winter (daily average) peak flood of 4,110 cfs for the 1926-2000 post-dam period of record.

Winter baseflows

Winter baseflows varied consistently with water year type during the unimpaired record, with higher median baseflows in wetter years, and ranging from approximately 100-500 cfs. Minimum unimpaired winter baseflows reached as low as 30-40 cfs during Normal to Critically Dry water years. The highest unimpaired median winter baseflows were approximately 800 cfs.

Post-dam winter baseflows before diversions began in 1967 were slightly higher than unimpaired winter baseflows in all water year types due to water deliveries to the aqueduct, with median flows ranging between 520-720 cfs. The maximum winter baseflows occurred in Wet and Extremely Wet years and exceeded 1,200 cfs post-dam, compared to the highest unimpaired winter baseflow of 800 cfs.

After diversions began in 1967, winter baseflow magnitude decreased significantly. Post-diversion median winter baseflows consistently remain below 100 cfs, except in Extremely Wet and Wet water years. The minimum-median winter baseflows generally remain below 40 cfs. The overall effect has been to make all post-dam with diversion water year types comparable to the driest unimpaired Critically Dry years.

Snowmelt peaks

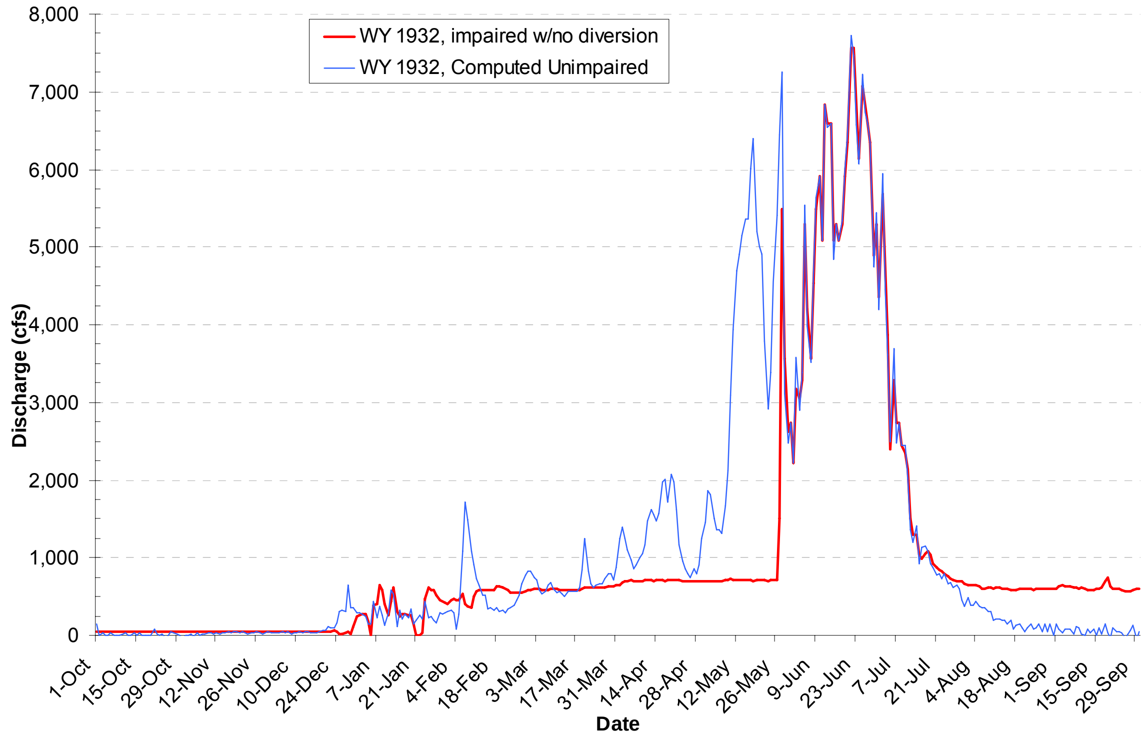
The unimpaired snowmelt peak floods were relatively predictable hydrologic events (as compared to winter floods), and were geomorphically and ecologically important. The average and median peak magnitudes ranged between 4,000-10,000 cfs, dependably increasing in magnitude during wetter water years with larger snow pack. The range of peak magnitudes was narrower in wetter water year types; for example Extremely Wet minimum and maximum peak daily average values were 8,000 and 12,800 cfs, but also ranged from 3,000 to 12,000 cfs in Dry years. Despite the variability in peak flow magnitudes, virtually all water years had some discernable snowmelt peak: the driest water year on record, WY 1977, had a computed unimpaired snowmelt peak of 4,160 cfs; the lowest snowmelt peak recorded was 2,540 cfs in WY 1934.

In general, the effect of the dam prior to the start of diversions was a 10-20% reduction in peak snowmelt magnitude across most water years, and elimination of many snowmelt peaks during Dry and Critically Dry years. With diversions, the snowmelt peak magnitude was reduced even further, by approximately 20-50% during Extremely Wet to Normal years, respectively, and eliminated in Dry and Critically Dry years. During post-dam Critically Dry years (n=5), peak snowmelt magnitude (April 20-July 20) did not exceed 300 cfs, and exceeded 300 cfs in only two of nine Dry water years.

In addition to reducing the snowmelt peak magnitude, O'Shaughnessy Dam also altered the overall shape of the snowmelt hydrograph. Prior to regulation, the snowmelt hydrograph had a long, gradual ascension often punctuated by one or several early and progressively larger peaks caused by early season cycles of warming and cooling. Construction of the dam effectively allowed the capture of most or the entire ascending hydrograph limb until enough snow melted to fill the reservoir. Post-dam no diversion flows then resembled unimpaired conditions with reservoir releases matching inflow, and passing the remainder of the snowmelt runoff (Figure 5-13). In drier years Hetch Hetchy reservoir was able to capture the entire snowmelt hydrograph, and the snowmelt hydrograph release was eliminated.

The timing of the snowmelt peak magnitude was also relatively consistent during unimpaired conditions. The median date of the peak ranged from mid-May in Critically Dry years to mid-June in Extremely Wet years. The median peak date generally occurred later in the season in wetter water years, because a larger snow packs required more time to melt and attain the peak magnitude (Figure 5-14). Most water year types had one or several peaks occurring as early as late April and May, and later peaks occurring in July. During the post-dam no diversion period, there was no detectable change in the timing of the snowmelt peak from unimpaired conditions, and peak dates ranged from late-April through mid-July. As discussed above, diversions eliminated drier year peaks which typically occurred earlier in the season, so the timing of the peaks has become biased toward later in the summer season, with very few peaks now occurring in April or May.

Figure 5-13: Impaired and Computed Unimpaired Annual Hydrograph at the Tuolumne River near Hetch Hetchy, CA Gaging Station (USGS 11-276500) for Water Year 1932, Showing Effect of the Original O'Shaughnessy Dam (Prior to Height Increase) on Winter Floods and Baseflows.



Snowmelt recession

The unimpaired snowmelt recession typically had two or more phases during most water years, an early phase following the peak characterized by a steep rate of decline, then a second phase characterized by a slower rate of decline. Often the inflection or "node" defining the transition between phases was visible in the annual hydrographs. The unimpaired recession often extended into August before transitioning into summer or fall baseflows.

The regulated pre-diversion hydrographs often had a relatively unimpaired snowmelt recession because the reservoir was full and passing all the snowmelt discharge. This scenario was particularly true during wetter water years when the reservoir filled early or mid-snowmelt season. After diversions began in 1967, the snowmelt recession was more dramatically impacted. Regulated hydrographs often had precipitously steep recessions that dropped directly to summer baseflow levels, or had no snowmelt recession at all.

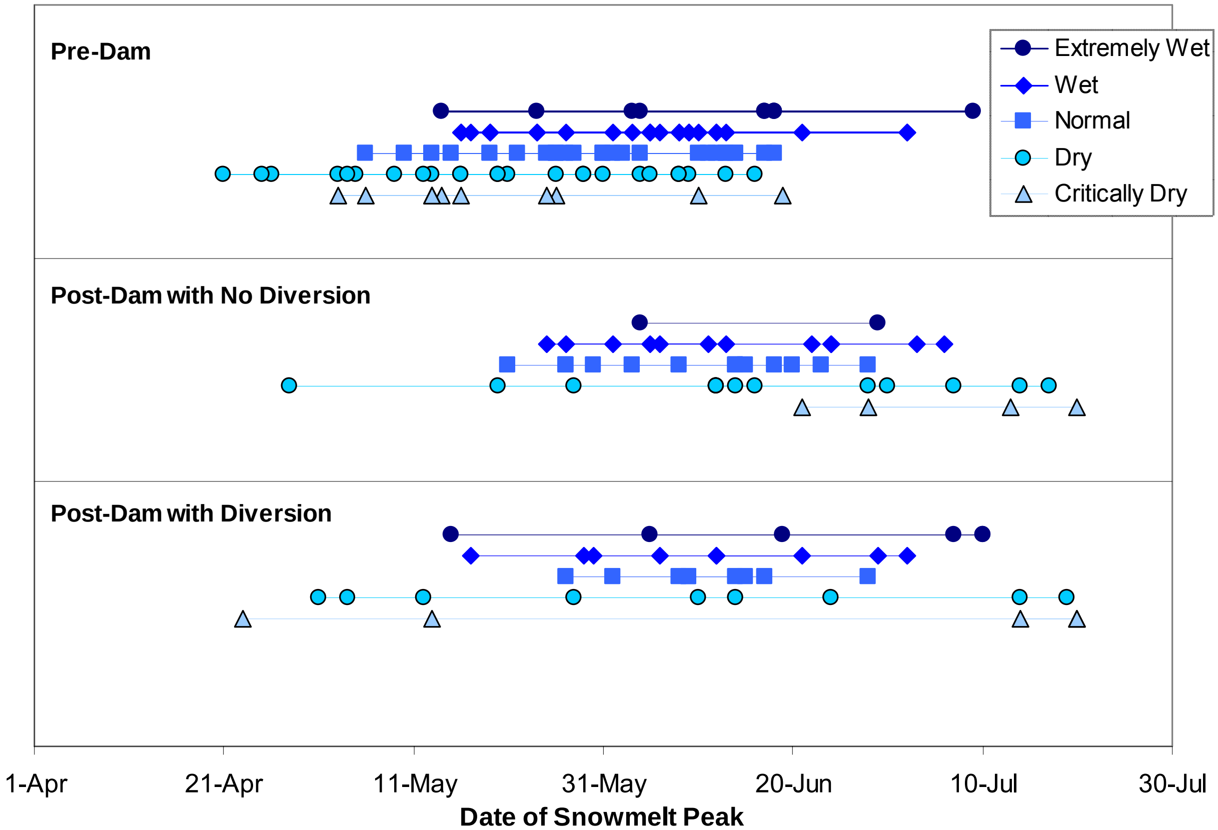
5.5.4 Cherry Creek near Hetch Hetchy Hydrograph Components

Quantification of hydrograph components for unimpaired and post-dam with diversion are summarized in Table 5-13 and Table 5-14, respectively, and described below. The post-dam period with no diversion was very short (2 years), so it was not analyzed or quantified.

Summer and fall baseflows

The lengthy record of measured unimpaired flows on Cherry Creek (WY 1911 to 1955) provide an important reference for annual hydrograph components; therefore computed unimpaired flow data were not used in baseflow analyses for Cherry Creek. The unimpaired median summer and fall baseflows ranged from 1 to 22 cfs across all water year types, with summer baseflows slightly lower than fall flows in drier years. Wetter years had higher summer baseflows than fall flows, ranging as high as 50 cfs.

Figure 5-14: Snowmelt Peak Timing for Tuolumne River near Hetch Hetchy, CA Gaging Station (USGS 11-276500) Showing Effects of O'Shaughnessy Dam on the Timing of Snowmelt Peaks.



The construction of Cherry Valley Dam in 1955 and Cherry Power Tunnel in 1960 did not appear to substantially change summer and fall baseflows compared to unimpaired flows. Median post-dam summer baseflows increased slightly in drier years, and now range from 12-16 cfs, which are more comparable to wet year magnitudes. Fall baseflows were slightly lower, ranging below 10 cfs. Minimum baseflows are now set at 15.5 cfs for August and September and 5 cfs for October and November based on the 1985 Flow Stipulation (Table 5-1).

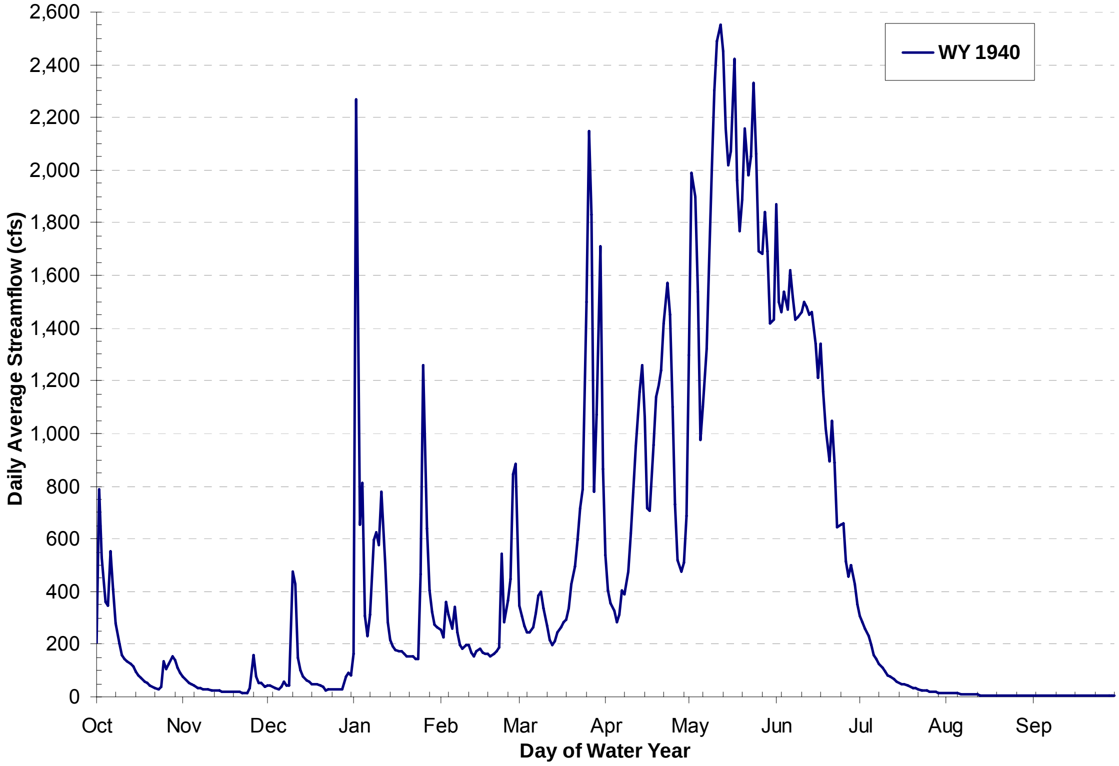
Winter floods

Winter floods were common events in most water year types in Cherry Creek during unimpaired conditions, but particularly during Normal, Wet, and Extremely Wet years. Only two Normal and two Wet years had winter maximum daily average flows that did not exceed 600 cfs. Most median winter peaks ranged between 1,000 and 7,000 cfs, and the computed unimpaired daily average flow for the 1997 flood was 22,800 cfs. The lowest magnitude median winter flood for Extremely Wet years was 1,480 cfs. Several water years in the unimpaired record also had two or more winter peaks, and illustrate how each successive winter flood progressively increased the subsequent winter baseflow level (Figure 5-15; also see Appendix C WYs 1911, 1914, 1921, 1930, 1943; and contrast with WY 1946 with two temporally separate winter flood peaks and comparable winter baseflows).

Following construction of Cherry Valley Dam (1955) and Cherry Power Tunnel (1960), the winter flood hydrograph component was totally eliminated from all water years. During post-dam conditions, only the 1997 flood was large enough to exceed the dam capacity and cause a winter flood peak downstream (peak daily average flow = 1,350 cfs). The next largest peak daily average value during the winter period (Dec

10-Mar 20) was 258 cfs. Most post-dam water years had year-round flows comparable to summer baseflows, with no flow variability throughout the year.

Figure 5-15: Unimpaired Annual Hydrograph for Cherry Creek near Hetch Hetchy, CA Gaging Station (USGS 11-277000), Showing Progressively Increasing Winter Baseflow Magnitudes with Successive Winter Peaks.



Winter baseflows

Unimpaired winter baseflows exhibited a pattern of higher baseflows in wetter water year types and lower baseflows in drier years. The median winter baseflow values ranged between 90 and 200 cfs in Critically Dry and Extremely Wet years, respectively, with the lowest median baseflows of 45 cfs in Dry years. As mentioned above, winter baseflows typically increased following a succession of winter storms.

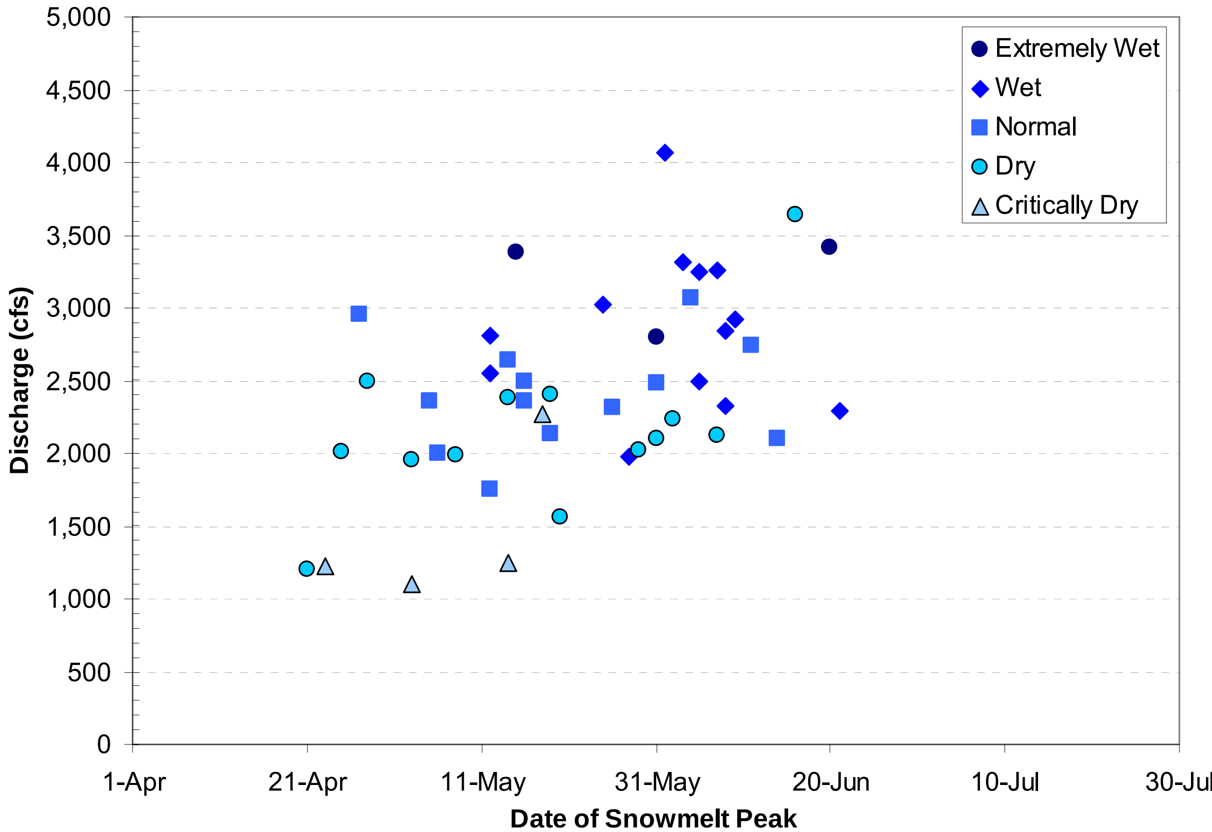
Cherry Valley Dam and Cherry Power Tunnel substantially lowered winter baseflows in all water years. Post-dam median winter baseflows were typically less than 15 cfs, with exception of brief periods during two anomalous water years (WY 1960 and 1977) when median winter baseflows were 89 cfs and 149 cfs, respectively.

Snowmelt peaks

As with the Tuolumne River at Hetch Hetchy gage, Cherry Creek also had relatively predictable snowmelt floods during all unimpaired water years (as compared to winter floods), that were likely geomorphically and ecologically important. The median snowmelt peaks ranged from 1,240 cfs in Critically Dry years to 3,380 cfs in Extremely Wet years, and varied within a very narrow range across all water year types (Figure 5-16). The biggest snowmelt peaks (3,420 cfs and 3,640 cfs) were only slightly higher than the median values.

Snowmelt flood magnitudes were substantially reduced by Cherry Valley Dam and Cherry Power Tunnel in all water year types, and were virtually eliminated in Normal, Dry, and Critically Dry years. Only 9 out of 45 years (mostly Wet and Extremely Wet years) had peaks that exceeded 1,000 cfs, and the maximum snowmelt peak was 2,800 cfs. In post-dam water years that still had a snowmelt hydrograph, the duration of the snowmelt hydrographs were also substantially shorter than in unimpaired water years. More substantially, at least 23 of the 45 post-dam water years of record had no annual flow variability at all, and flow releases were similar in magnitude to summer baseflows (10-20 cfs) throughout the entire water year. The snowmelt peak release in 2006 that helped support our reconnaissance studies was 5,040 cfs, which is the largest post-dam snowmelt peak or winter peak.

Figure 5-16: Timing of Unimpaired Spring Snowmelt Hydrograph for Cherry Creek near Hetch Hetchy, CA Gaging Station (USGS 11-277000).



Snowmelt recession

The unimpaired snowmelt recession on Cherry Creek also exhibited patterns similar to the Tuolumne River, with early and late recession phases of much different rates, a transitional inflection or "node" separating phases, and receding snowmelt limbs that occasionally extended through August and subsumed summer baseflow in wetter years (e.g., WY 1911, 1914).

With the substantial impacts to the snowmelt hydrograph caused by Cherry Valley Dam and Cherry Power Tunnel, the snowmelt recession was also reduced or eliminated in most water years. In post-dam water years that still had a snowmelt hydrograph, the ascension and recession rates were artificially steep, the snowmelt duration was significantly curtailed compared to unimpaired conditions.

5.5.5 Eleanor Creek near Hetch Hetchy Hydrograph Components

Quantification of hydrograph components for unimpaired, post-dam with no diversion, and post-dam with diversion are summarized in Table 5-15, Table 5-16, and Table 5-17, respectively, and described below.

Summer and fall baseflows

Unimpaired summer and fall baseflows were much lower in Eleanor Creek than in the Tuolumne River, due to the smaller drainage basin and higher elevation (less soil and groundwater contribution). Median baseflows generally remained below 10 cfs in summer and 16 cfs in fall in all water year types, but did not exhibit a distinct pattern of diminished baseflow magnitude with drier water year type. Maximum summer baseflows ranged from 16 to 35 cfs. Maximum unimpaired fall baseflows were influenced by both a short period of record, anomalies in the computed unimpaired data, and by small storms producing elevated runoff. Only the “measured unimpaired” data (WY 1910 to 1918) were used to estimate fall baseflows, which resulted in a range of 3 to 103 cfs.

Construction of the dam in 1918 significantly increased summer and fall baseflows, as water retained in the reservoir during snowmelt was released downstream for consumption for the post-dam, no diversion period (1918-1960). The post-dam, no diversion median summer baseflows ranged from 58 cfs in Critically Dry years to 113 cfs in Extremely Wet years. Following the onset of diversions in 1961, summer and fall baseflows were reduced to magnitudes comparable to unimpaired levels. Median summer baseflows ranged from 15 to 21 cfs, with minimum and maximum baseflows ranging from <1cfs to 100 cfs. During the post-dam with diversion period of record, water year type appears to have a larger influence on baseflows. Median summer and fall baseflows now range from 15-21 cfs and 5-9 cfs, respectively. Minimum baseflows (during pumping) are set at 20 and 10 cfs for August and September, respectively, and 10 and 5 cfs for October and November, respectively, based on the 1985 Flow Stipulation (Table 5-4). When no pumping is occurring, minimum baseflows are 15.5 cfs for August and September, and 5 cfs for October and November (Table 5-4).

Winter floods

Winter floods occurred in most water year types during the pre-dam period and in the computed unimpaired data, but most water year types also had several years in which no winter floods occurred. Occurrence and magnitude of winter floods was moderately correlated with water year type. The median winter flood ranged from 470 to 7,200 cfs; the maximum (daily average) winter flood was 14,800 cfs (which was the computed unimpaired 1997 flood).

The expansion of Lake Eleanor in 1918 had a greater effect on the magnitude and frequency of winter flood peaks than on snowmelt peaks (discussed below), particularly the early and mid-winter peaks. When several winter floods occurred in succession (e.g., WY 1943 and 1945), Lake Eleanor filled through the winter, and late-winter floods passed relatively unimpaired or only partially diminished. Because of the reduction or elimination of early winter floods which were typically the larger rain-on-snow events, the overall magnitude of post-dam, pre-diversion floods was reduced, and median peaks generally remained below 6,000 cfs.

The post-dam with diversion winter floods were again reduced in magnitude and frequency below Lake Eleanor. Most Normal, Dry, and Critically Dry water years had no winter floods. Only ten of 46 water years had winter floods that exceeded 400 cfs, eight of which were in Extremely Wet or Wet years (compared with 23 of 56 unimpaired water years with winter floods).

Winter baseflows

Pre-dam winter baseflows had median values ranging from 73 to 190 cfs, with only moderate variability within water year types. For example the highest variability was in Wet years with minimum and maximum values of 20 and 198 cfs, respectively. The post-dam, no-diversion period of record indicates median winter baseflows were not altered significantly during Normal and wetter years, but many drier water years had dramatically reduced winter baseflows (below 22 cfs). With the ability to divert water from Lake Eleanor to Cherry Valley Dam, the post-diversion winter baseflows were drastically reduced, and typically remain between 5-10 cfs. Only the wettest of Extremely Wet and Wet years have median winter baseflows that exceed 10 cfs.

Snowmelt peaks

Unimpaired snowmelt peaks were usually much lower magnitude than winter peaks, but most unimpaired water years had a distinct snowmelt hydrograph component. Whereas median snowmelt peaks in Critically Dry years may have barely exceeded 500 cfs (e.g., computed unimpaired WY 1939 and WY 1947), wetter years had snowmelt peaks ranging as high as 5,400 cfs and frequently over 1,500 cfs.

Similar to the late-winter flood component, the snowmelt flood peak magnitude was not significantly reduced by the enlargement of Lake Eleanor in 1918. In most water years, the combination of winter baseflows, winter floods, and early spring snowmelt filled Lake Eleanor, such that the magnitude and timing of the post-dam snowmelt floods were comparable or identical to unimpaired conditions. Following construction of diversion facilities, the snowmelt peak magnitude was reduced, but primarily in Dry and Critically Dry years. Extremely Wet, Wet, and some Normal water years still retained a snowmelt peak, with median and maximum peak values between 1,000 and 5,000 cfs.

As mentioned above, the early stages of snowmelt runoff were often captured by a drawn-down reservoir, delaying the onset of and the snowmelt runoff below the dam. The snowmelt ascension was then often artificially rapid, with early snowmelt peaks lost, and flows often ascended directly to the peak (e.g., WY 1963 and WY 1983).

Despite the relatively modest changes to Extremely Wet and Wet snowmelt peaks, the dam and diversion facilities have dramatically altered the hydrographs in Normal, Dry, and Critically Dry years. In those water year types, daily average flow did not exceed 500 cfs in 18 of 46 years, and in Dry and Critically Dry years, only 3 in 18 years exceeded 500 cfs. Many of those years had year-round flat-lined hydrographs, with extremely low baseflows (5-20 cfs) and no annual flow variation (WY's 1961, 1964, 1966, 1971, 1972, 1976, 1977, 1985, 1989, 1990-92, 2001, and 2002).

The timing of the unimpaired snowmelt peak was consistently earlier on Eleanor Creek than on the Tuolumne River, with median date of the peak falling in early May in all water year types. The earliest peak dates ranged from April 20 to May 1, whereas the latest peak dates extended through mid-June. In general, the effect of flow regulation and diversion was to broaden the range and considerably delay the timing of peak dates. Most post-diversion peaks occur after mid-May.

Snowmelt recession

The unimpaired snowmelt recession on Eleanor Creek was similar to the Tuolumne River snowmelt recession, with several phases of distinctly different recession rates and a transitional "node" identified in the annual hydrograph. Given that the timing of the peak was earlier on Eleanor Creek than the Tuolumne River, the end of the snowmelt recession also came earlier, usually by the end of July in Normal to Critically Dry years. However, the unimpaired August hydrograph in Extremely Wet and Wet years often exhibited a slow descent from 400-500 cfs down to summer baseflows by the end of August (e.g., WY's 1911, 1914-1917). This flow magnitude must have preserved cold water temperatures during typically the hottest summer month.

As described above, the enlargement of Lake Eleanor did not significantly alter the snowmelt hydrograph. Following the onset of flow diversions, the snowmelt recession was impacted, but more so in drier water year types. The water years in which the computed unimpaired hydrographs overlap with impaired with-diversion hydrographs (since WY 1997) demonstrate modest alterations in the snowmelt recession, with steeper recession rates and earlier onset of summer baseflows (e.g., WY 2005).

Table 5-10: Tuolumne River Hydrograph Components for Unimpaired Conditions at the Tuolumne River near Hetch Hetchy Gaging Station (USGS 11-276500).

Hydrograph Component	WATER YEAR TYPE				
Hydrograph Component Probabilty of Exceedence	Extremely Wet 0%-10%	Wet 10%-35%	Normal 35%-65%	Dry 65%-90%	Critically Dry 90%-100%
Number of Water Years	10	25	25	25	10
Average Daily Flow (cfs)	1,724	1,089	789	650	671
Average Annual Yield (af)	1,308,686	984,378	725,949	502,294	342,110
Maximum Annual Yield (af)	1,695,876	1,320,422	883,761	641,700	485,476
Minimum Annual Yield (af)	1,076,281	740,555	527,556	366,053	203,996
Fall Baseflows (Oct 1 - Nov 15)					
Median	77	74	53	56	67
Minimum	19	11	13	14	37
Maximum	704	422	235	281	405
Winter Baseflows (Dec 10 - Mar 20)					
Median	510	472	294	196	123
Minimum	381	208	32	41	28
Maximum	726	813	415	340	349
Winter Floods (Dec 10 - Mar 20)					
Average Peak Magnitude	12,188	4,012	2,623	1,637	690
Median Peak Magnitude	6,381	2,207	1,616	852	700
Minimum	2,613	715	722	379	199
Maximum	37,001	24,973	14,624	10,457	1,135
Snowmelt Floods (Apr 20 - Jul 20)					
Average Peak Magnitude	10,385	9,021	7,559	6,132	4,045
Median Peak Magnitude	10,722	8,569	7,575	5,309	3,872
Minimum	7,970	5,774	5,485	2,987	2,537
Maximum	12,871	15,249	11,043	12,531	6,485
Median Date of Peak	17-Jun	5-Jun	31-May	20-May	15-May
Earliest Peak	14-May	16-May	6-May	21-Apr	3-May
Latest Peak	9-Jul	2-Jul	18-Jun	16-Jun	19-Jun
Summer Baseflows (Aug 15 - Sep 30)					
Baseflow Median	194	99	56	43	58
Minimum	82	45	6	18	3
Maximum	700	426	111	90	177

Table 5-11: Tuolumne River Hydrograph Components for Post-Dam Conditions With No Diversion at the Tuolumne River near Hetch Hetchy Gaging Station (USGS 11-276500).

	WATER YEAR TYPE				
Hydrograph Component *Probabilty of Exceedence*	***Extremely Wet*** *0%-10%*	***Wet*** *10%-35%*	***Normal*** *35%-65%*	***Dry*** *65%-90%*	***Critically Dry*** *90%-100%*
Number of Water Years	2	12	13	13	4
Average Daily Flow (cfs)	1,571	1,238	1,003	765	579
Average Annual Yield (af)	1,138,674	897,174	726,137	553,983	419,476
Maximum Annual Yield (af)	1,151,062	1,095,213	869,347	624,462	462,768
Minimum Annual Yield (af)	1,126,286	709,539	563,372	441,283	374,352
Fall Baseflows (Oct 1 - Nov 15)					
Median	647	733	744	736	703
Minimum	565	551	345	602	685
Maximum	728	746	772	768	760
Winter Baseflows (Dec 10 - Mar 20)					
Median	693	694	723	689	520
Minimum	640	445	219	125	236
Maximum	745	1,265	766	769	706
Winter Floods (Dec 10 - Mar 20)					
Average Peak Magnitude	824	1,203	748	748	575
Median Peak Magnitude	824	760	772	745	682
Minimum	822	565	410	628	176
Maximum	825	4,110	860	875	760
Snowmelt Floods (Apr 20 - Jul 20)					
Average Peak Magnitude	9,230	7,258	6,125	3,673	1,555
Median Peak Magnitude	9,230	7,440	5,840	3,110	1,250
Minimum	7,860	4,730	3,670	763	670
Maximum	10,600	11,000	7,830	8,610	3,050
Median Date of Peak	16-Jun	12-Jun	14-Jun	14-Jun	5-Jul
Earliest Peak	4-Jun	25-May	21-May	28-Apr	21-Jun
Latest Peak	29-Jun	6-Jul	28-Jun	17-Jul	20-Jul
Summer Baseflows (Aug 15 - Sep 30)					
Baseflow Median	738	736	736	718	375
Minimum	731	602	552	578	33
Maximum	745	912	1,240	1,320	730

Table 5-12: Tuolumne River Hydrograph Components for Post-Dam Conditions with Diversion at the Tuolumne River near Hetch Hetchy Gaging Station (USGS 11-276500).

	WATER YEAR TYPE				
Hydrograph Component	*Extremely Wet*	*Wet*	*Normal*	*Dry*	*Critically Dry*
Probabilty of Exceedence	*0%-10%*	*10%-35%*	*35%-65%*	*65%-90%*	*90%-100%*
Number of Water Years	6	9	9	9	5
Average Daily Flow (cfs)	947	578	267	82	68
Average Annual Yield (af)	685,444	418,987	193,408	59,091	49,567
Maximum Annual Yield (af)	1,037,498	594,123	275,278	112,203	82,163
Minimum Annual Yield (af)	489,590	257,228	88,026	45,189	35,865
Fall Baseflows (Oct 1 - Nov 15)					
Median	48	46	40	53	40
Minimum	35	36	33	34	36
Maximum	60	73	66	68	107
Winter Baseflows (Dec 10 - Mar 20)					
Median	95	52	48	42	38
Minimum	35	38	30	35	34
Maximum	133	140	61	61	61
Winter Floods (Dec 10 - Mar 20)					
Average Peak Magnitude	2,803	228	92	137	52
Median Peak Magnitude	452	147	71	69	53
Minimum	167	80	48	51	38
Maximum	13,800	736	161	373	68
Snowmelt Floods (Apr 20 - Jul 20)					
Average Peak Magnitude	8,537	6,210	4,098	623	129
Median Peak Magnitude	8,765	6,500	3,730	165	110
Minimum	5,080	3,420	1,040	82	84
Maximum	11,400	9,640	6,950	2,950	244
Median Date of Peak	28-Jun	12-Jun	9-Jun	10-Jun	14-Jul
Earliest Peak	15-May	17-May	27-May	1-May	23-Apr
Latest Peak	10-Jul	2-Jul	28-Jun	19-Jul	20-Jul
Summer Baseflows (Aug 15 - Sep 30)					
Baseflow Median	104	85	110	75	78
Minimum	90	32	74	34	75
Maximum	137	124	163	119	106

Table 5-13: Cherry Creek Hydrograph Components for Unimpaired Conditions at the Cherry Creek near Hetch Hetchy Gaging Station (USGS 11-277000).

	WATER YEAR TYPE				
Hydrograph Component Probabilty of Exceedence	Extremely Wet 0%-10%	Wet 10%-35%	Normal 35%-65%	Dry 65%-90%	Critically Dry 90%-100%
Number of Water Years	5	15	15	15	4
Average Daily Flow (cfs)	609	508	384	288	181
Average Annual Yield (af)	440,678	368,327	278,315	196,823	130,979
Maximum Annual Yield (af)	468,704	766,273	366,748	298,226	163,801
Minimum Annual Yield (af)	391,494	305,509	223,009	160,449	97,705
Fall Baseflows (Oct 1 - Nov 15)					
Median	6	15	7	5	5
Minimum	2	0	1	1	3
Maximum	16	41	48	18	9
Winter Baseflows (Dec 10 - Mar 20)					
Median	205	153	162	91	93
Minimum	181	92	66	45	60
Maximum	243	265	182	161	176
Winter Floods (Dec 10 - Mar 20)					
Average Peak Magnitude	8,959	1,463	1,669	731	508
Median Peak Magnitude	7,000	1,440	1,360	582	528
Minimum	1,483	483	432	150	190
Maximum	22,841	3,000	4,450	2,560	788
Snowmelt Floods (Apr 20 - Jul 20)					
Average Peak Magnitude	3,090	2,879	2,497	2,191	1,463
Median Peak Magnitude	3,380	2,920	2,480	2,120	1,240
Minimum	2,464	1,980	1,750	1,200	1,100
Maximum	3,420	10,903	3,233	3,640	2,270
Snowmelt Recession					
Median Date of Peak	4-Jun	5-Jun	19-May	19-May	8-May
Earliest Peak	15-May	12-May	27-Apr	21-Apr	23-Apr
Latest Peak	20-Jun	21-Jun	14-Jun	16-Jun	18-May
Summer Baseflows (Aug 15 - Sep 30)					
Baseflow Median	14	5	6	2	1
Minimum	13	3	1	0	0
Maximum	26	24	13	6	7

FINAL

Table 5-14: Cherry Creek Hydrograph Components for Post-Dam Conditions with Diversion at the Cherry Creek below Valley Dam Gaging Station (USGS 11-277300).

Hydrograph Component Probabilty of Exceedence	WATER YEAR TYPE Extremely Wet 0%-10%	Wet 10%-35%	Normal 35%-65%	Dry 65%-90%	Critically Dry 90%-100%
Number of Water Years	6	10	11	12	6
Average Daily Flow (cfs)	96	31	18	24	45
Average Annual Yield (af)	69,695	22,578	13,047	17,387	32,762
Maximum Annual Yield (af)	140,850	60,250	38,910	136,244	93,453
Minimum Annual Yield (af)	26,988	6,317	5,628	5,359	5,125
Fall Baseflows (Oct 1 - Nov 15)					
Median	5	5	6	6	6
Minimum	5	4	3	4	5
Maximum	7	160	8	102	6
Winter Baseflows (Dec 10 - Mar 20)					
Median	10	8	7	6	6
Minimum	8	5	6	5	5
Maximum	13	10	9	89	149
Winter Floods (Dec 10 - Mar 20)					
Average Peak Magnitude	262	43	23	43	37
Median Peak Magnitude	54	36	20	9	11
Minimum	24	10	9	6	6
Maximum	1,350	127	54	258	160
Snowmelt Floods (Apr 20 - Jul 20)					
Average Peak Magnitude	1,641	850	443	254	132
Median Peak Magnitude	1,685	736	435	18	86
Minimum	38	16	16	14	13
Maximum	2,830	2,680	1,040	1,810	415
Snowmelt Recession					
Median Date of Peak	2-Jul	28-Jun	22-Jun	10-Jul	12-Jul
Earliest Peak	19-Jun	17-May	5-Jun	28-May	1-Jun
Latest Peak	10-Jul	20-Jul	20-Jul	20-Jul	20-Jul
Summer Baseflows (Aug 15 - Sep 30)					
Baseflow Median	15	16	15	16	93
Minimum	11	14	13	12	12
Maximum	16	17	17	18	177

Table 5-15: Eleanor Creek Hydrograph Components for Unimpaired Conditions at the Eleanor Creek near Hetch Hetchy Gaging Station (USGS 11-278000).

Hydrograph Component	WATER YEAR TYPE				
	Extremely Wet	Wet	Normal	Dry	Critically Dry
Probabilty of Exceedence	0%-10%	10%-35%	35%-65%	65%-90%	90%-100%
Number of Water Years	6	15	16	15	4
Average Daily Flow (cfs)	376	291	226	160	107
Average Annual Yield (af)	272,288	211,003	163,850	115,675	77,685
Maximum Annual Yield (af)	323,124	280,357	208,600	194,766	103,912
Minimum Annual Yield (af)	229,058	176,115	122,042	84,224	58,310
Fall Baseflows (Oct 1 - Nov 15)					
Median	6	16	0	8	3
Minimum	1	0	-5	7	3
Maximum	12	103	99	9	3
Winter Baseflows (Dec 10 - Mar 20)					
Median	190	155	127	89	73
Minimum	140	89	20	51	61
Maximum	276	225	198	179	152
Winter Floods (Dec 10 - Mar 20)					
Average Peak Magnitude	7,201	1,257	1,550	662	470
Median Peak Magnitude	7,253	1,375	974	686	487
Minimum	1,558	370	423	134	177
Maximum	14,848	3,427	4,517	1,505	730
Snowmelt Floods (Apr 20 - Jul 20)					
Average Peak Magnitude	1,720	1,827	1,389	1,101	592
Median Peak Magnitude	1,762	1,590	1,197	1,017	530
Minimum	1,190	634	925	572	392
Maximum	2,223	5,416	2,555	2,133	915
Snowmelt Recession					
Median Date of Peak	14-May	12-May	15-May	3-May	8-May
Earliest Peak	20-Apr	28-Apr	26-Apr	20-Apr	1-May
Latest Peak	12-Jun	10-Jun	4-Jun	16-Jun	18-May
Summer Baseflows (Aug 15 - Sep 30)					
Baseflow Median	8	4	9	6	2
Minimum	-12	-11	-20	-17	-8
Maximum	21	16	35	29	17

Table 5-16: Eleanor Creek Hydrograph Components for Post-Dam Conditions With No Diversion at the Eleanor Creek near Hetch Hetchy Gaging Station (USGS 11-278000).

			WATER YEAR TYPE		
Hydrograph Component Probabilty of Exceedence	Extremely Wet 0%-10%	Wet 10%-35%	Normal 35%-65%	Dry 65%-90%	Critically Dry 90%-100%
Number of Water Years	2	11	13	12	3
Average Daily Flow (cfs)	354	284	223	156	99
Average Annual Yield (af)	256,713	205,938	161,217	112,954	71,860
Maximum Annual Yield (af)	257,733	231,692	187,726	125,609	81,204
Minimum Annual Yield (af)	255,694	180,286	123,913	93,924	62,561
Fall Baseflows (Oct 1 - Nov 15)					
Median	113	72	72	82	18
Minimum	88	4	5	4	0
Maximum	137	147	143	182	119
Winter Baseflows (Dec 10 - Mar 20)					
Median	257	104	114	58	34
Minimum	154	34	3	3	22
Maximum	359	235	211	133	56
Winter Floods (Dec 10 - Mar 20)					
Average Peak Magnitude	5,970	823	1,029	190	215
Median Peak Magnitude	5,970	750	451	135	134
Minimum	4,450	162	91	76	133
Maximum	7,490	2,570	3,710	611	378
Snowmelt Floods (Apr 20 - Jul 20)					
Average Peak Magnitude	1,780	1,531	1,244	1,037	481
Median Peak Magnitude	1,780	1,640	1,180	915	468
Minimum	1,400	657	832	469	384
Maximum	2,160	2,160	2,000	2,030	590
Snowmelt Recession					
Median Date of Peak	19-May	24-May	9-May	10-May	24-Apr
Earliest Peak	15-May	28-Apr	26-Apr	22-Apr	21-Apr
Latest Peak	23-May	7-Jun	4-Jun	16-Jun	2-May
Summer Baseflows (Aug 15 - Sep 30)					
Baseflow Median	58	110	118	118	72
Minimum	30	14	7	16	4
Maximum	85	160	140	180	117

Table 5-17: Eleanor Creek Hydrograph Components for Post-Dam Conditions with Diversion at the Eleanor Creek near Hetch Hetchy Gaging Station (USGS 11-278000).

Hydrograph Component			WATER YEAR TYPE		
	Extremely Wet	Wet	Normal	Dry	Critically Dry
Probabilty of Exceedence	0%-10%	10%-35%	35%-65%	65%-90%	90%-100%
Number of Water Years	6	11	11	12	6
Average Daily Flow (cfs)	256	155	64	23	23
Average Annual Yield (af)	185,451	112,660	46,710	16,983	16,486
Maximum Annual Yield (af)	231,919	201,725	105,989	51,896	34,447
Minimum Annual Yield (af)	125,926	63,754	9,679	3,763	3,427
Fall Baseflows (Oct 1 - Nov 15)					
Median	9	6	5	6	6
Minimum	4	0	1	2	4
Maximum	91	49	13	42	17
Winter Baseflows (Dec 10 - Mar 20)					
Median	8	7	6	6	6
Minimum	5	4	4	5	5
Maximum	258	262	38	9	7
Winter Floods (Dec 10 - Mar 20)					
Average Peak Magnitude	3,208	1,741	662	32	55
Median Peak Magnitude	379	1,540	13	13	17
Minimum	20	11	6	7	5
Maximum	15,100	4,140	5,310	141	207
Snowmelt Floods (Apr 20 - Jul 20)					
Average Peak Magnitude	1,968	1,823	1,052	242	220
Median Peak Magnitude	1,785	1,160	1,200	24	185
Minimum	1,000	825	225	13	13
Maximum	3,510	5,200	2,640	924	478
Snowmelt Recession					
Median Date of Peak	14-May	26-May	29-May	2-Jul	6-Jun
Earliest Peak	20-Apr	12-May	8-May	23-Apr	20-Apr
Latest Peak	16-Jun	19-Jun	29-Jun	20-Jul	20-Jul
Summer Baseflows (Aug 15 - Sep 30)					
Baseflow Median	21	20	16	16	15
Minimum	15	11	12	1	0
Maximum	47	102	24	20	20

5.5.6 Cherry Creek Above and Below Holm Powerhouse

McBain and Trush did not analyze hydrograph components on Cherry Creek above and below Holm Powerhouse, but instead focused on describing the effects of Holm Powerhouse on flows to the Holm Reach of lower Cherry Creek and the Lumsden Reach of the Tuolumne River. 15-minute stage and discharge data were obtained from USGS for 2004 (a representative Dry water year) and 2005 (a representative Wet water year) for the following two stations: 1) Cherry Creek near Hetch Hetchy, above Dion R. Holm Powerhouse (USGS 11-278300) and 2) Cherry Creek below Holm Powerhouse (USGS 11-278400). This initial analysis isolates the effect of the Holm Powerhouse on flows, and ignores any effects of Cherry Lake and Lake Eleanor regulation from storage. A subset of the data is illustrated in the section below, and all stage and discharge data reviewed are included in Appendix D.

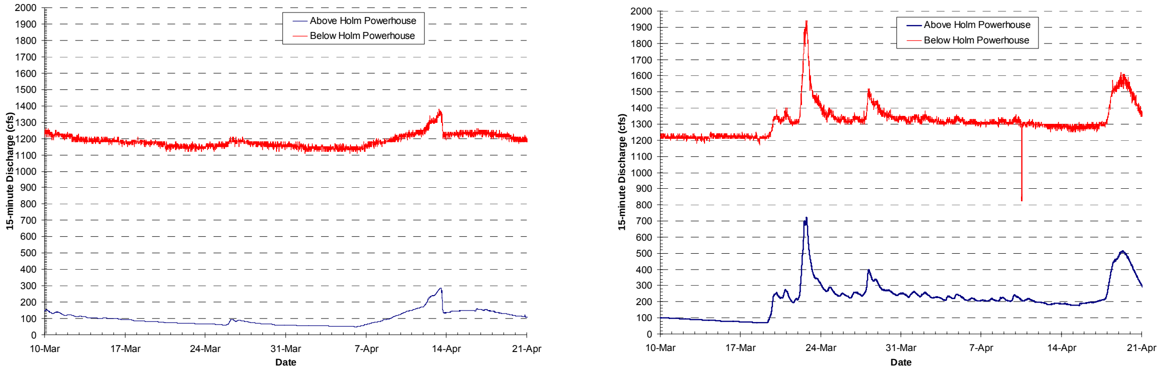
Discharge data for the stations above and below the Powerhouse was overlaid for each month of the two water years. However, some adjustment of stage data was required to improve the comparison. The USGS stage data sets zero (0) stage at different elevations, such that a low flow at one station may be 1.0 foot stage, and the same flow at the other station may be 7.5 foot stage. Therefore, USGS stage readings were adjusted to a common base stage for both stations above and below Holm Powerhouse to reduce possible stage differences due to the rating curves. The lowest common flow above and below the Powerhouse was found to be 23 cfs for the 2004 water year. Stage height on the date and time at which discharge was 23 cfs was then subtracted from all the stage data. This created adjusted stage data wherein the water surface elevation on the date and time of the 23 cfs flow became the zero (0) foot stage for 2004 at both stations. The same procedure was also done to the 2005 stage data, again using 23 cfs as the common flow. The adjusted stage data from both stations was then overlaid on top of each other for each of the two years in a similar manner as the discharge data.

This stage and discharge comparison is not a comprehensive analysis of all water years; it is more aptly described as a semi-quantitative narrative that provides insight on how the Holm Powerhouse is managed seasonally, for wetter and drier years, as well as the manifestation of the management on stage and discharge changes on lower Cherry Creek. Because flows contributed by the mainstem Tuolumne River (as measured by the Tuolumne River below Early Intake gage 11-276900) are often low (100 to 150 cfs), much of the stage and discharge variability observed on lower Cherry Creek due to Powerhouse management are translated (albeit buffered by Tuolumne River flows and a wider Tuolumne River channel) to the Tuolumne River below the Cherry Creek confluence.

The data suggest three different operational patterns of flow fluctuation from Holm Powerhouse: (1) High diversions with zero or low fluctuations in the later winter to spring months when Cherry Lake is full, (2) low or zero diversion and no fluctuation in the later summer and early fall months when Cherry Lake is low, and (3) High fluctuation and high diversion during the late spring and summer months when there is both adequate inflow to and storage in Cherry Lake, power peaking demand is high, and recreational use is high.

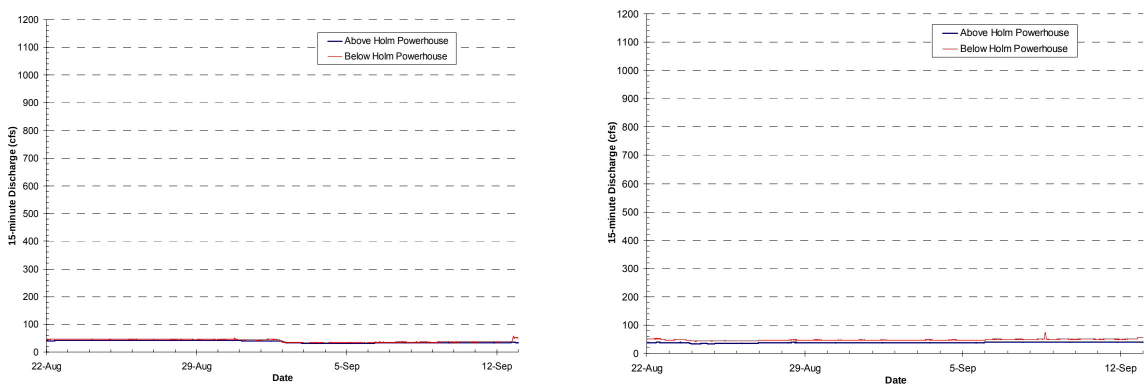
When Cherry Lake is full, the Powerhouse is managed at a steady state, with little to no fluctuation and often at maximum capacity because there is minimal storage space in the lake to allow for fluctuations, inflows are high, and spills or downstream releases are avoided. This type of operation occurred from October 18 through July 30 during the example wet year, with discharge from the Powerhouse ranging from 600 to 1,100 cfs. In the dry year, this type of operation occurs over a much shorter period (from March 2 through June 10 in the example dry year) with discharge from the Powerhouse generally around 1,000 cfs (Figure 5-17). During the dry year, Cherry Lake is full for a shorter time, in turn reducing the amount of time at a steady state as well as the amount of discharge from the Powerhouse.

Figure 5-17: Cherry Creek Above and Below Holm Powerhouse (USGS 11-278300 and 11-278400, Respectively). 15-minute Discharge Plot for March 10 through April 20, 2004. Dry Water Year (2004) on Left; Wet Water Year (2005) on Right.



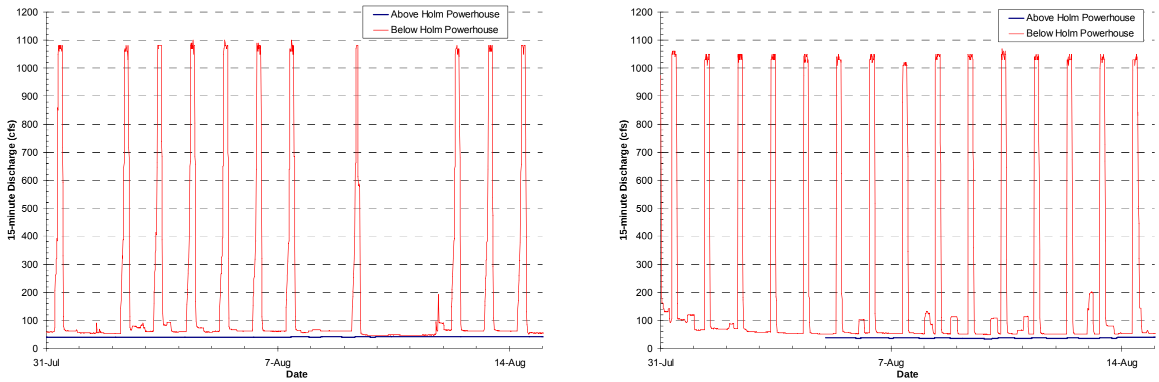
When the lake storage is low, diversions stop fluctuating, are low and may shut off altogether (Figure 5-18). This likely occurs for a shorter duration during the wetter years (August 22 – September 12 in the 2005 example) than during the drier years (August 15 – October 17 in the 2004 example). During wetter years, inflow into Cherry Lake is bigger and longer duration, such that higher and longer diversions can occur while maintaining storage in Cherry Lake. Conversely, during drier years, inflow is smaller and shorter duration, such that the diversion amount and duration must be shortened to maintain storage in Cherry Lake.

Figure 5-18: Cherry Creek Above and Below Holm Powerhouse (USGS 11-278300 and 11-278400, Respectively). 15-minute Discharge Plot for August 22 – September 12. Dry Water Year (2004) on Left; Wet Water Year (2005) on Right.



The largest flow fluctuations occur at times of the year (for both wetter and drier years) when there is adequate inflow and storage, power peaking demands are high, and recreational use is high. Daily flow fluctuations of 1,100 cfs, equivalent to a 2.5 ft stage fluctuation, occurred from July 31 through August 21 during the wet year example. Daily flow fluctuations in the 400 to 1,000 cfs range occurred from October 1 through March 1 and again from June 11 through August 14 during the dry water year example. The data show that the maximum flow fluctuation is up to 1,100 cfs (Figure 5-19), which is greater than the maximum diversion capacity of 990 cfs described in Chapter 2. The purpose of these daily flow fluctuations is power generation during the winter months and both power generation and recreation (rafting) during the summer months. In the wet year, there is high enough inflow to Cherry Lake (and/or storage) to generate power without daily fluctuation during the winter months, but not during the summer. The lower flows in the dry year necessitate daily fluctuation throughout the winter and the summer months.

Figure 5-19: Cherry Creek Above and Below Holm Powerhouse (USGS 11-278300 and 11-278400, Respectively). 15-minute Discharge Plot for July 31 – August 14. Dry Water Year (2004) on Left; Wet Water Year (2005) on Right.

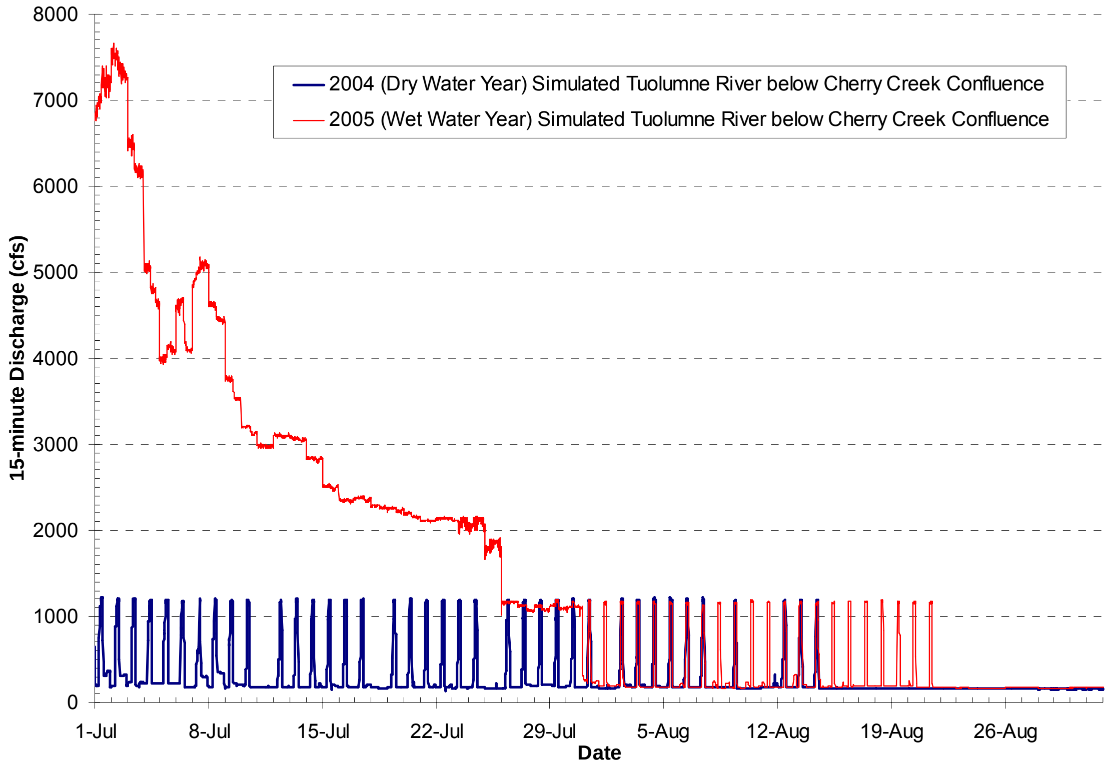


Periodic shutdowns of the diversion and Powerhouse occur due to maintenance at various times over any given year, and certain repeating days presumably when power peaking demand is lower. Review of longer-term daily average flow data do not show an obvious seasonal shutdown period for maintenance; however, review of daily shutdowns appear to occur once a week during dryer years and slightly less often during wetter years, and typically occurs on Sundays when recreational and power generation demands are lower.

5.5.7 Tuolumne River Immediately Downstream of Cherry Creek

Also, 15-minute discharge data were simulated for the Tuolumne River below Cherry Creek confluence (USGS 11-276900) by adding the 15-minute discharge data from Cherry Creek below Holm Powerhouse (USGS 11-278400) to the daily average flow data from the Tuolumne River below Cherry Creek confluence station. This data was simulated for July through August of 2004 (a representative dry year) and 2005 (a representative wet year) and then overlaid on top of each other (Figure 5-20). The data show that flow fluctuations from Cherry Creek (1,100 cfs) are much larger than the typical summer baseflows on the Tuolumne River (125 cfs for these two water years). The data also illustrate that high flow releases from Cherry Valley Dam and/or O'Shaughnessy Dam in wetter water years are larger than flow fluctuations. As shown in the previous section, Holm Powerhouse is run at steady conditions (no fluctuations) when Cherry Lake inflows are high and the lake is full, until inflows decrease and storage space is available to resume flow fluctuations (August 1 in the 2005 example). In contrast, flow fluctuation occurs much earlier in drier years because there is less inflow and more storage capacity in Cherry Lake.

Figure 5-20: Simulated 15-minute Discharge Data for Tuolumne River Below Cherry Creek Confluence (Sum of USGS 11-276900 and 11-278400). July – August for Dry (2004) and Wet (2005) Water Years.



Chapter 6 Synthesis of Available Information

Technical Memorandum #2 prepared by McBain & Trush and RMC Water and Environment summarized existing available information collected to date. Additional field observations were made in spring and summer 2006 focusing on the high flow releases provided by the SFPUC and natural high flows provided by the Extremely Wet water year. This section synthesizes existing available information with our 2006 field observations to refine hypotheses about how the river ecosystem historically functioned and how it change in order to guide additional monitoring priorities (Section 7), and eventually developing recommendations for operational adjustment to improve ecosystem function. The following section focuses on stream geomorphology, riparian vegetation, and priority analysis species (fish, amphibians, benthic macroinvertebrates, etc).

6.1 Eleanor Creek

6.1.1 Geomorphology

Sources of geomorphic information on Eleanor Creek are few. The primary geomorphic information sources are USGS topographic maps, USGS digital elevation model (DEM), and our 2006 field reconnaissance. The best quantitative information that provides insights to Eleanor Creek geomorphology is long-term USGS flow data at the Eleanor Creek near Hetch Hetchy gaging station (USGS 11-278000).

Based on our field reconnaissance and the USGS 10 meter grid DEM, a general overview of Eleanor Creek geomorphology was developed. First, glaciers during the Tioga glaciation (approximately 10,000 years ago) likely extended downstream to the confluence of Cherry Creek, resulting in extensive exposed granite, shallow soils, and sparse forested land above Lake Eleanor. Second, a pronounced feature of the Eleanor Creek profile (and most other streams draining the west side of the Sierra Nevada) is the nick point where the rapid incision of the streams into the uplifting Sierra Nevada range tapers off (Figure 6-1). The morphology of the valley and the stream is markedly different upstream and downstream of this transition. On Eleanor Creek, this location is approximately ¾ mile downstream of Eleanor Dam. Upstream of the nick point, the valley has been frequently glaciated, is broader and less confined, has shallow soils and exposed granitic bedrock, and is moderate gradient (2% to 3%). The dominant sediment delivery mechanism to the creek is granite block exfoliation and decomposed granitic sand delivery from wind and surface water flow. The stream channel morphology is largely shaped by historic glaciation rather than the stream itself: there are periodic lower gradient reaches separated by steep cascades over steep bedrock drops, as is observed at the Eleanor Dam site (Figure 6-2) and likely numerous other locations upstream. However, none of these glaciated bedrock drops were observed downstream of the dam site. The substrate upstream of the nick point is largely exposed granite bedrock and locally derived boulders, with some pockets of cobbles, gravel, and sand (Figure 6-3).

Downstream of the nick point, the channel morphology is largely dictated by fluvial processes of the stream itself, and less so than glacial processes. The channel is incised within the uplifting Sierra Nevada bedrock, is much steeper (>6%), and very confined by the valley walls. The dominant sediment delivery mechanism to the creek is landslides and rockfalls of fractured granitic blocks from the valley walls. Fires and timber management are very frequent downstream of Eleanor Dam, which likely increases fine sediment contribution to the stream. The steep confined channel easily transports fine sediment downstream, largely masking any morphologic response to this potential increase in fine sediment supply. The bed surface is typically a thin layer of large boulders on top of bedrock (Figure 6-4). There are several falls/cascades that create large pools downstream (Figure 6-5).

As described in Section 5, low magnitude floods in the 1.5 to 2.3-year flood recurrence have been substantially reduced, while the larger, less frequent floods greater than 5-year recurrence have been less impacted by flow regulation from Lake Eleanor. Therefore, bed mobility still occurs, but likely less frequently than pre-dam conditions. Based on our field reconnaissance, the frequency of high flows has remained sufficient to prevent riparian or upland vegetation encroachment into the low flow channel, and there does not appear to have been any morphologic effect on the channel from riparian vegetation encroachment (in contrast to Cherry Creek). Additionally, because Eleanor Dam is simply an enlarged natural lake, the sediment supply from the upper watershed was always trapped, thus the sediment supply to the project reach immediately downstream of Eleanor Dam has not changed. Lastly, during large floods, water and large wood appear to flow over the top of the dam, such that change in large wood supply to downstream reaches due to Eleanor Dam is likely small. Large wood accumulations were observed at several locations downstream of the dam (Figure 6-6). The net result is that the Eleanor Creek geomorphology appears to be functioning similarly to unregulated streams regionally.

Figure 6-1: Eleanor Creek Profile from USGS 10 m Digital Elevation Model Showing Increase in Channel Gradient ¾ mile Downstream of Eleanor Dam.

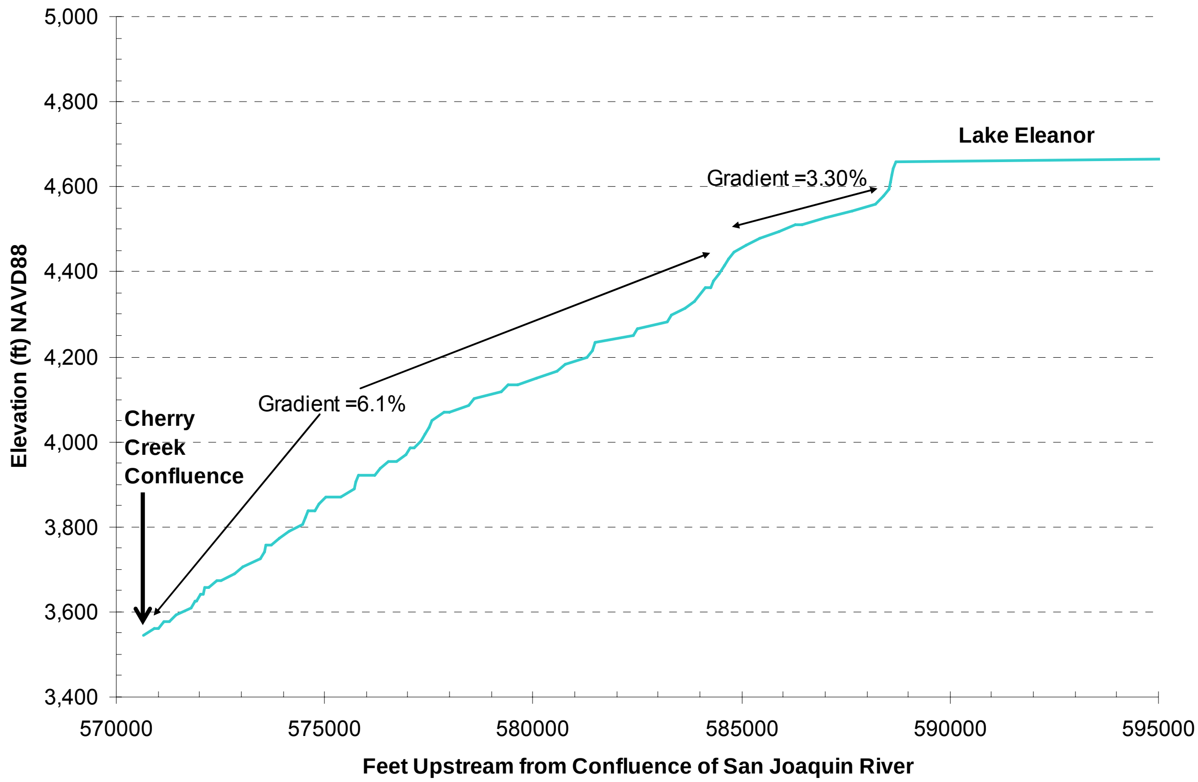


Figure 6-2: Eleanor Creek Looking Downstream from Eleanor Dam, Illustrating Steep Bedrock Drop Followed by Moderate Gradient, Less Confined Reach.

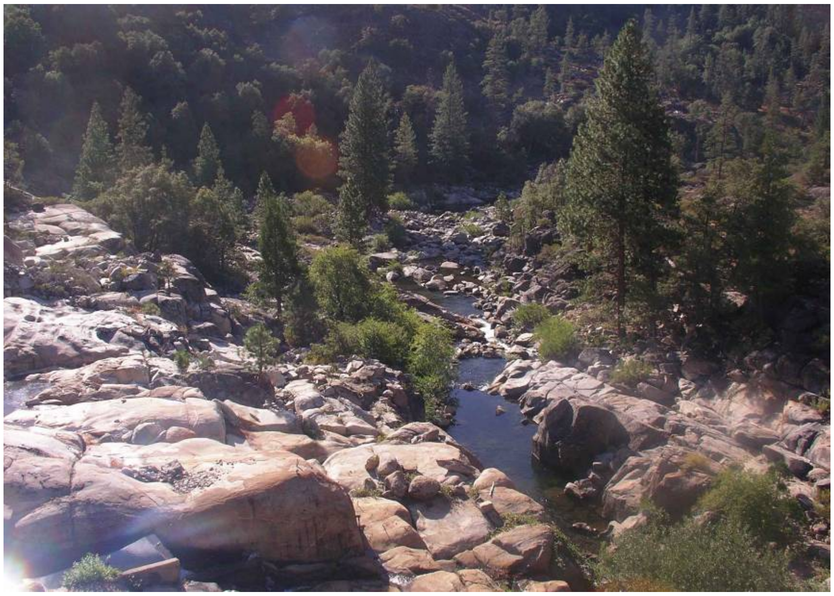


Figure 6-3: Eleanor Creek Looking Upstream and Downstream near USGS Gaging Station ¼ mile Downstream of Eleanor Dam, Illustrating Exposed Granite Bedrock Channel Bed with Granite Boulders (left photo) with Cobble/Gravel/Sand Pockets (right photo).

Figure 6-4: Lower Eleanor Creek Showing Valley Confinement, Steep Gradient, and Boulder Bed.

Figure 6-5: Large Pool at Top of Lower Eleanor Creek Canyon.

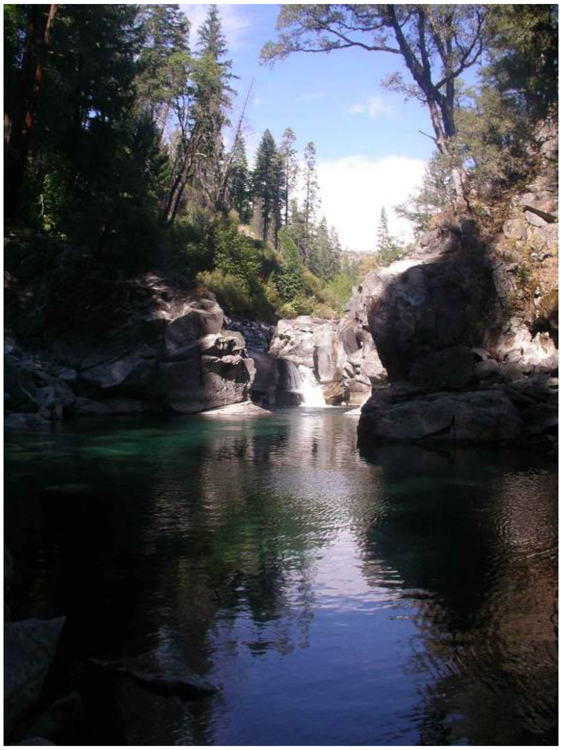


Figure 6-6: 1997 Flood Debris (19,500 cfs) at Eleanor Creek near Hetch Hetchy Gaging Station (USGS 11-278000) Approximately 20 ft Above Low Flow Water Surface (Left Photo), and 2005 Flood Debris (7,400 cfs) Downstream 1 Mile (Right Photo), Showing that Eleanor Creek Floods Move Entire Trees, Boulders, and Cobbles.

6.1.2 Water Temperature

Of all the reservoirs operated by the SFPUC, Lake Eleanor has likely caused the fewest changes to the downstream water temperature regime in Eleanor Creek. Under natural conditions, water temperatures in the stream were dictated by water temperatures in the epilimnion of the pre-dam Lake Eleanor. The outlet works of the post-dam Lake Eleanor is also in the epilimnion, such that post-dam water temperatures are likely very similar to those under pre-dam conditions. Under natural conditions, summer water temperatures below Lake Eleanor were likely at the upper end of rainbow trout tolerances (Moyle and Baltz 1981); under present conditions, water temperatures at the Eleanor Creek near Hetch Hetchy gaging station (USGS 11-278000) can exceed 70^{o} F (Appendix I). Perhaps the primary difference in water temperature between the pre-dam and post-dam period would be caused by reductions in the snowmelt hydrograph magnitude and duration, which may decrease the length of stream with preferable water temperatures in the spring and early summer.

6.1.3 Riparian Vegetation

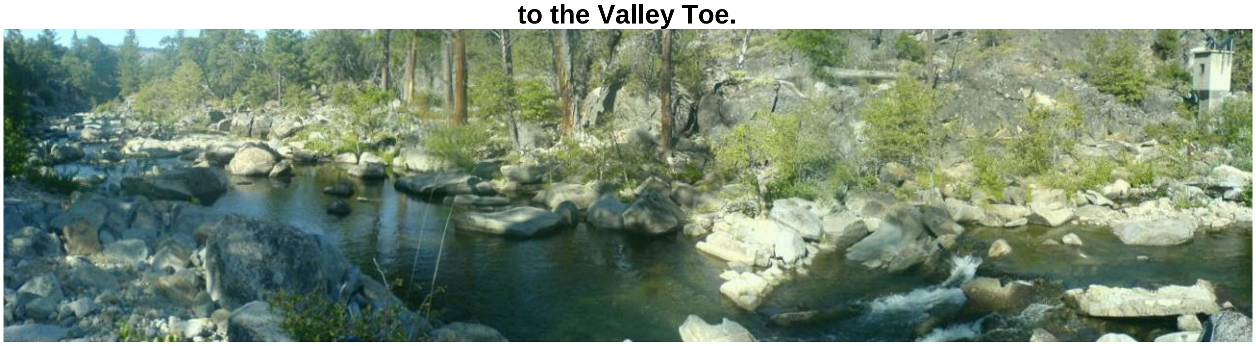
Information about riparian vegetation specifically related to Eleanor Creek below the dam is limited to the Yosemite National Park Vegetation Inventory; however the inventory was very broad and no local descriptions were included (TNC 1998). The relationship of riparian vegetation dynamics along Eleanor Creek below the dam to substrate, topography and hydrologic environments is described based on qualitative observations made during the 2006 field reconnaissance.

Technical Memo 2 (McBain & Trush and RMC Water and Environment 2006) emphasized that the greatest hydrologic impacts to Eleanor Creek have been in reducing flood peak magnitudes of the less than five-year recurrence flood. Due to the small storage capacity of Lake Eleanor, flood peaks still pass over the dam (i.e., those greater than 5-yr recurrence), scouring the channel and inhibiting riparian woody plant encroachment of the degree seen on Cherry Creek below Cherry Valley Dam. Based on our observations of other regulated and unregulated Sierra Nevada streams, impacts of Eleanor Dam operations on riparian vegetation were not obvious. No riparian encroachment was observed, evidence of frequent riparian woody plant scour was observed, and species diversity and location were comparable to unregulated Sierra Nevada streams. Riparian vegetation growing within the active channel was limited to widely spaced, small individual dusky willow (*Salix melanopsis*) shrubs, young white alders (*Alnus rhombifolia*), grasses, and sedges, reflecting an environment that experiences periodic high magnitude flood peaks. Mature white alders were inhibited from growing in the active channel. Adjacent to the active channel in the riparian upland transition, canyon live oak (*Quercus chrysolepis*) and conifers were generally restricted to where the valley toe met the river channel, above the extent of true riparian corridor conditions (Figure 6-7). Canyon live oak and conifers are presumably prevented from encroaching onto active surfaces by the occurrence of frequent and prolonged flood peaks.

Willow species richness is typically low on streams where the snowmelt hydrograph has been reduced or eliminated. Willow species richness along Eleanor Creek was relatively high compared to streams where the snowmelt hydrograph has been eliminated or reduced. Red willow (*Salix laevigata*) and arroyo willow (*S. lasiolepis*) were common, dusky willow was occasionally observed and narrowleaf willow (*S. exigua*) and shiny willow (*S. lucida* ssp. *lasiandra*) were rarely observed. The richness in willow species and the bank locations where they grow suggests that the snowmelt hydrograph was a stronger influence on vegetation pattern than the rainfall hydrograph. Arroyo willow commonality may indicate a subtle shift to increasing influence of the rainfall hydrograph compared to historical (i.e., pre-dam) conditions. Arroyo willow is the earliest seed disperser of the willows observed, and typically disperses its seeds in March and April (early at lower elevations) often before the snowmelt hydrograph begins to ascend.

The gradation in channel locations for observed species was consistent with observations along other unregulated rivers nearby (e.g., the Clavey River) and the individual woody plant species life histories. There was a strong gradation in the channel locations where the different woody riparian species grew (Figure 6-7). Riparian herbaceous species typically grew on lower bar surfaces close to the low water channel and mature woody riparian species grew on upper bar surfaces 3-4 ft above the summer water elevation. Arroyo willow was common 3-4 ft above the low water surface. White alder was also common, but large individuals (i.e., > 8 inches diameter at breast height) were restricted to channel margins near the toe of the valley slope or areas of hydraulic shadows in boulder gardens or bedrock outcrops (i.e., safe sites, or locations with a "guardian angel"). Dusky willow was occasionally observed within 1-2 ft of the low-water surface.

Figure 6-7: Riparian Vegetation Gradation in Eleanor Creek below Eleanor Dam. Note White Alder Growing at the Upper Active Channel Edge and Ponderosa Pine and Canyon Live Oak Restricted to the Valley Toe.



6.1.4 Analysis Species

Rainbow Trout

Documented fish fauna in Eleanor Creek and Lake Eleanor consists of rainbow trout, Sacramento sucker, and green sunfish (*Lepomis cyanellus*) (Baltz and Moyle 1984). The presence of fish in Lake Eleanor is likely the result of human introductions, since natural barriers downstream of Eleanor Dam would have prevented colonization of the reservoir site (formerly a natural lake) following the Pleistocene glaciations. Rainbow trout were stocked in Lake Eleanor as early as 1877 (Hubbs and Wallis 1948, as cited in Moyle and Baltz 1982).

The most complete study of fish habitat, abundance, and population structure in Eleanor Creek was conducted by Moyle and Baltz in 1981 to assess potential effects of pumping water from Lake Eleanor to Cherry Lake via the Eleanor-Cherry Diversion Tunnel on fish in Eleanor Creek and Lake Eleanor. This study included habitat quantification using the Instream Flow Incremental Methodology (IFIM), quantitative surveys of fish abundance and size at one site downstream of Eleanor Dam and in Lake Eleanor, and temperature monitoring in Eleanor Creek and Lake Eleanor (Table 6-1). Habitat modeling and fish surveys were limited to the 3/4-mile-long, moderate-gradient reach immediately downstream of Eleanor Dam.

Table 6-1: Fish Habitat and Abundance Surveys Available for Eleanor Creek.

Survey/Study	Comments	Report
Habitat quantification[a]	7 transects in a 154-foot reach 0.6 miles downstream of Eleanor Dam, calibrated for flows of 6 cfs, 20 cfs, and 24 cfs	Moyle and Baltz 1981
Trout abundance	Multiple pass-depletion electrofishing in a 108-ft reach during flows of 5 cfs	Moyle and Baltz 1981
Water temperature	June – Sept. 1981	Moyle and Baltz 1981
	Summer 2006 – present[b] USGS	

Footnotes:

a. Habitat included rainbow trout and Sacramento sucker.

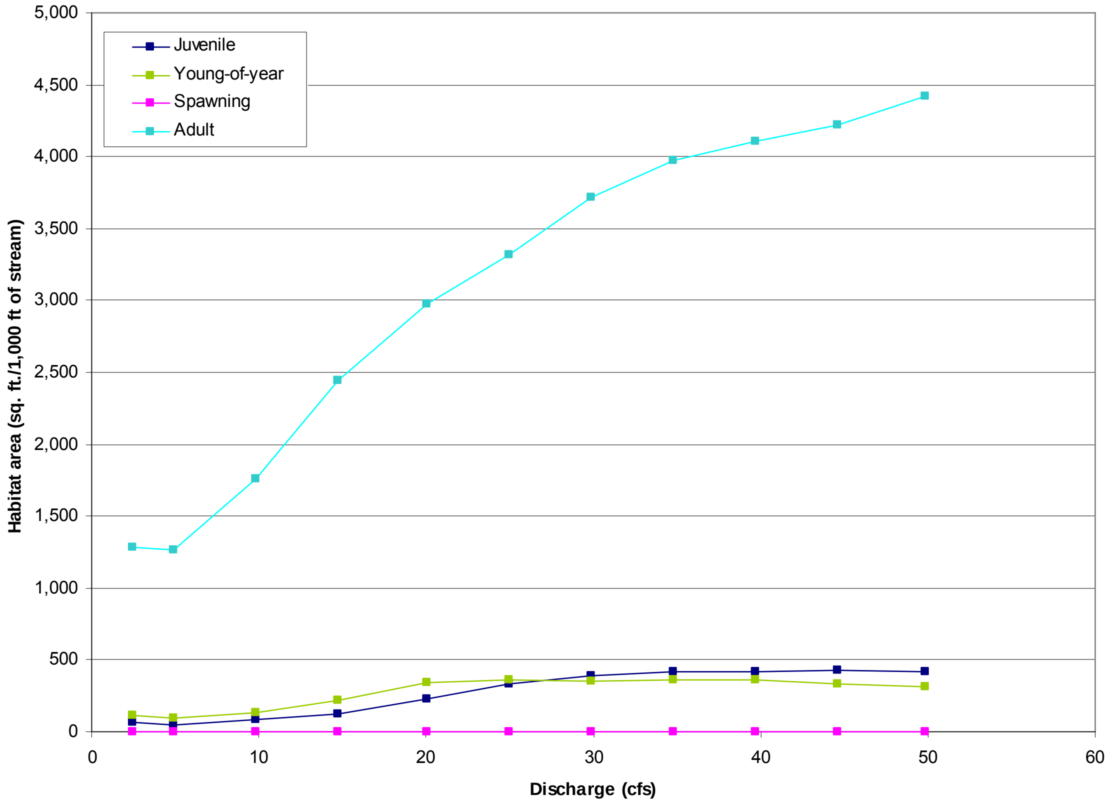
b. See Appendix I for data.

The habitat quantification was used to predict available rainbow trout[3] habitat area for adult holding, spawning, and juvenile and young-of-year rearing for flows ranging from 2.5 cfs to 50 cfs and was calibrated for flows of 6 cfs, 20 cfs, and 24 cfs. In reaches examined for the study, spawning habitat was limited to small gravel pockets, and no spawning habitat was present in the habitat quantification reach. The quantification, therefore, could not estimate spawning habitat area. The habitat quantification effort also could not be applied to the remainder of the Eleanor Creek Reach because it was unable to predict hydraulic relationships or habitat availability in the steeper channel reaches. Moreover, the habitat quantification did not include temperature as a parameter. The effects of water temperature on habitat suitability, therefore, were not reflected in the habitat quantification results. From these results, Moyle and Baltz (1981) concluded that: (1) adult habitat area responds dramatically to flow and continues to increase beyond the range of flows measured; (2) juvenile habitat area peaks at 45 cfs; and (3) young-of-year habitat area peaks at 25 cfs to 40 cfs (Figure 6-8).

The habitat quantification results represented only flow depth, flow velocity, and channel substrate; they did not reflect the effects of temperature on fish abundance and health nor relationships between flow and temperature. During late summer, water temperature in Eleanor Creek can exceed the upper threshold for adult trout survival. Between July 15 and August 20, 1981, maximum daily water temperature downstream of Eleanor Dam approached 77°F (Figure 6-9) (Moyle and Baltz 1981). High water temperatures are due to a combination of low flows and epilimnionic releases from Lake Eleanor. Unlike many reservoirs, flow released from Lake Eleanor is from the epilimnion, the layer of water above the thermocline. Moyle and Baltz (1981) observed thermal stratification in the reservoir during late summer. Below the thermocline, which was at a depth of 46 ft to 52 ft, water temperature was 54°F; surface water temperature in the reservoir was 72°F to 75°F. The thermocline began breaking up by October 16, when reservoir surface temperature reached 54°F.

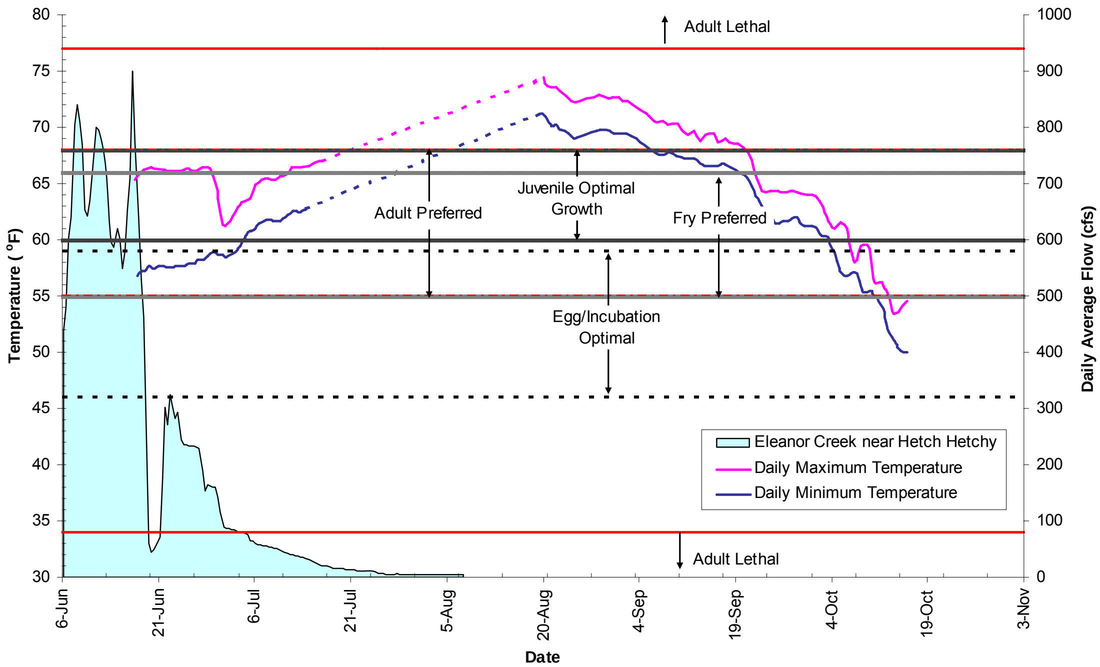
[3] The quantification also included habitat for Sacramento sucker.

Figure 6-8: Predicted Available Rainbow Trout Habitat Area in Eleanor Creek (Moyle and Baltz 1981).



Moyle and Baltz (1981) concluded that water temperature "may be the most important limiting factor for trout, especially in late summer." Given these temperatures, they concluded that the "potential exists for a summer kill of trout if warm days are combined with low flows, especially in Eleanor and lower Cherry creeks." In additional to direct mortality from chronic or acute exposure, high water temperatures can stunt fish growth. In Eleanor Creek, rainbow trout growth rate is among the poorest recorded for any Sierra stream (Snider and Linden 1981, as cited in Moyle and Baltz 1981), which Moyle and Baltz deduced is "no doubt due to excessively warm, but not critical, stream temperatures during much of the summer." Moyle and Baltz concluded that a minimum flow of at least 15 cfs during summer months was "crucial" for maintaining a viable trout population in Eleanor Creek. Moyle and Baltz (1981) also recommended more gradual reduction in flows after observing stranded fish after flow was reduced to 5 cfs in early summer.

Figure 6-9: Daily Minimum and Maximum Water Temperature in Eleanor Creek in Summer 1981 (Moyle and Baltz 1981) and Rainbow Trout Temperature Thresholds (Moyle and Marchetti 1992).



Trout abundance surveys indicated that adult trout density in Eleanor Creek (in 1981) was similar to densities observed in the Upper and Lower Cherry reaches. Observed density of trout > 2 in SL was 9.3 fish/1,000 ft^2 (Moyle and Baltz 1981). Very few young-of-year trout (< 2 in SL) were captured; density was 1 fish/1,000 ft^2. During our September 2006 field reconnaissance, numerous adult trout were observed in pools in the gorge reach (i.e., from downstream of Moyle and Baltz's study site to the confluence with Cherry Creek). Anecdotally, adult trout density in Eleanor Creek appeared to be higher than in the Upper Cherry Reach and Hetchy Reach.

Foothill Yellow-legged Frog

No available studies or surveys for foothill yellow-legged frogs or other amphibians in Eleanor Creek were identified during the course of this project. The presence or absence of this species in the reach, therefore, is not known. The reach is within the elevation range of the species, but potential breeding habitat (open cobble bars) is sparse. If foothill yellow-legged frogs do breed in the Eleanor Reach, eggs and larvae would be vulnerable to rapid changes in flow depth and velocity. Eggs laid and larvae hatched during low flow conditions prior to spring spills could be displaced or destroyed after spill begins. Eggs laid along the channel margins and on submerged bars during spring spills, conversely, would be stranded as flow is quickly reduced to summer minimum flow levels. Tadpoles rearing in side channels or other depressions on bars could also be stranded by rapidly dropping flow levels.

Benthic Macroinvertebrates

No available studies or surveys for benthic macroinvertebrates in Eleanor Creek were identified during the course of this project. Low flows and high water temperatures may limit spring/summer invertebrate production downstream of Eleanor Dam.

6.2 Cherry Creek - Upper Cherry Reach

6.2.1 Geomorphology

Sources of geomorphic information on Upper Cherry Creek are few, but more than the Eleanor Reach, Lower Cherry Reach, and the Holm Reach. The primary geomorphic information sources are USGS topographic maps, USGS digital elevation model (DEM), 1953 (pre-dam) ground photos at the USGS gaging station below Cherry Valley Dam, geomorphic monitoring conducted at a site 1.5 miles downstream of Cherry Valley Dam in 1993 (IRE 1994) and 2006 (McBain & Trush), and our 2006 field reconnaissance. The 1993 and 2006 data collection, including a large right bank cobble/gravel point bar, emphasized cross section surveys, pebble counts, and tracer rocks. The long-term USGS flow data at the Cherry Creek near Hetch Hetchy gaging station (USGS 11-277000) for the pre-dam period and Cherry Creek below Cherry Valley Dam gaging station (USGS 11-277300) for the post-dam period also help explain changes to Cherry Creek geomorphology as a result of Cherry Valley Dam.

Based on our field reconnaissance and the USGS 10 meter grid DEM, the general setting of Cherry Creek geomorphology is very similar to that of Eleanor Creek. First, glaciers during the Tioga glaciation likely extended downstream of the Cherry Valley Dam site to the confluence of Eleanor Creek. Glaciation upstream of the Cherry Valley Dam site resulted in extensive exposed granite, shallow soils, and sparse forested land above Cherry Lake. From the dam downstream 2 miles to the nick point, the signature from glaciation on the channel is less than on Eleanor Creek, yet the valley remains broader and less confined than downstream of the nick point. The nick point on Cherry Creek where the rapid incision into the uplifting Sierra Nevada range tapers off is more pronounced than on Eleanor Creek (Figure 6-10). As with Eleanor Creek, the morphology of the valley and the stream is markedly different upstream and downstream of the nick point. The gradient (less than 2%) is much less than lower Cherry Creek (4%-5%), and less than the corresponding portion of Eleanor Creek immediately below the dam (2%-3%). In the low gradient portion of the Upper Cherry Reach, the dominant sediment delivery mechanism to the channel is granite block exfoliation and decomposed granitic sand delivery from wind and surface water flow. The substrate upstream of the nick point is small boulder, cobbles, gravel, and sands within a semi-alluvial channel, separated by short steep reaches of exposed granite bedrock.

As was the case for Eleanor Creek, the channel morphology downstream of the nick point is largely shaped by the stream itself, and less so than by glacial processes. The channel is incised within the uplifting Sierra Nevada bedrock, is much steeper (>4%), and very confined by the valley walls. The dominant sediment delivery mechanism to the creek is landslides and rockfalls of fractured granitic blocks from the valley walls. Fires and timber management are very frequent downstream of Cherry Valley Dam, which likely increases fine sediment contribution to the stream. Extensive riparian encroachment in the reach, combined with more severe flow regulation from Cherry Valley Dam, allows much more fine sediment (granitic sand) to deposit in pools, riparian berms, and channel margins in the low gradient reach and the higher gradient reach. The channel geometry has noticeably changed due to fine sediment deposition; in lower gradient semi-alluvial reaches, gravel and sand have deposited along encroaching riparian and upland vegetation, leading to a more rectangular channel. This process was observed at the Cherry Bar monitoring site in 2006, as illustrated on Cross Section 300 (Figure 6-11).

As described in Section 5, the entire range of flood magnitudes from the 1.5 to 25-year flood recurrence has been substantially reduced by flow regulation from Cherry Valley Lake. Therefore, the frequency of bed mobilization has been greatly reduced compared to pre-dam conditions. Based on our cross section surveys, tracer rock data, riparian surveys, and field reconnaissance, the frequency of high flows has been reduced enough to cause extensive riparian and upland vegetation encroachment into the low flow channel, and change channel morphology. Figure 6-12, Figure 6-13, and Figure 6-14 illustrate how riparian and upland vegetation encroachment has occurred between 1953 and 2006. The riparian initiation process along the low flow channel margin likely required only a short time (a few years) after dam completion, after which the vegetation matured, fine sediment deposited in the roughened channel margins, and changes to channel geometry started.

Not only was the hydrology of Cherry Creek altered, but the Cherry Valley Dam substantially altered the sediment regime by trapping sediments originating from the upstream watershed. This reduced sediment supply to the reach immediately downstream of Cherry Valley Dam has likely been largely offset by the substantial drop in sediment transport capacity resulting from high flow regulation (winter floods and snowmelt runoff), such that the coarse sediment budget downstream may have remained in balance or in slight surplus (see USGS spoils piles at their gaging station control in Figure 6-14). The fine sediment budget is also likely in slight surplus as evidenced by sand deposition in riparian berms and channel margins (Figure 6-15).

Last, the large wood regime downstream of the dam has likely been severely reduced due to dam infrastructure and operations. Unlike Eleanor Dam, Cherry Valley Dam rarely if ever spills (flows over the spillway), with controlled high flows released instead from dam outlet works. This prevents large wood from the upper watershed from routing through the lake to downstream reaches. While there is large wood supply downstream of Cherry Lake, logs are rarely routed by the post-dam flow regime. Substantial log jam accumulations downstream (in contrast to Eleanor Creek) were not observed. However, flows approaching 5,000 cfs as observed in spring 2006 begin to approach the threshold for toppling and removing maturing alders along the low flow channel (Figure 6-16).

In summary, the geomorphology of Upper Cherry Creek has changed substantially due to Cherry Valley Dam, with more pronounced changes in the lower gradient, largely depositional reaches. Of all reaches within the project area, the channel morphology in this reach is the most altered by the project. Our field reconnaissance suggests that, while not as severe as the low gradient reach, there are still substantial geomorphic changes to the channel in the steeper reach downstream of the nick point, including riparian encroachment, channel simplification, and fine sediment infilling of the channel margins.

Figure 6-10: Cherry Creek Profile From USGS 10 m Digital Elevation Model.

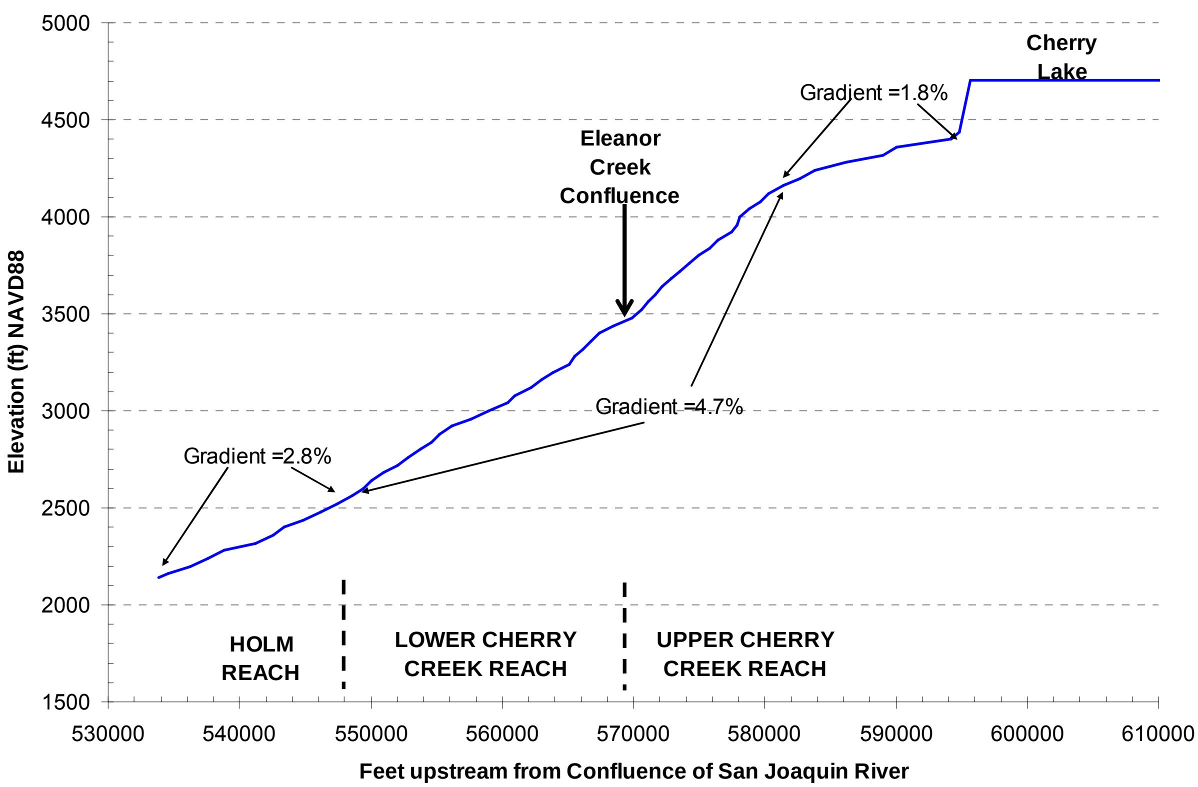


Figure 6-11: Channel Geometry Change from the 2006 High Flow Release on Cherry Bar Cross Section 300.

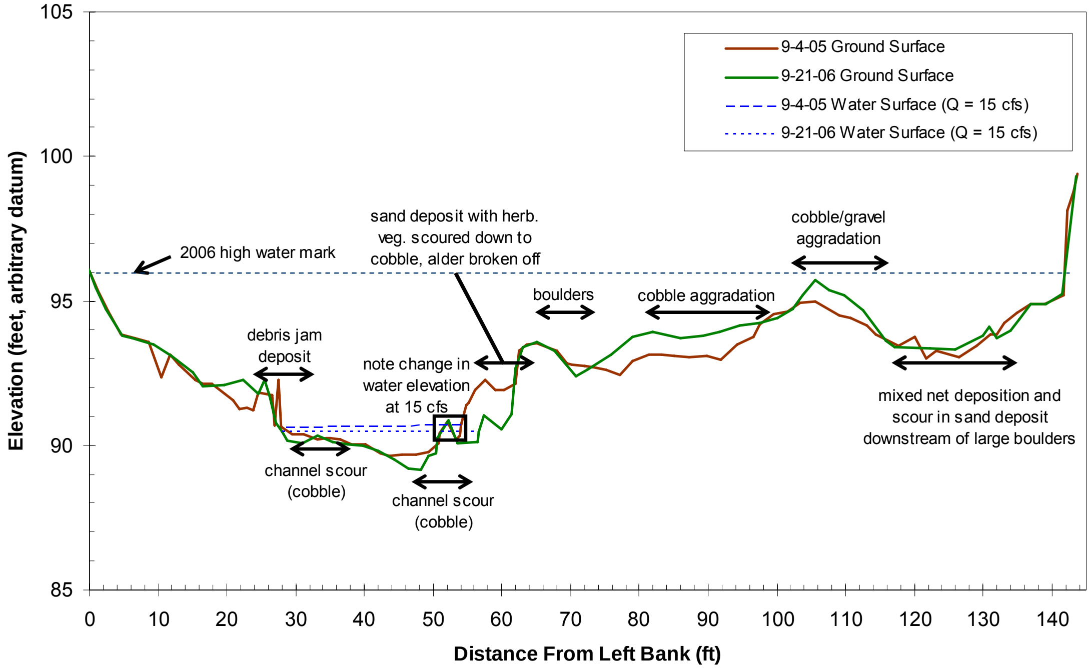


Figure 6-12: Upper Cherry Creek at the USGS Gaging Station Cableway (Cherry Creek below Cherry Valley Dam) in 1953, Compared with 2006 at Same Location. Note Same Boulders, Slight Channel Incision, Bed Coarsening, and Extensive Riparian and Upland Encroachment into the Channel.

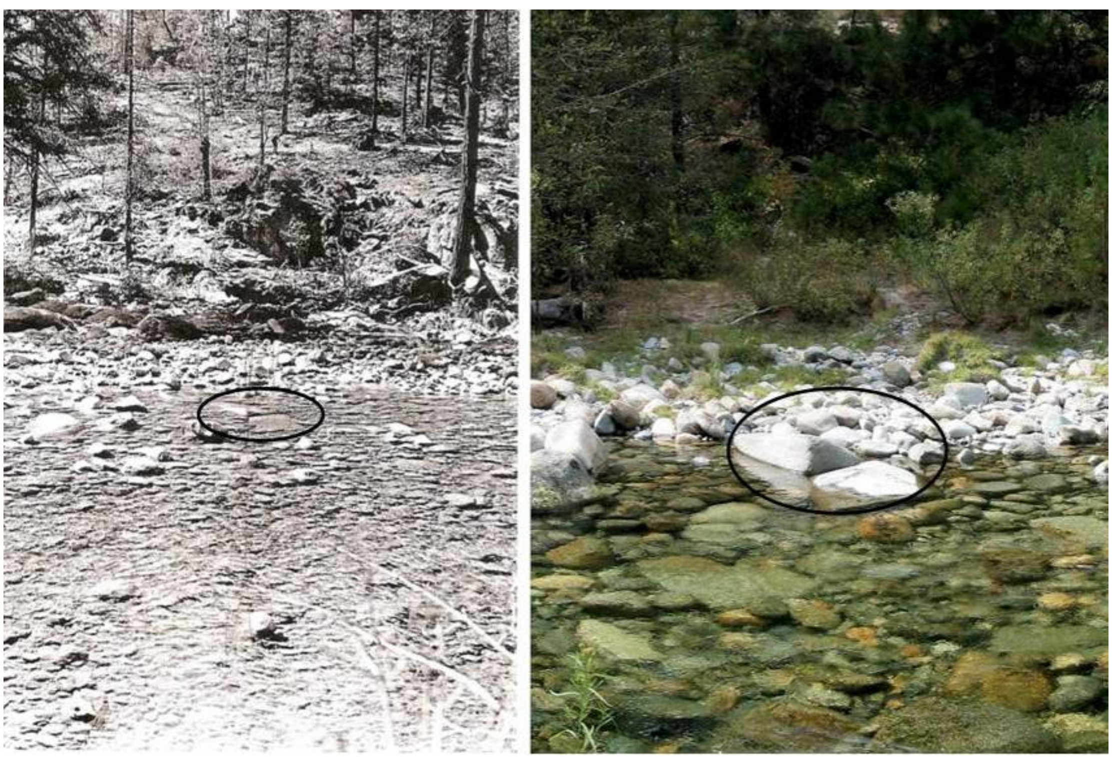


Figure 6-13: Upper Cherry Creek at the USGS Gaging Station Gage House (Cherry Creek below Cherry Valley Dam) in 1953, Compared with 2006 at Same Location. Note Riparian and Upland Vegetation Encroachment onto the Cobble Bar on Opposite Bank.

Figure 6-14: Upper Cherry Creek at the USGS Gaging Station Control (Cherry Creek below Cherry Valley Dam) in 1953, Compared with 2006 at Same Location. Note Extensive Riparian and Upland Encroachment into the Channel, and Cobble/Gravel Spoils on Opposite Bank from USGS Maintenance of Deposited Coarse Sediment.

Figure 6-15: Upper Cherry Creek Lee Deposit near the USGS Gaging Station (Cherry Creek below Cherry Valley Dam) Showing How 2006 Peak Flow Release (approximately 5,000 cfs) did not Approach the Threshold to Remove Sheltered Maturing Alders along Low Flow Channel.

Figure 6-16: Upper Cherry Creek Cobble Bar near the USGS Gaging Station (Cherry Creek below Cherry Valley Dam) Showing How 2006 Peak Flow Release (approximately 5,000 cfs) Approached the Threshold to Remove Unsheltered Maturing Alders along Low Flow Channel. Note Cobble and Small Boulder Movement.

6.2.2 Water Temperature

Reservoirs commonly reverse the seasonal water temperature regime in downstream reaches by releasing warmer than natural water in the winter, and colder than normal hypolimnial releases in the summer months. This appears to be the case with Cherry Valley Dam, where winter release temperatures are likely 5-8º F warmer than what would occur without the dam in place, and summer release temperatures are likely 10-15º F cooler than what would naturally occur. In many cases (e.g., fish or benthic macroinvertebrate productivity), this reversal of thermal regime can be beneficial; in other cases (e.g., amphibian productivity), the reversal can be detrimental. Post-dam summer water temperatures near the USGS gaging station immediately below the dam are usually within the thermal tolerances of rainbow trout (Appendix F) yet may exceed preferable temperatures downstream. The transition in this trend that occurs during the snowmelt hydrograph is important (McBain & Trush 2006). If flow releases during the snowmelt runoff period are smaller magnitude than historical, then the "cooler release" benefit to certain species is short lived as one progresses downstream. Even though release temperatures are cooler than what would naturally occur, the smaller thermal mass of the reduced snowmelt hydrograph release allows the water to warm up quicker as it routes downstream, such that the length of river downstream of the dam with preferable water temperatures is shorter than pre-dam conditions. The reduced stream length with preferable water temperatures could correspondingly reduce benthic macroinvertebrate production, reduce fish growth, and benefit exotic warm-water fish species.

6.2.3 Riparian Vegetation

Two studies have evaluated the interaction of riparian vegetation with the physical and hydrologic conditions below the Cherry Creek Dam (IRE 1994, McBain & Trush 2006). The McBain & Trush (2006) study included: (1) observations of riparian hardwood species occurring in the Upper Cherry Reach, and (2) cross section surveys to document root elevation of riparian hardwoods relative to summer water elevation at one study site. These data have been only partially analyzed. Study reach boundaries and locations of vegetation cross sections are shown in Figure 6-17. Based on our observations of other regulated and unregulated Sierra Nevada streams, operational impacts on riparian vegetation were obvious due to the elimination of the snowmelt hydrograph. Riparian encroachment was widespread and there was little evidence of frequent riparian woody plant scour even after the post-dam flood of record. Species diversity and location was comparable to regulated Sierra Nevada streams with large storage reservoirs (i.e., the ratio of storage capacity to annual water yield >1).

Many hardwood species dominate the thick band of riparian vegetation lining Cherry Creek (Table 6-2, Figure 6-18). This species list was compiled from reconnaissance-level observations conducted in 2005 and cross section surveys at Cherry Bar; it does not present a complete list of species occurring or likely to occur in the reach. Mature willows and alders grow in a dense band along the low-water channel. Conifers, western serviceberry (*Amelanchier alnifolia*), and western azalea (*Rhododendron occidentale*) dominate the riparian-upland transition zone on what were historically depositional features before the Cherry Creek Dam.

Riparian vegetation growing within the active channel consisted of dense bands of mature white alder, grasses, and sedges, reflecting an environment that does not experience periodic high magnitude flood peaks except in extremely wet years. Mature riparian woody plant species are not inhibited from growing in the active channel. Previous studies discuss the role of Cherry Creek Dam in creating conditions that have facilitated the widespread encroachment of white alder, shiny willow and ponderosa pine (*Pinus ponderosa*) into the pre-dam active channel. These studies established that the Cherry Valley Dam has altered the snowmelt hydrograph to the extent that flood peaks no longer remove establishing riparian woody plant species from coarse alluvial deposits. Ponderosa pine has formed large patches on pre-dam point bars and floodplains, and white alder and shiny willow have formed nearly continuous bands along the summer baseflow water edge between the baseflow water elevation and the post-dam 1.2-year flood elevation (Figure 6-18).

Effects of the 2006 flood peak on riparian vegetation were observed during the 2006 field reconnaissance surveys. The 2006 flood (approximately 6,500, which is the post-dam flood of record) mobilized coarse sediment, causing localized riparian disturbance mostly through mechanical damage and deposition (rather than scour). The 2006 flood mobilized large cobbles and small boulders and deposited them around encroaching white alders (Figure 6-19). More than a foot of coarse sediment deposition around alders was observed. There was little finer textured sediment in the interstitial spaces of cobble deposits. The lack of fines may account for why these alders did not suffocate as a result of the deposition. A few white alders were scoured or snapped off as a result of the 2006 flood peak. Although the 2006 flood-induced mechanical damage was substantial (i.e., bark abrasion, pushed over trees, branch removal etc.) few riparian woody plants died.

Figure 6-17: Upper Cherry Creek Study Reach Boundaries and Vegetation Transect Locations (McBain & Trush 2006).

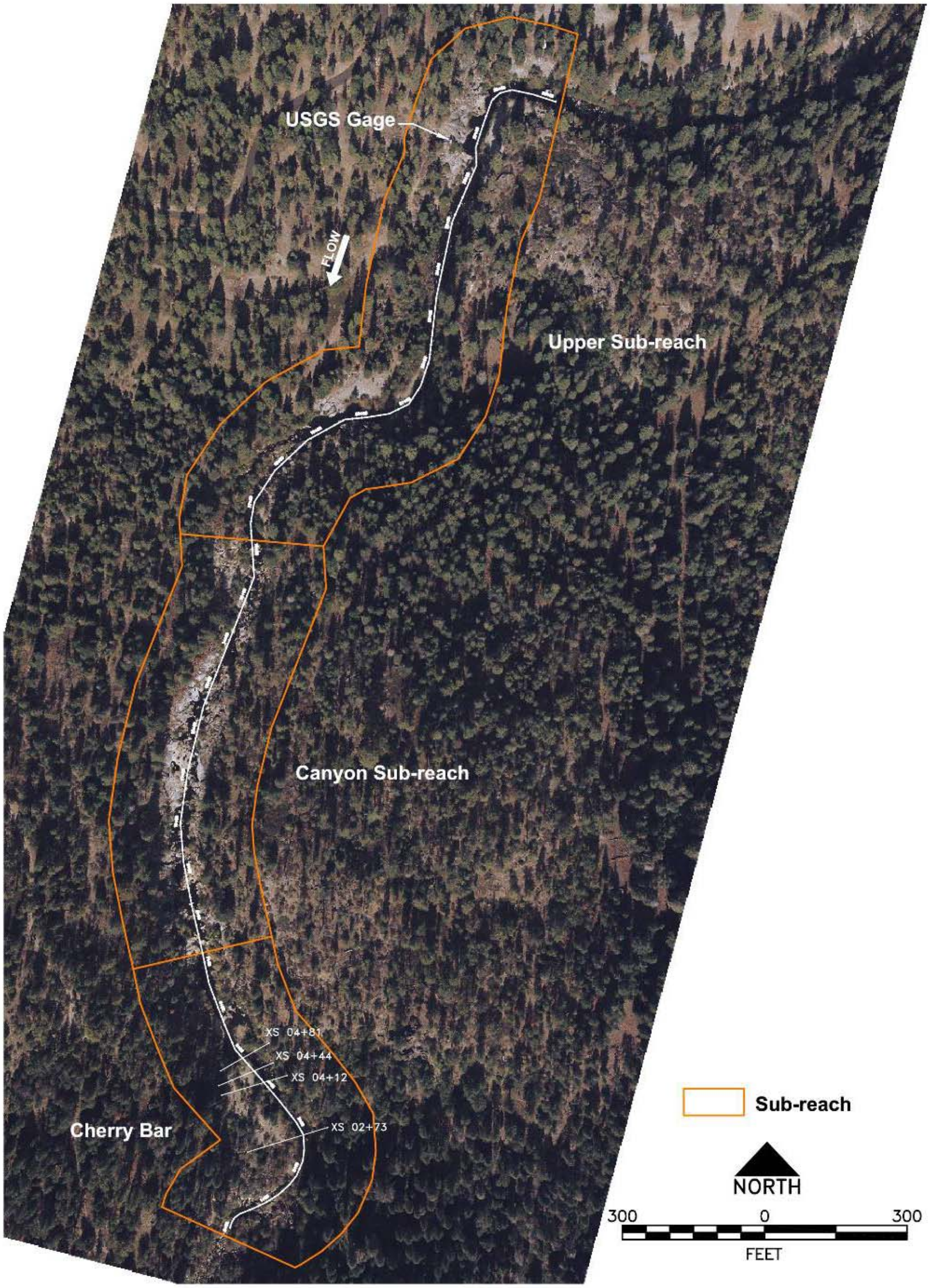


Table 6-2: Plant Species Observed on Cherry Creek during 2005 (McBain & Trush 2006).

Common Name	Scientific Name	Planform Preference
white fir	*Abies concolor*	Upland
big leaf maple	*Acer macrophyllum*	Transitional riparian
white alder	*Alnus rhombifolia*	Riparian floodplain
western serviceberry	*Amelanchier alnifolia*	Transitional riparian
elk clover	*Aralia californica*	Riparian low water
incense cedar	*Calocedrus decurrens*	Transitional upland
sedge	*Carex*	Riparian low water
	Ceanothus	Upland
Mountain misery	*Chamaebatia foliolosa*	Upland
Red-twig dogwood	*Cornus sericea*	Riparian bar
manzanita	*Arctostaphylos* spp. Upla	nd
mock orange	*Philadelphus lewisii*	Transitional riparian
ponderosa pine	*Pinus ponderosa*	Upland
Douglas fir	*Pseudotsuga menziesii*	Transitional upland
canyon live oak	*Quercus chrysolepis*	Transitional upland
black oak	*Quercus kelloggii*	Upland
interior live oak	*Quercus wislizenii* ssp. *wislizenii*	Transitional upland
western azalea	*Rhododendron occidentale*	Transitional riparian
gooseberry	*Ribes roezlii*	Upland
red currant	*Ribes sanguineum*	Transitional upland
narrowleaf willow	*Salix exigua*	Riparian bar
Jepson's willow	*Salix jepsonii*	Riparian bar
red willow	*Salix laevigata*	Riparian floodplain
arroyo willow	*Salix lasiolepis*	Riparian bar
shiny willow	*Salix lucida* ssp. *lasiandra*	Riparian floodplain
dusky willow	*Salix melanopsis*	Riparian bar
poison oak	*Toxicodendron diversilobum*	Transitional upland
grape	*Vitus californica*	Riparian floodplain
indian rhubarb	*Darmera peltata*	Riparian low water

Figure 6-18: Willow, White Alder, Big Leaf Maple, and Conifer Bank Positions Measured at Cherry Creek (McBain & Trush, unpublished data).

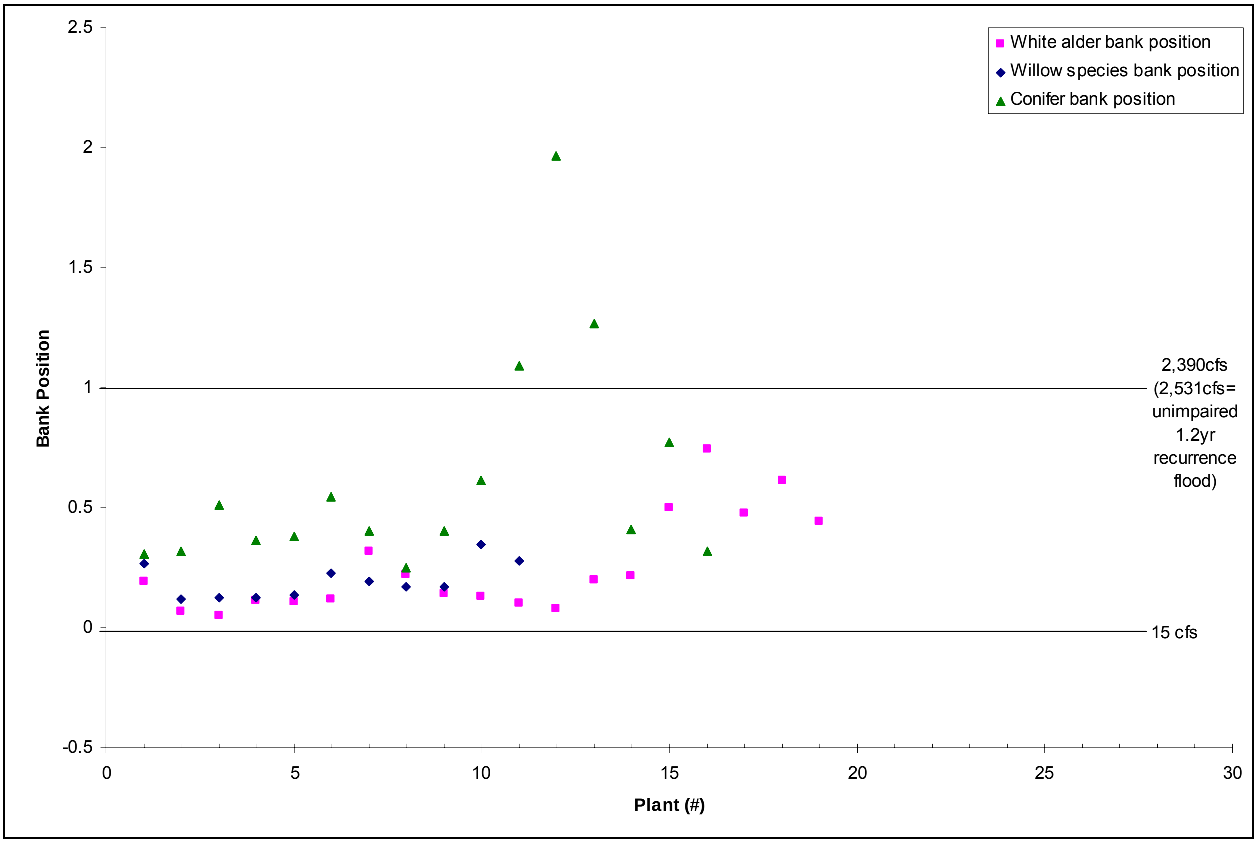


Figure 6-19: Cobble Deposition around White Alders along Cherry Creek near Cherry Valley Dam Resulting from the WY2006 Flood Peak (approximately 6,500 cfs).

Stable hydrology associated with flow regulation on Cherry Creek meets the life history requirements of many riparian plant species. However, because flow regulation has reduced or eliminated the spring snowmelt hydrograph, the life history requirements for native plants with short-lived seeds (i.e., willows and cottonwoods) are not met. Willow species richness on Cherry Creek, therefore, is lower than that found on streams with unimpaired snowmelt hydrology. During the 2005 and 2006 reconnaissance surveys, arroyo willow and shiny willow were common, Jepson’s willow was occasionally observed, and dusky willow was rarely observed. A reduced number of willow species is typical of streams where the snowmelt hydrograph has been reduced or eliminated.

The presence of white alder and similar abundances of arroyo and shiny willows implies several changes to pre-dam hydrology that have influenced the current vegetation pattern downstream of Cherry Valley Dam. Shiny willow is just as common as arroyo willow, suggesting that the snowmelt component of the hydrograph has been shortened and peaks reduced. This would provide the rainfall hydrograph an equal chance of recruiting arroyo willow at a given bank location as the snowmelt hydrograph of recruiting shiny willow at the same location. The abundance of white alder at bank positions close to the low-water edge also suggests that a shift in the dominance of snowmelt hydrology to rainfall dominated hydrology has occurred.

There was not a strong gradation between the bank locations where white alder, arroyo willow, and shiny willow grow. Mature and establishing shiny willows and white alders often occurred within the same 3-6 ft elevation range of the low-water channel. White alder was the most common woody species, with large individuals (i.e., > 8 inches diameter at breast height) often occurring on the lower portions of pre-diversion bars along the low-water edge. The lack of strong gradation in channel locations for the observed woody riparian species is consistent with observations and descriptions of riparian vegetation patterns along streams with large storage reservoirs (i.e., the lower Tuolumne River).

Adjacent to the low-water channel in the riparian upland transition, canyon live oak and even-aged stands of ponderosa pine have extended from the valley toe and colonized upper surfaces of pre-diversion bars (> 6ft above the summer baseflows). This suggests that the extent of post Cherry Valley Dam riparian conditions is limited to the lower pre-diversion bar surface. Before Cherry Valley Dam was completed, canyon live oak and conifers were presumably prevented from coming onto active surfaces by the presence of frequent and prolonged flood peaks. The lack of high magnitude floods no longer excludes ponderosa pine and canyon live oak from encroaching into the riparian corridor.

Field observations made in the fall 2006 suggest that the 2006 flows increased channel confinement at Cherry Bar. Assuming that flow regulation patterns in Cherry Creek remain unchanged, it is plausible that with future flood peaks, established woody riparian plants growing on pre-diversion bars and post dam riparian berms will continue to prevent bed scour on those surfaces with little or no riparian mortality. Furthermore, it is possible with the current low flow management that channel incision may increase, further isolating bars from the channel. Riparian woody plant species will recruit on the flanks of these incising channels and further prevent substantial channel resets from occurring. Vegetation colonizing the upper surfaces of bars will become more xeric. The net result may be a further simplified, coarse active channel with senescent riparian vegetation that has low age-class diversity and species richness.

6.2.4 Analysis Species

Rainbow Trout

Information on rainbow trout habitat and abundance in the Upper Cherry Reach is limited to an approximately 2-mile reach upstream of the gorge. Rainbow trout is the only fish species recorded in this reach (Moyle and Baltz 1981, CDFG 1989). Studies and surveys available for this reach include IFIM habitat quantification, habitat mapping, fish abundance surveys and temperature monitoring (Table 6-3). Moyle and Baltz (1981) quantified habitat availability for adult holding, spawning, and young-of-year and juvenile rearing for flows up to 50 cfs at one site downstream of Cherry Valley Dam. McBain & Trush

(2006) mapped trout habitat over a longer reach and a broader range of flows (18 cfs to 1,730 cfs) in 2005 using habitat suitability criteria discussed in Section 4.5.1. Habitat mapping focused on spawning and fry rearing. Juvenile rearing habitat was mapped only for two flows.

Table 6-3: Fish Habitat and Abundance Surveys Available for the Upper Cherry Reach.

Survey/Study	Comments	Report
Habitat quantification[a]	6 transects in one 230-foot reach 1.2 miles downstream of Cherry Valley Dam, calibrated for flows of 4 cfs, 13 cfs, and 30 cfs	Moyle and Baltz 1981
Habitat mapping[b]	In 2,700-foot reach upstream of gorge during flows of 18, 131, 563, 734, 1,730 cfs	McBain & Trush 2006
Trout abundance	1981 snorkel survey within IFIM model reach[c]	Moyle and Baltz 1981
	1989 multiple pass electrofishing survey 0.5 mi downstream of Cherry Valley Dam	CDFG 1989
Water temperature	June – Sept. 1981	Moyle and Baltz 1981
	Sept. 2005	McBain & Trush, 2006
	May – Sept 2006[d]	Data collected for this study
	Summer 2006 – present[d] USGS	

Footnotes:

a. Habitat quantification included rainbow trout and Sacramento sucker.
b. Mapping included habitat for rainbow trout, foothill yellow-legged frog, western toad, and benthic macroinvertebrates.
c. The study authors considered the results of this survey to be a “ballpark minimum estimate” of trout abundance.
d. See Appendix F and G for data.

The habitat quantification was applied to a narrow range of flows. The habitat quantification predicted that adult trout habitat would increase with flow beyond the range of flows measured and that young-of-year and juvenile habitat peaked at 10 cfs and 15 cfs, respectively (Moyle and Baltz 1981) (Figure 6-20). The habitat quantification underestimated spawning habitat area, which was more extensive than in the Eleanor Creek and Lower Cherry model reaches (Moyle and Baltz 1981).

The habitat mapping included a much broader range of flows and a longer study reach. Where mapping and habitat quantification flows overlapped, the mapping predicted more extensive habitat area than the quantification. Habitat mapping in the longer study reach identified more extensive fry rearing and spawning habitat (per 1,000 ft of channel length) than predicted by the habitat quantification effort. For instance, during flows of 18 cfs (the only habitat mapping flow that was within the range of the habitat quantification), mapped fry habitat area was 2,800 ft^2/1,000 feet of stream, nearly five times more than predicted by the habitat quantification. Mapping also captured habitat conditions during higher flows when lateral bars and other depositional features outside of the low-flow channel were inundated. For example, fry habitat area increased sharply as Cherry Bar and other lateral bars were inundated, peaked at 734 cfs (Figure 6-21), then dropped off as flow became too deep and swift for fry. Spawning habitat was found primarily along the edges of lateral bars, along riffles and riffle crests, and in small patches downstream of boulders and bedrock obstructions. Mapped spawning habitat peaked at 131 cfs at 594 ft^2 /1,000 ft of stream.

Rainbow trout density and biomass in the Upper Cherry Reach is high relative to the Eleanor and Lower Cherry reaches, and may be higher than on the Clavey River (i.e., a nearby, unregulated reference stream). During the 1981 surveys, juvenile and adult trout (> 2 in SL) density was 1 fish/100 ft^2, which is similar to the Eleanor and Lower Cherry sites during the same year. The Upper Cherry site, however, supported higher densities of young-of-year trout – 2.2 fish/100 ft^2 compared to 0.1 fish/100 ft^2 at the

Eleanor site and 0.6 fish/100 ft^2 at the Eleanor site. Baltz and Moyle (1984) attribute the higher density of young-of-year trout in the Upper Cherry Reach to greater availability of rearing habitat in the reach. CDFG conducted electrofishing surveys in fall 1988 in Cherry Creek and in 1989 in the Clavey River to compare trout abundance in regulated and unregulated streams in the drainage. Estimated trout abundance at the Upper Cherry Creek survey site was 3.5 trout/100 ft^2 for all size classes combined, which is similar to the Baltz and Moyle (1984) results. Standing crop at the Upper Cherry site was 72 lb/ac. CDFG surveyed four sites on the Clavey River. One site, located 500 ft upstream of the 1N04 Bridge, was at an elevation similar to the Upper Cherry Reach. Trout abundance at the 1N04 site was 2.1 fish/100 ft^2; standing crop was 24 lb/ac.

Water temperature in the Upper Cherry Reach is fairly constant due to hypolimnionic releases from Cherry Lake (Figure 6-22 and Figure 6-23). In 1981, water temperatures were within optimal range for trout egg incubation during the spring and early summer spawning and incubation periods. For the rest of the spring and summer rearing period, daily maximum temperatures remained just under 60°F, and daily minimum temperatures remained just over 46°F. These temperatures are slightly cooler than published conditions for optimal juvenile and adult growth, but high young-of-year density in August 1981 suggests that low temperatures are not suppressing trout abundance (although they may reduce trout growth rates). In 2006, high flow releases in July pushed daily average water temperature down to 45–46°F, well below preferred rearing temperature ranges. With reduced flow, daily average water temperature increased to 50°F–55°F, and daily maximum temperature increased to 55°F –60°F. The low temperature of water released from Cherry Lake poses some management challenges in balancing habitat availability and water temperature. For example, trout fry rearing habitat peaks at flows of nearly 800 cfs, but water temperature during 800-cfs flows is around 45°F (based on 2006 monitoring data), which is 10°F–21°F below optimal fry rearing temperatures (Figure 6-23).

Figure 6-20: Predicted Available Rainbow Trout Habitat Area in the Upper Cherry Reach Upstream of Cherry Creek Gorge (Moyle and Baltz 1981).

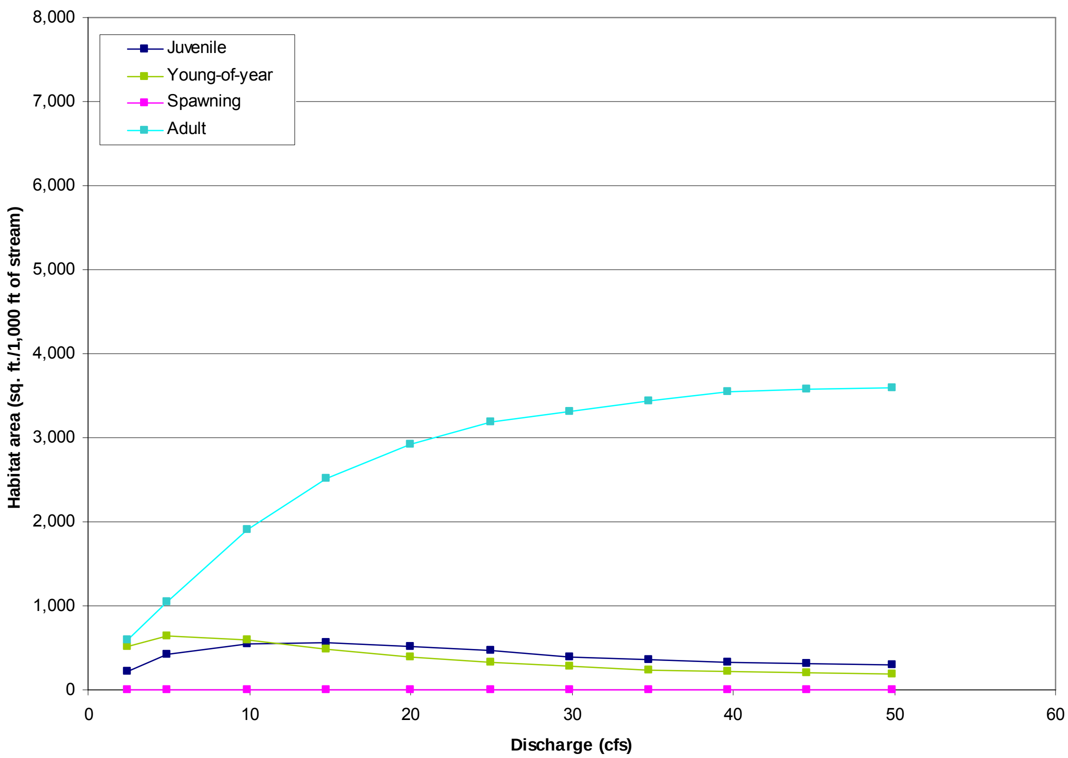


Figure 6-21: Mapped Available Rainbow Trout Habitat Area in the Upper Cherry Reach Upstream of Cherry Creek Gorge (McBain & Trush 2006).

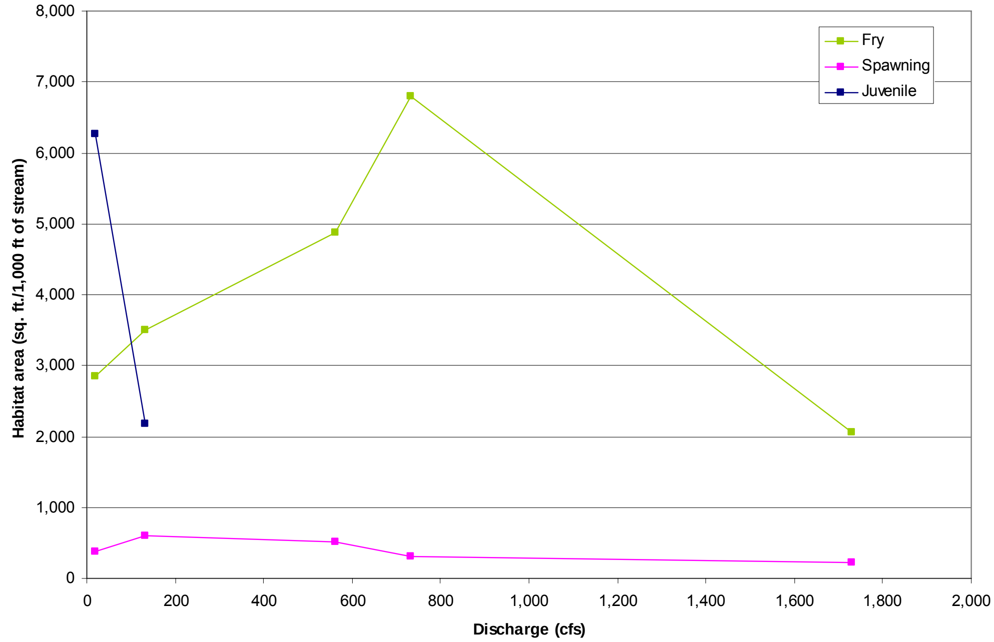


Figure 6-22: Daily Minimum and Maximum Water Temperature in the Upper Cherry Reach in Summer 1981 (Moyle and Baltz 1981) and Rainbow Trout Temperature Thresholds (Moyle and Marchetti 1992).

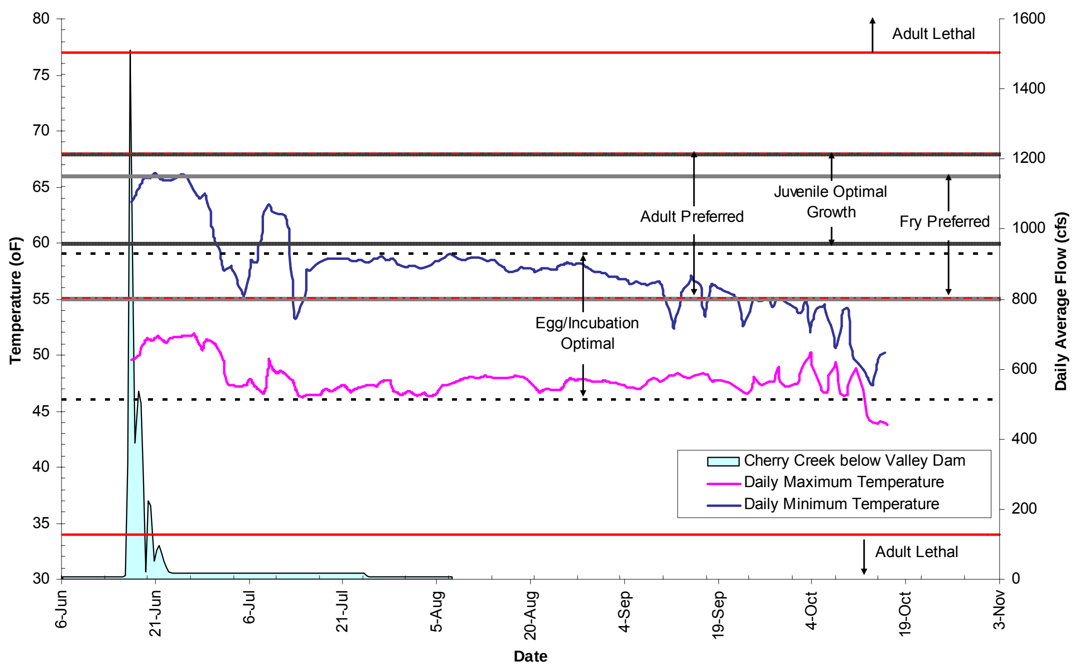
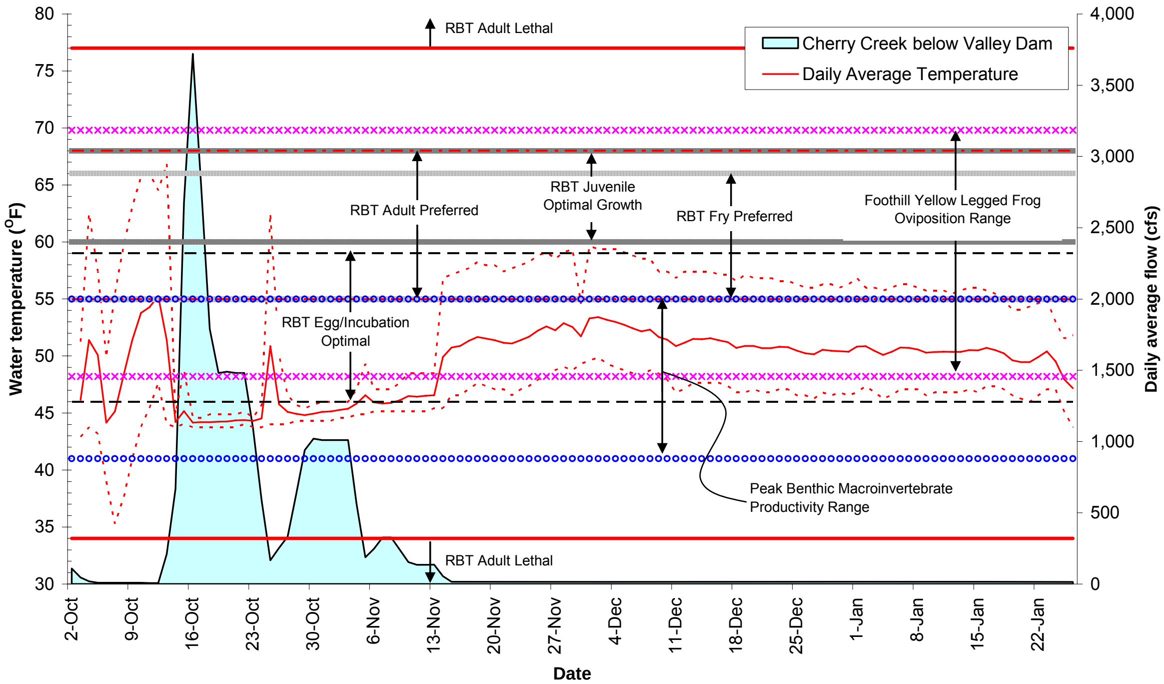


Figure 6-23: Daily Average, Minimum, and Maximum Flow and Water Temperate in Upper Cherry Reach – May through September 2006.



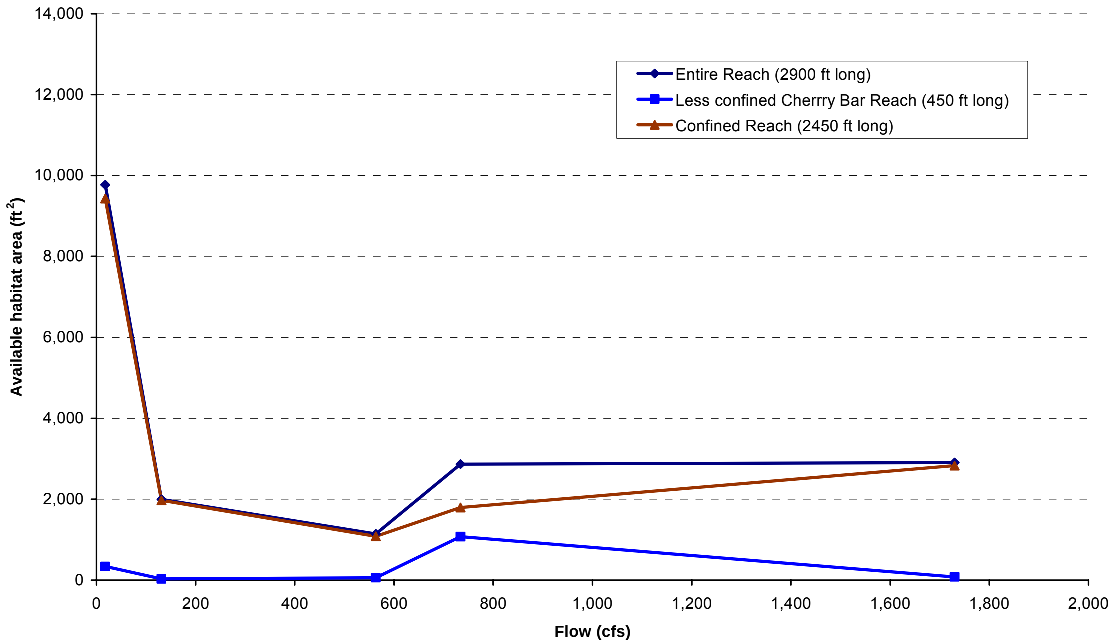
Foothill Yellow-legged Frog

No available studies or surveys for foothill yellow-legged frogs or other amphibians in Cherry Creek were identified during the course of this project. The current and historic presence or absence of this species in the reach, therefore, is not known. The reach is within the elevation range of the species, although no foothill yellow-legged frogs were identified at similar elevations along the Clavey River in surveys conducted by the USFS in 2001 (USFS, unpublished data).

Prior to construction of Cherry Valley Dam, open cobble/gravel bars provided extensive potential breeding habitat for foothill yellow-legged frogs. Vegetation encroachment onto these bars has reduced their value for foothill yellow-legged frog breeding, but extensive potential breeding areas remain in the reach, including bedrock side pools and terraces. McBain & Trush (2006) mapped potential foothill yellow-legged frog breeding habitat in the Upper Cherry Reach using habitat suitability criteria discussed in Section 4.5.2. The mapping reach and flows observed are the same as described for rainbow trout, above. Potential breeding habitat was most abundant during the lowest flow mapped (i.e., 18 cfs) and was found along cobbles, boulders and bedrock outcrops along the low-flow channel (Figure 6-24).

The early-life stage habitat rating curve for the Cherry Creek study site peaked twice: once at a minor peak probably between 550 cfs and 700 cfs, and a prominent peak at 25 cfs to 40 cfs (Figure 6-24). More streamflows need to be habitat mapped to better identify peak habitat abundance. The Cherry Creek habitat rating curve likely dips between 700 cfs and 1200 cfs because riparian berm and sand deposition confine streamflows before they begin to spread significantly among encroached bar features at higher streamflows. At around 700 cfs, habitat became available on inundated cobble bars, but encroached riparian vegetation reduced both the area and quality of this habitat. If foothill yellow-legged frogs do breed in the Upper Cherry Reach, eggs and larvae would be vulnerable to rapid changes in flow depth and velocity which could scour, desiccate, and or strand eggs and larvae.

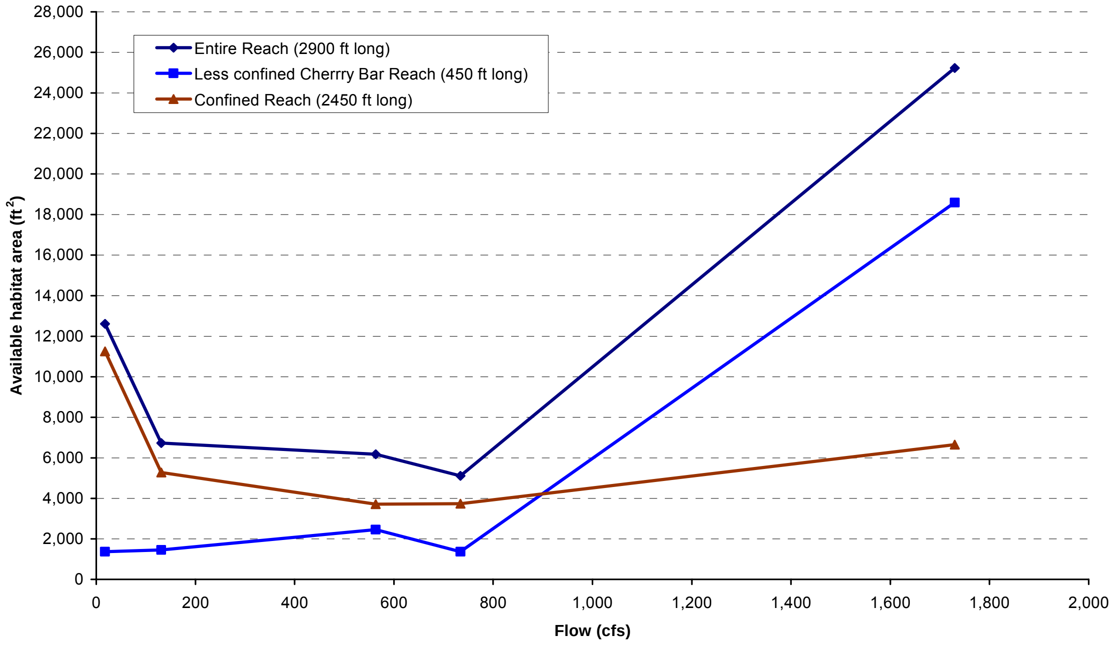
Figure 6-24: Mapped Available Foothill Yellow-legged Frog Habitat Area in the Upper Cherry Reach Upstream of Cherry Creek Gorge (McBain & Trush 2006).



Benthic Macroinvertebrates

No available studies or surveys for benthic macroinvertebrates in Cherry Creek were identified during the course of this project. McBain & Trush (2006) mapped potential productive benthic macroinvertebrate area in the Upper Cherry Reach using suitability criteria discussed in Section 4.5.3. The mapping reach and flows observed are the same as described for rainbow trout and foothill yellow-legged frogs, above. The benthic macroinvertebrate habitat rating curve for Cherry Creek (Figure 6-25) shows the effect of woody riparian encroachment and deposition. At intermediate streamflows (roughly 200 cfs to 800 cfs), the depositional features that support open cobble bars are missing. Habitat is available only within the baseflow channel or at relatively high (and very infrequent) streamflows that inundate Cherry Bar and other larger depositional features with exposed patches among ponderosa pines. From May through September 2006 (i.e., the period during which temperature was monitored), daily average water temperature remained within the range for peak macroinvertebrate production (Figure 6-23).

Figure 6-25: Mapped Available Productive Benthic Macroinvertebrate Area in the Upper Cherry Reach Upstream of Cherry Creek Gorge (McBain & Trush 2006).



6.3 Cherry Creek - Lower Cherry Reach

6.3.1 Geomorphology

The best quantitative information on the Lower Cherry Reach geomorphology is the post-dam USGS flow data at the Cherry Creek near Hetch Hetchy gaging station (USGS 11-278300). This gage is immediately upstream of the Holm Powerhouse and downstream of the Eleanor Creek confluence, so it represents flow contributions from both the Upper Cherry Reach and the Eleanor Reach. Unfortunately, the gage was installed in 1955, preventing a direct comparison with the pre-dam flow regime (annual hydrographs and peak flow data).

As was the case for the high gradient portion of the Upper Cherry Reach, the Lower Cherry Reach is also downstream of the nick point where the rapid incision of the streams into the uplifting Sierra Nevada range tapers off (Figure 6-10). The pre-dam morphology of the valley and stream was very similar to that in the high gradient portion of Upper Cherry Reach, and won't be restated here. A single pre-dam 1953 photo was found for the Cherry Creek near Hetch Hetchy gaging station, and shows a boulder-bed channel with very little riparian vegetation within the active channel (Figure 6-26).

After completion of Cherry Valley Dam, hydrology in the reach was severely regulated; however, the notable exception is that due to the substantial high flow contribution from Eleanor Creek. Riparian and upland encroachment into the channel is much less pronounced, and the geomorphology of the stream functions closer to regional unregulated streams than the Upper Cherry Reach. The substrate of the reach has large boulders over granite bedrock, with cobble, gravel, and sand lee behind large boulders and bedrock outcrops (Figure 6-27).

Figure 6-26: Lower Cherry Creek at the USGS Gaging Station Cherry Creek near Early Intake (Upstream of Holm Powerhouse) in 1953. Present-Day Photo Comparison at Exact Location is not yet Available.

Figure 6-27: Lower Cherry Creek Reach Looking Downstream from Cherry Lake Road Bridge (5 Miles Downstream of Eleanor Creek Confluence). Note Some Riparian Vegetation Encroachment into the Active Channel, Boulder Substrate with Gravel/Cobble Pockets, and Steep Channel Gradient.

6.3.2 Riparian Vegetation

No available studies or surveys of riparian vegetation specifically related to lower Cherry Creek below the confluence of Eleanor Creek to the Holm Powerhouse were identified during the course of this project. The relationship of riparian vegetation dynamics along lower Cherry Creek to substrate, topography and hydrologic environments is described based on a few qualitative observations made during limited field reconnaissance conducted in fall 2006; species richness and spatial distribution/gradation were not assessed.

The influence of the Cherry Valley Dam on flood peaks and snowmelt hydrographs was less evident downstream of the Eleanor Creek confluence than in the Upper Cherry Reach. Valley confinement and contribution of the streamflow from Eleanor Creek inhibit riparian vegetation encroachment into the active channel typical of the Upper Cherry Reach. Alluvial deposits are few in this reach of valley confinement. Where alluvial deposits occur, frequent scour during floods prevents riparian vegetation establishment. Riparian encroachment was evident at some locations, where small patches of vegetation occurred on alluvial deposits in the active channel (Figure 6-27). Species diversity and location was comparable to regulated Sierra Nevada streams with large storage reservoirs.

6.3.3 Analysis Species

Rainbow Trout

Documented fish fauna in the Lower Cherry Reach consists of rainbow trout, Sacramento sucker, and Sacramento pikeminnow (Moyle and Baltz 1981, CDFG 1989). One site in the Lower Cherry Reach was included in the Moyle and Baltz (1981) study. Moyle and Baltz (1981) quantified habitat availability for adult holding, spawning, and young-of-year and juvenile rearing for flows up to 100 cfs (Table 6-4). The habitat quantification predicted that adult trout habitat area increases with flow and peaks at 90 cfs, young-of-year habitat area peaks at 35 cfs, and juvenile habitat area peaks at 45 cfs (Figure 6-28). The habitat quantification underestimated spawning habitat area. Trout spawning substrate was limited to small patches in the Lower Cherry Reach; no patches were within the habitat quantification reach. The quantification effort did not assess habitat area during flows exceeding 100 cfs. It is unlikely that habitat area would increase during higher flows in this confined channel reach.

In the 1981 study, density of trout >2 in SL was highest in Lower Cherry Creek (compared to the Upper Cherry and Eleanor reaches). Density of trout >2 in was 1.1 fish/100 ft^2. Density of trout <2 in was 0.6 fish/100 ft^2, six times higher than the Eleanor Reach but only 25% of young-of-year density observed in the Upper Cherry Reach. CDFG (1989) found that fish standing crop in the Upper Cherry and Lower Cherry reaches were similar, but Upper Cherry stock was entirely rainbow trout while Lower Cherry Creek was dominated by Sacramento suckers. Squawfish were also present at Lower Cherry site. Trout and Sacramento sucker densities during the 1988 CDFG survey were 0.7 fish/100 ft^2 and 1.1 fish/100 ft^2, respectively (CDFG 1989). Standing crop of tout and Sacramento sucker were 19.0 lb/ac and 47.5 lb/ac, respectively (CDFG 1989).

Table 6-4: Fish Habitat and Abundance Surveys Available for Lower Cherry Creek.

Survey/Study	Comments	Report
Habitat quantification[a]	6 transects in one 240-foot reach downstream of Cherry Oil Rd bridge, calibrated for flows of 18 cfs, 24 cfs, and 41 cfs	Moyle and Baltz 1981
Trout abundance	1981 snorkel survey within IFIM model reach[b]	Moyle and Baltz 1981
	1989 multiple pass electrofishing survey 0.75 mi downstream of Cherry Oil Rd	CDFG 1989
Water temperature	June – Sept. 1981	Moyle and Baltz 1981
	Summer 2006 – present[c] USGS	

Footnotes:

a. Habitat quantification included rainbow trout and Sacramento sucker.

b. The study authors considered the results of this survey to be a "ballpark minimum estimate" of trout abundance.

c. See Appendix H for data.

During the 1981 study, maximum daily water temperature reached 70°F (i.e., the upper critical threshold for rainbow trout) during mid-August (Figure 6-29). High water temperatures could reduce or eliminate habitat area suitable for trout in this reach during summer months when flow is low, air temperatures are warm, and inflow from Eleanor Creek is warm. Moyle and Baltz (1981) concluded that "temperature should be a prime consideration when discharges from Lloyd and Eleanor lakes are mixed to meet discharge requirements." Warmer temperatures, however, benefit Sacramento suckers.

Figure 6-28: Predicted Available Rainbow Trout Habitat Area in the Lower Cherry Reach (Moyle and Baltz 1981).

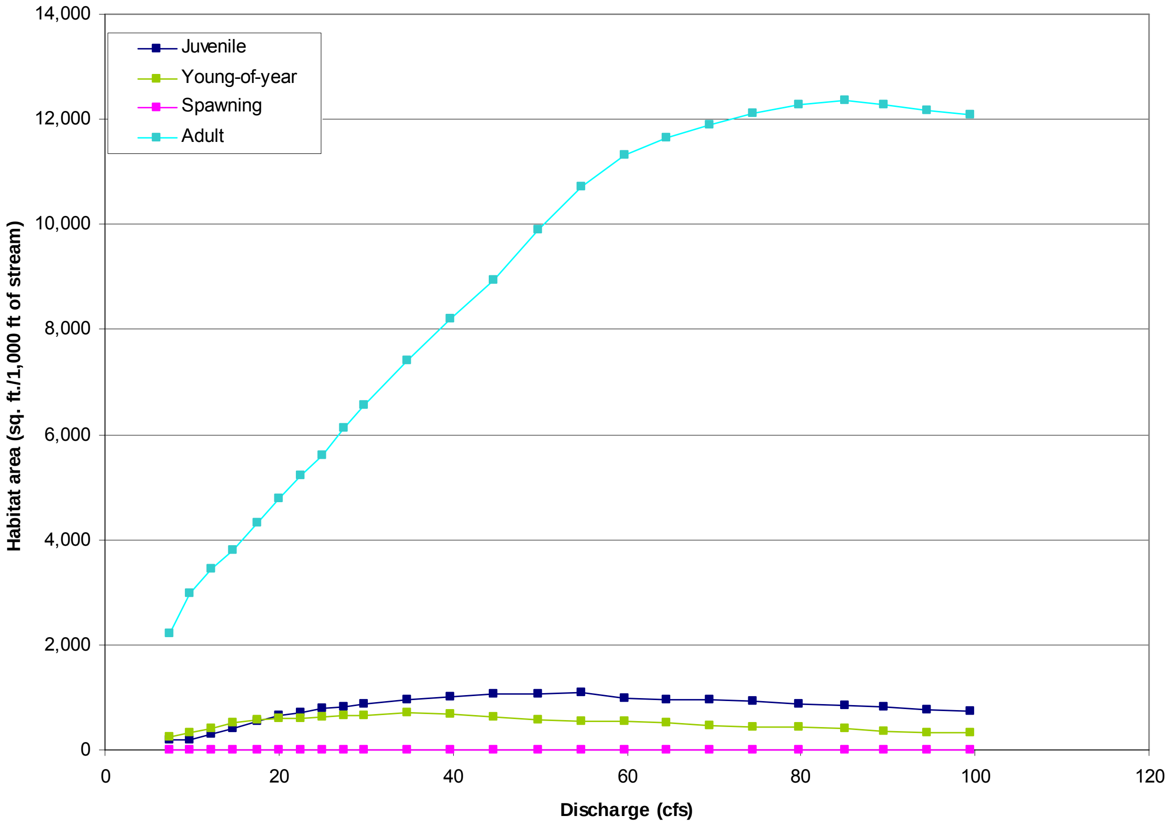
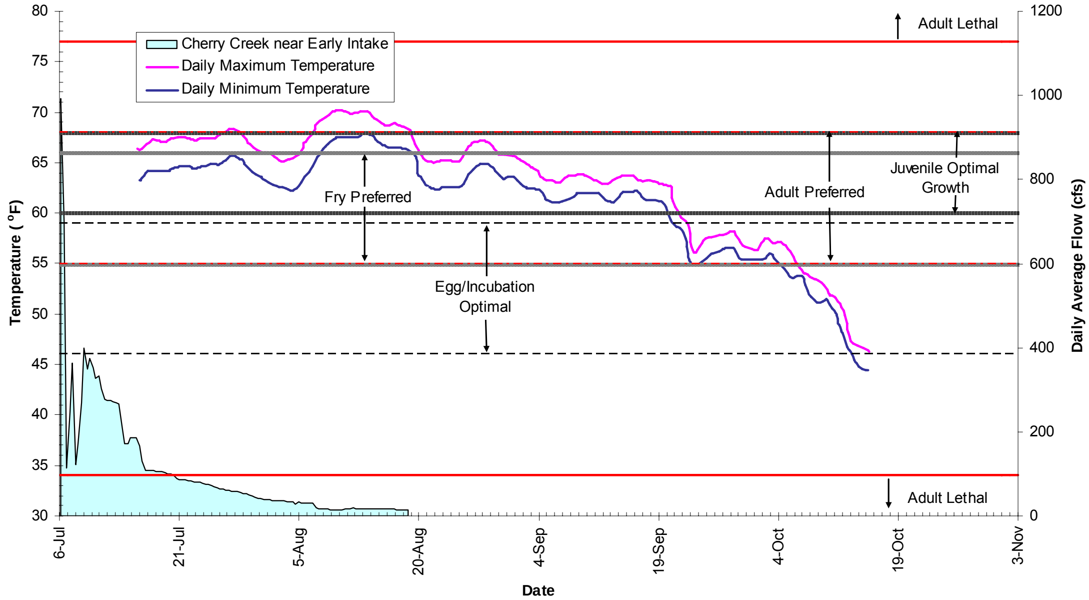


Figure 6-29: Daily Minimum and Maximum Water Temperature in the Lower Cherry Reach in Summer 1981 (Moyle and Baltz 1981) and Rainbow Trout Temperature Thresholds (Moyle and Marchetti 1992).



Foothill Yellow-legged Frog

No available studies or surveys for foothill yellow-legged frogs or other amphibians in Cherry Creek were identified during the course of this project. The current and historic presence or absence of this species in the reach, therefore, is not known. The reach is within the elevation range of the species, and foothill yellow-legged frogs were identified at similar elevations along the Clavey River in surveys conducted by the USFS in 2001 (USFS, unpublished data). This suggests that foothill-yellow legged frogs might potentially occur in this reach. If this species does breed in the reach, it would be sensitive to rapid flow fluctuations from changing releases from Cherry Valley and Eleanor dams.

Benthic Macroinvertebrates

No available studies or surveys for benthic macroinvertebrates in Cherry Creek were identified during the course of this project. Water temperature data from 1981 (the only temperature data available to date; Moyle and Baltz 1981) suggest that warm spring and summer water temperatures may reduce benthic macroinvertebrate production in this reach relative to unregulated conditions.

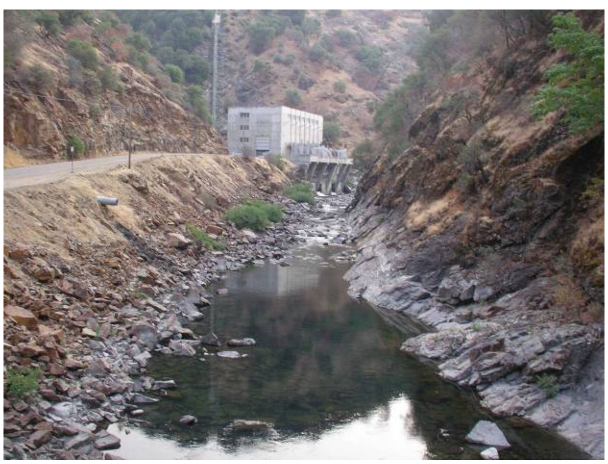
6.4 Cherry Creek - Holm Reach

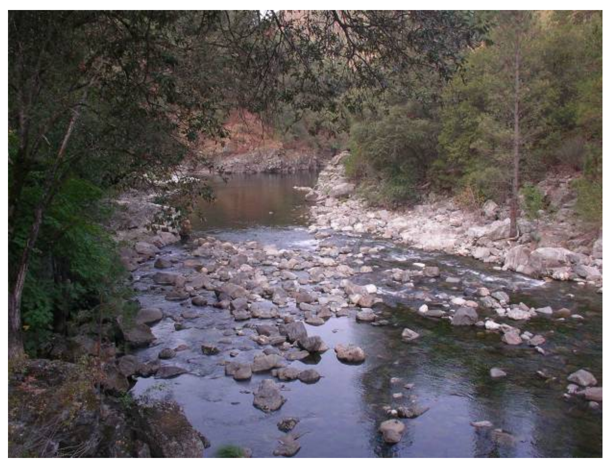
6.4.1 Geomorphology

The best quantitative information on the Lower Cherry Reach geomorphology is the post-dam USGS flow data at the Cherry Creek below Holm Powerhouse gaging station (USGS 11-278400). This gage is approximately half-way between the Holm Powerhouse and the Tuolumne River confluence, and when contrasted with the Cherry Creek near Hetch Hetchy gaging station, effectively isolates the effect of the Cherry Power Tunnel diversion on flows to the reach. Similar to the Cherry Creek near Hetch Hetchy gage, this gaging station was installed in 1962, and there is not a direct comparison with pre-dam flow data. However, this gaging station is downstream of the Holm Powerhouse and all diversions, so the entire natural flow volume of the watershed passes through this reach, albeit severely regulated by upstream reservoirs and Holm powerhouse operation.

The Holm Reach is also downstream of the nick point where the rapid incision of the streams into the uplifting Sierra Nevada range tapers off, yet the gradient decreases from the 4.7% gradient in the Lower Cherry Reach to 2.7% in the Holm Reach (Figure 6-10). The reduction in high flow regime from Eleanor Dam, and in particular, Cherry Valley Dam, has likely reduced bed mobility frequency, but the change in the Holm Reach continues to decay due to tributary accretion and flow return through Holm Powerhouse. While Cherry Valley Dam has reduced sediment supply from the upper watershed, substantial coarse sediment delivery to the channel from valley walls and tributaries between Cherry Valley Dam and the Holm Reach greatly mitigates coarse sediment lost from the upper watershed. Due to the substantial high flow contribution from Eleanor Creek and the return flows from Holm Powerhouse, riparian and upland encroachment into the channel is much less, and the vegetation has little to no impact on geomorphology of the stream in the Holm Reach. The substrate of the reach is characterized by large boulders with periodic bedrock exposures (Figure 6-30). The lower slope may also allow the boulders to organize into bar features where valley width permits. Our one-day field review encountered less cobble, gravel, and sand storage in hydraulically sheltered areas behind large boulders and bedrock outcrops than was observed in the Lower Cherry Reach (Figure 6-27). One possible hypothesis for this observation (if accurate) is that the 1,000 cfs flow fluctuations from Holm Powerhouse over time has winnowed sand, gravel, and small cobbles from storage in the Holm Reach.

Figure 6-30: Holm Reach of Cherry Creek Reach Looking Upstream at Holm Powerhouse (Left Photo) and Looking Downstream Towards the Tuolumne River Confluence (Right Photo). Note Sparse Riparian Vegetation in the Active Channel, Boulder Substrate with Gravel/Cobble Pockets, and Steep Channel Gradient.





6.4.2 Water Temperature

Water temperatures in Cherry Creek below Holm Powerhouse are largely driven by how much water is being diverted from Cherry Lake through the Holm Powerhouse. Flows in this reach are much higher in the summer for the post-dam period due to power generation and recreational flows. If the Cherry Power Tunnel intake elevation is in the hypolimnion, then summer water temperatures would be much colder (due to augmented flows of colder water than in the stream) and winter water temperatures may be the same or slightly warmer. If the intake elevation is in the epilimnion, then summer and winter water temperatures may be similar to that prior to the dams. Review of 2006 and 2007 temperatures suggests that: 1) fall and winter water temperatures fluctuate more when diversion flows fluctuate (see 2007 data in Appendix H), 2) the range of daily water temperatures is larger when no diversions occur (see 2006 data in Appendix H) than when diversions occur, and 3) water temperatures with and without diversions are usually within preferable tolerances to rainbow trout. These hypotheses are solely based on the two partial years shown in Appendix H, so additional data collection is needed to evaluate and refine these hypotheses.

6.4.3 Riparian Vegetation

No available studies or surveys of riparian vegetation specifically related to Cherry Creek below the Holm Powerhouse were identified during the course of this project. The relationship of riparian vegetation dynamics to substrate, topography and hydrologic environments along Cherry Creek below Holm Powerhouse is described based on qualitative observations made during a limited field reconnaissance conducted in fall 2006.

The combination of flood peaks contributed from Eleanor Creek and releases from Holm Powerhouse appear to have inhibited woody riparian vegetation from establishing on alluvial deposits in the active channel, except as occasional individual trees or shrubs. Although the valley confinement is high, point bars and instream deposits have formed at a few locations in this reach. Dense bands of riparian woody plants have been inhibited from encroaching along the summer baseflow water surface in this reach (Figure 6-31).

Figure 6-31: Point Bar on Cherry Creek Downstream of Holm Powerhouse, Illustrating the Lack of Perennial Herbaceous Plants within and along the Low-Water Channel.

Similar to the upstream reaches of Cherry Creek closer to the dam, the willow species richness in the Holm Reach was lower than that found on streams with unimpaired snowmelt hydrology. Red willow and dusky willow were common, arroyo willow was occasionally observed and narrowleaf willow was rarely observed. The presence of red willow suggests that the snowmelt hydrograph plays a role in riparian woody plant recruitment, though the presence of arroyo willow suggests that rainfall also plays an important role. The fact that red willow was more common than arroyo suggests that the snowmelt hydrograph plays a more formative role than the rainfall hydrograph in riparian woody plant recruitment in this reach. Dusky willow is common on less regulated Sierra Nevada streams (i.e., the Clavey) where stable summer baseflows facilitate the establishment of dusky willow. The presence and rarity of narrowleaf willow suggests the beginning of a transition to plant species typical of lower elevations ranges.

Flow fluctuations from Holm Powerhouse also affect riparian plant distribution. In unregulated streams (such as the Clavey River), spring-time diurnal fluctuations of 1-3 ft are typical and inhibit woody riparian plants from colonizing most channel deposits. As snowmelt recession continues into early summer, the magnitude of diurnal fluctuations decreases, and plants can colonize exposed substrate along the active channel. In the Holm Reach, powerhouse releases result in daily water surface fluctuation of 0.9–2 ft. These operations effectively extend extreme diurnal fluctuations throughout the entire growing season, thus preventing plant initiation within 2–4 ft of the summer baseflow elevation. Herbaceous perennial plants (such as Indian rhubarb, sedges, and grasses) are limited to rare small clumps along the low-water margin because they cannot establish elsewhere on in-channel bars.

6.4.4 Analysis Species

Rainbow Trout

No available studies or surveys for rainbow trout in the Holm Reach were identified during the course of this project. This reach is expected to support trout, though the habitat area:flow relationships, trout density, and trout age-class structure are not known. Trout in this reach are affected by daily flow fluctuations resulting from power generation and recreation flow releases. Such rapid changes in flow could subject incubating eggs to scour and desiccation, displace fry, and reduce adult and juvenile growth rates. Cold-water releases from Holm Powerhouse (which Lewis [1989] states are 50°F) likely exclude Sacramento sucker and Sacramento pikeminnow from this reach.

Foothill Yellow-legged Frog

No available studies or surveys for foothill yellow-legged frogs or other amphibians in Cherry Creek were identified during the course of this project. The current and historic presence or absence of this species in the reach, therefore, is not known. The reach is within the elevation range of the species, and foothill yellow-legged frogs were identified at similar elevations along the Clavey River in surveys conducted by the USFS in 2001 (USFS, unpublished data). This suggests that foothill-yellow legged frogs might occur in this reach. If this species does breed in the reach, it would be sensitive to rapid flow fluctuations from changing releases from Cherry Valley and Eleanor dams.

Benthic Macroinvertebrates

No available studies or surveys for benthic macroinvertebrates in Cherry Creek were identified during the course of this project. Assuming that water temperature in this reach is around 50°F, water temperature should be within the highly productive range for benthic macroinvertebrates. The habitat area:flow relationships are not known. Also, benthic macroinvertebrates in this reach are affected by daily flow fluctuations resulting from power generation and recreation flow releases.

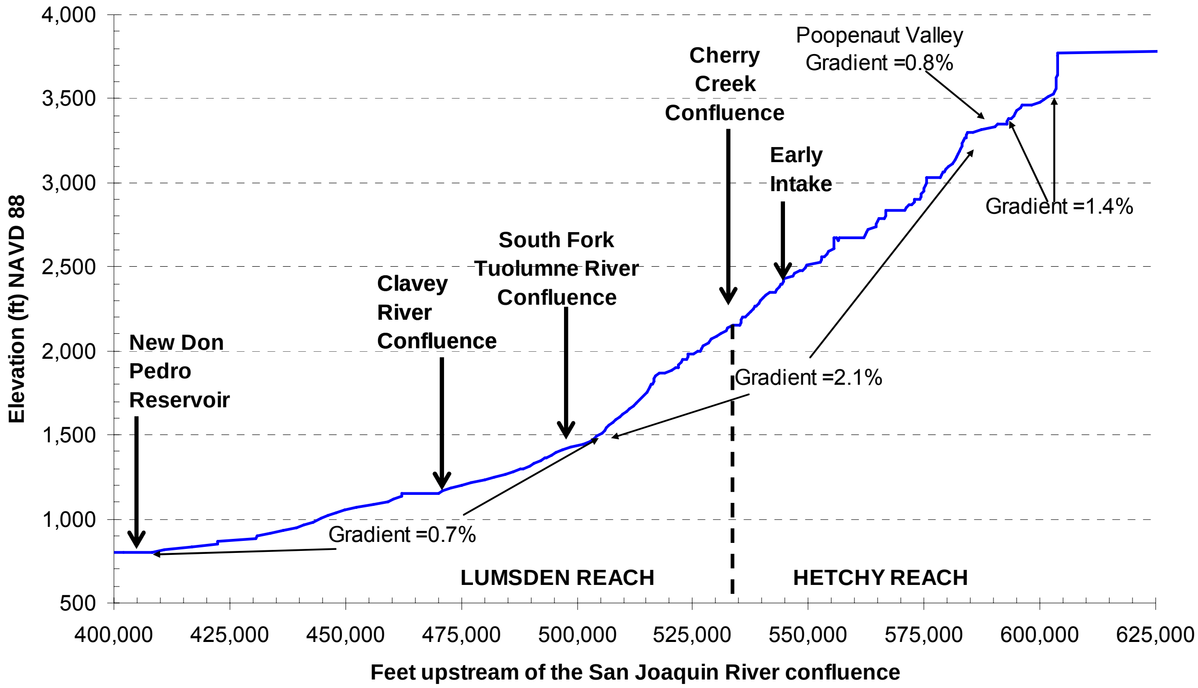
6.5 Tuolumne River – Hetchy Reach

6.5.1 Geomorphology

Descriptions of gaging stations in 1918 USGS Water Supply Papers, general description in Freeman (1912), historic ground photos from Hetch Hetchy archives, the pre-dam and post-dam USGS flow data at the Tuolumne River near Hetch Hetchy gaging station (USGS 11-276500), and our 2006 field reconnaissance provide helpful quantitative information on the Hetchy Reach geomorphology. The USGS gaging station is approximately ½ mile downstream of O’Shaughnessy Dam and has been in operation since water year 1911. The natural hydrology for the Hetchy Reach as measured by this station, including project-induced hydrologic changes, is described in Section 5, and will be referenced as it applies to the geomorphic description in this reach.

The Hetchy Reach is geomorphically significant because the reach is immediately downstream of O’Shaughnessy Dam where geomorphic impacts would be expected to be most pronounced. Furthermore, the channel morphology tends to adjust more dramatically in alluvial settings rather than confined, boulder-bed settings. Poopenaut Valley is very low gradient (0.8%, Figure 6-32), with a wide valley and bed comprised of small gravel and sand. This reach is likely the most impacted by O’Shaughnessy Dam, thus more focus is given to this subreach of the Hetchy Reach in the discussion below.

Figure 6-32: Tuolumne River Profile from O'Shaughnessy Dam to Cherry Creek Confluence from USGS 10 m Digital Elevation Model.



Discussing pre-dam conditions in the reaches downstream of the O'Shaughnessy Dam site requires some discussion of pre-dam conditions upstream. First, the Hetch Hetchy valley was glaciated up to the top of the valley walls during the Tioga glaciation, extending downstream toward Early Intake, whereas Yosemite Valley was not (Huber 2004). After the retreat of the glaciers and return of fluvial processes, Hetch Hetchy Valley evolved similarly to Yosemite Valley on the Merced River: a meandering, alluvial, gravel-bed reach that had periodic overbank floods onto the valley floor. Despite steep upstream reaches, including cascades and water falls, the geologic control at the downstream end of the Hetch Hetchy valley likely lessened slope in the valley to the point where all particle sizes larger than cobbles were trapped at the head of the valley. Hetch Hetchy Valley was likely a cobble and boulder filter, preventing these size particles from routing downstream until the next glacial period scoured the valley floor again. USGS (1918) describes the river bed at the gaging station in Hetch Hetchy Valley as being "composed of gravels" and "banks are high but subject to overbank flow", whereas they describe the river bed at the gaging station below O'Shaughnessy Dam (but above Poopenaut Valley) as being "composed of boulders." This hypothesis should be field checked by a reconnaissance of Yosemite Valley; however, if this hypothesis holds true, the implications are that the reach immediately downstream of O'Shaughnessy Dam, as well as the reach downstream of Poopenaut Valley, likely did not naturally have a supply of coarse sediment with grain sizes larger than small cobble other than from the local valley walls. Cobbles and boulders were observed near the gaging station (Figure 6-33), but may originate from locally derived sources (rockfall) or terminal moraine of the retreating glacier. This is not to say that all the gravel and sand supply was trapped by the Hetch Hetchy Valley, as these sediments certainly routed through the Hetch Hetchy Valley prior to the dam and played an important geomorphic role downstream, particularly in Poopenaut Valley. Additional effort is needed to refine the historic and contemporary sediment story in the Hetchy Reach.

The subreach between O'Shaughnessy Dam and Poopenaut Valley is of moderate gradient (1.4%), has vertical and lateral bedrock control, and has a bed surface composed of boulders and bedrock with a sand veneer in lower-gradient sections (Figure 6-33). Based on observations of the bed here and in Poopenaut Valley, there is a modest sand source within this subreach, but has not yet been identified. Coarse sediment supply is very low, but this is probably similar to pre-dam conditions if Hetch Hetchy Valley was a cobble trap as hypothesized above. The large wood budget has likely been reduced in a similar manner as Cherry Creek because O'Shaughnessy Dam likely traps most large wood transported from upstream reaches. Large wood may be able to route through the spillway, but if allowed to do so by operations, it would likely be broken into smaller pieces as it tumbles down the spillway.

Herbaceous, riparian, and upland vegetation encroachment is pronounced in this subreach, yet the modest fine sediment supply does not allow conspicuous riparian berms to form. As sand supply increases in the downstream direction, it is deposited in channel margins, which tend to encroach with herbaceous plants and create a small vertical bank (Figure 6-33). Observations after the 2006 high flow (8,000 cfs peak) suggest that the large cobbles and boulders within the low flow and channels did not mobilize; lichens on cobbles outside the low flow channel were largely undisturbed. However, some small scale gravel and small cobble depositional features were observed in the center of the low flow channel as a result of the 2006 peak flow, so marginal transport of these grain sizes occurs at 8,000 cfs.

Figure 6-33: Channel Morphology at the USGS Gaging Station Tuolumne River near Hetch Hetchy, Showing Boulder Bed Morphology with Shallow Bedrock, White Alder Riparian Encroachment along the Low Flow Water Edge, Ponderosa Pine and Canyon Live Oak Encroachment onto Pre-Dam Floodplains, and Sand Ribbons on Top of an Infrequently Mobilized Bed Surface (Peak 2006 release of 8,000 cfs did not Appear to Mobilize Cobbles and Boulders).

At the Poopenaut Valley transition, the gradient of the valley drops dramatically, even though the channel remains moderately confined by bedrock (Figure 6-34). The bed surface quickly transforms from bedrock and boulders to that of sand and small gravel, even before the confinement ends at the head of Poopenaut Valley (Figure 6-35). These finer grained sediment sizes deposit as alternate bars where valley confinement permits, and are more completely encroached by riparian vegetation. However, the channel is still moderately confined by the valley walls, and sand and gravel appear to be scoured frequently enough that the riparian encroachment has not dominated channel morphology in this transition zone.

Figure 6-34: Channel Morphology at the Upstream End of Poopenaut Valley in 2006, Looking Upstream Showing Exit of Tuolumne River from Confining Bedrock Valley that Extends to O'Shaughnessy Dam, at Transition Where Bedrock Confinement and Slope Decreases to Allow Small Gravel/Sand Bars to Form Immediately Downstream.

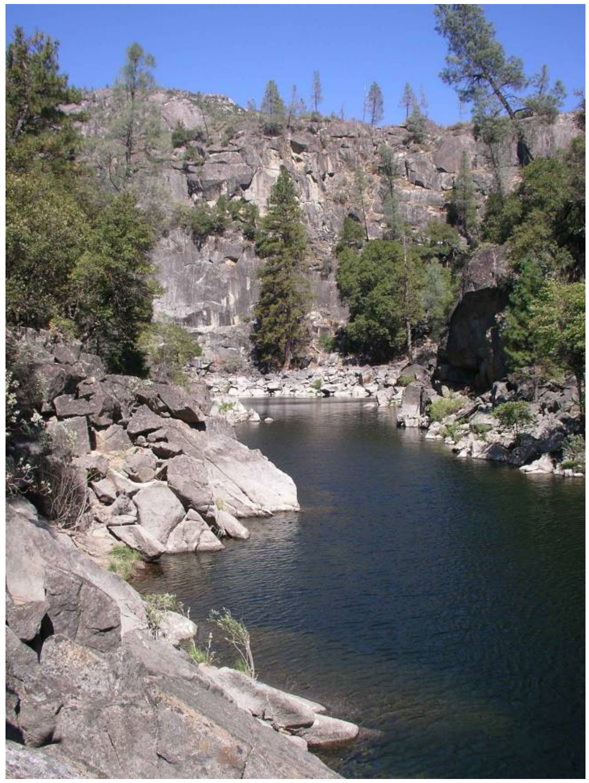
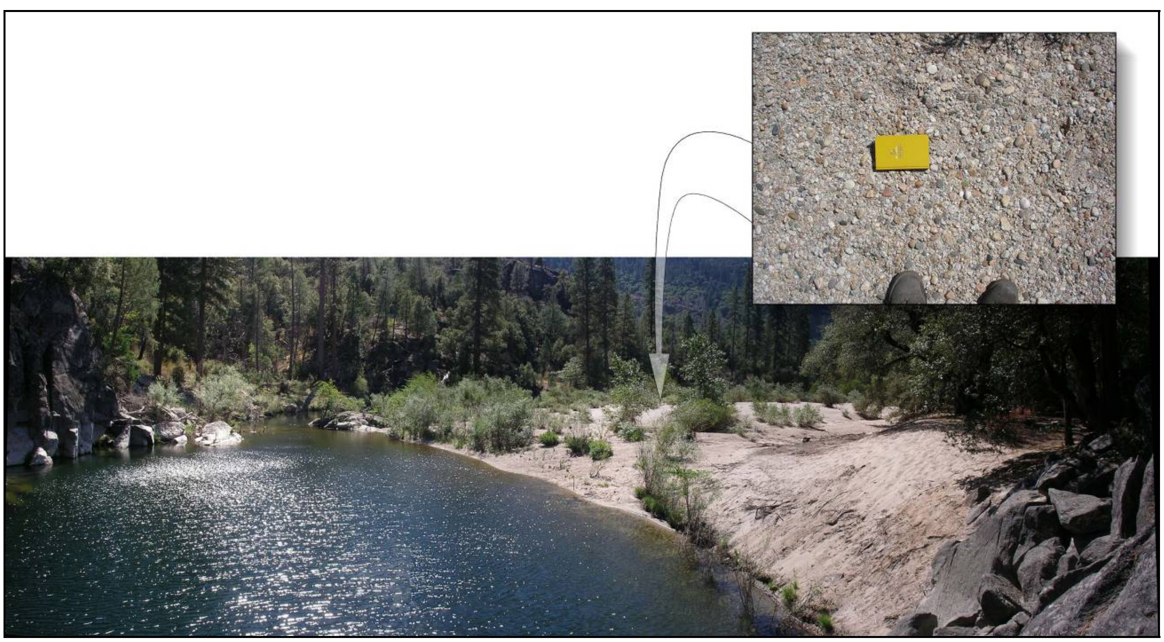
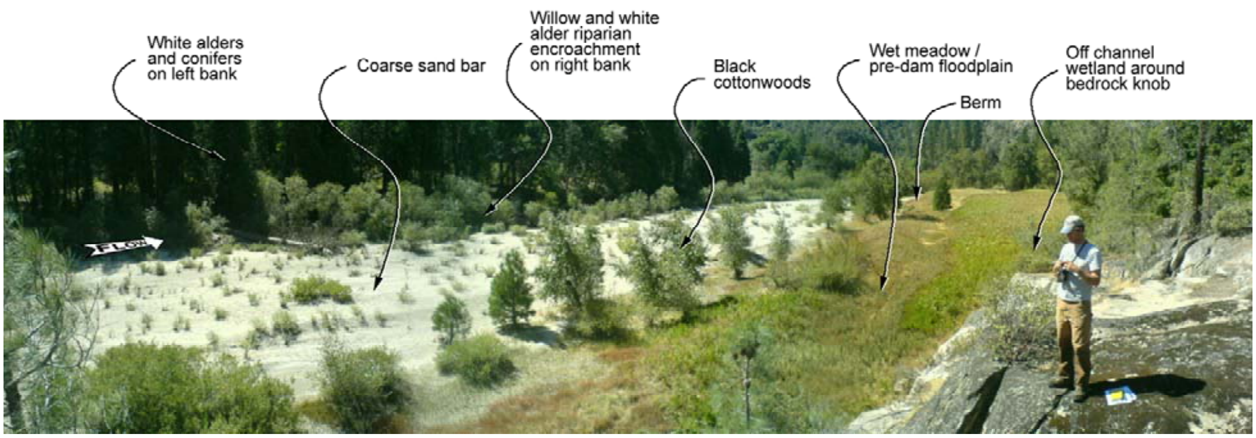


Figure 6-35: Channel Morphology at the Upstream End of Poopenaut Valley in 2006, Looking Downstream Showing Entrance of Tuolumne River into Less Confining Alluvial Valley that Extends to the End of Poopenaut Valley Where Bedrock Confinement and Slope Decreases to Allow Sand/gravel Bars to Form.



As mentioned above, Poopenaut Valley is unique given its low slope (0.8% from the DEM, which is probably a high estimate), low valley confinement, extensive meadows, off-channel wetland on the north bank, high flow scour channels, riparian vegetation, and potential for lateral channel migration. The channel through the valley is typified by a pre-dam floodplain on the south (left) bank with a combination of riparian and upland vegetation, a high flow scour channel on the south bank, riparian encroachment on the north (right) bank, a large sand/gravel bar on the north bank, a meadow and off-channel wetland on the north bank (Figure 6-36). Because of its low gradient alluvial morphology, Poopenaut Valley is more prone to the typical channel adjustments to flow and sediment regulation described in the literature. Many of these adjustments are conspicuous: riparian encroachment is extensive and the channel morphology has simplified as a result (steep banks, rectangular channel geometry). More pronounced coarsening of the bed surface was expected, yet the bed was still comprised of sand and small gravels. Again, the sediment budget story for the Poopenaut Valley needs additional attention.

Figure 6-36: Poopenaut Valley Panorama in 2006, Looking Downstream from the Upstream End of the Valley. Note Riparian Encroachment along the Low Flow Channel Margin and Exposed Sand/Gravel Bar Outside of Riparian Berm, and Meadow/Floodplain Beyond Bar.



Some historical evolution can be extracted from a comparison of 1915 and 2006 photos taken from the road to O’Shaughnessy Dam (Figure 6-37). While the scale and quality of the photo are poor, the location of the channel does not appear to have moved since 1915. Our field reconnaissance also observed the large conifers on the south (left) bank, and it appeared that the river had been anchored to that location for quite some time. Comparison with the 1915 photo also suggests that there has been very little to no channel migration since 1915. McBain and Trush would like to review selected historic maps and/or air photos to determine if there has been any lateral channel movement. This is one of the few locations in the entire project area where a channel could potentially move laterally (not bounded by lateral or vertical bedrock control), but the channel still appears laterally stable through the valley.

One interesting hydrologic change to the Hetchy Reach occurred in 1967 with completion of the Canyon Power Tunnel. Prior to its completion, O’Shaughnessy Dam released elevated summer baseflows (600 cfs to 700 cfs) to deliver water to the Hetch Hetchy Aqueduct and diversion at Early Intake. After completion of the Canyon Power Tunnel, summer baseflows were reduced to between 75 cfs and 125 cfs. Two distinct sequences of riparian encroachment are evident in Poopenaut Valley: a row of white alder rooted approximately one foot above the current low flow water edge and a second band of alders and willows at the current low flow water edge. Both appear to have contributed to some simplification of channel geometry in the Poopenaut Valley. While there was some evidence of riparian berm formation along the north (right) bank, there were no obvious signs of channel incision as a result of reduced coarse and fine sediment supply. This is likely due to the vertical bedrock at the downstream end of Poopenaut Valley controlling the grade of the stream and preventing significant channel incision.

Last, the reduced high flow regime and snowmelt hydrograph have likely reduced the magnitude, duration, and frequency of hydraulic connectivity between the mainstem Tuolumne River and the side channels and off-channel wetlands in the valley, but the degree of this potential change is unknown and needs to be investigated with some data collection.

Much of the discussion above presents preliminary hypotheses of how the Poopenaut Valley subreach historically functioned and evolved, because field data to support or reject them has not yet been collected. The high flow releases provided by the SFPUC in 2006 provided invaluable initial observations to begin framing these hypotheses, and additional work in this subreach of the Hetchy Reach should be a high priority task for 2007 and 2008.

Figure 6-37: Poopenaut Valley in 1915 and 2006, Looking Northwest. Note that the Conifers on the South Bank are much Taller and more Extensive, yet Exposed Sand/Gravel Bar on North Bank appears Similar.

Downstream of Poopenaut Valley, the river enters a steeper, confined canyon. The bed surface is mainly boulders with interspersed bedrock (Figure 6-38), with several falls (Preston Falls) and deep pools. There are no substantial tributaries in the Hetchy Reach to supplement flow and sediment downstream of the dam, so changes to hydrology, sediment, and wood supply caused by the dam continue to influence geomorphic processes and channel morphology downstream. Riparian and upland vegetation encroachment is observable above the low flow channel, which causes some infilling of channel margins, but the morphologic response appears subtle (Figure 6-39).

The diversion dam at Early Intake is small, and has filled with coarse sediment to the point where it likely allows full routing of fine and coarse sediment through the backwater of the dam. Some reconnaissance-level evaluation should be conducted to confirm this.

Figure 6-38: Looking Downstream from Below Preston Falls (Upstream of Early Intake) Showing Boulder Bed Channel Morphology and Subtle Riparian Encroachment into the Active Channel.

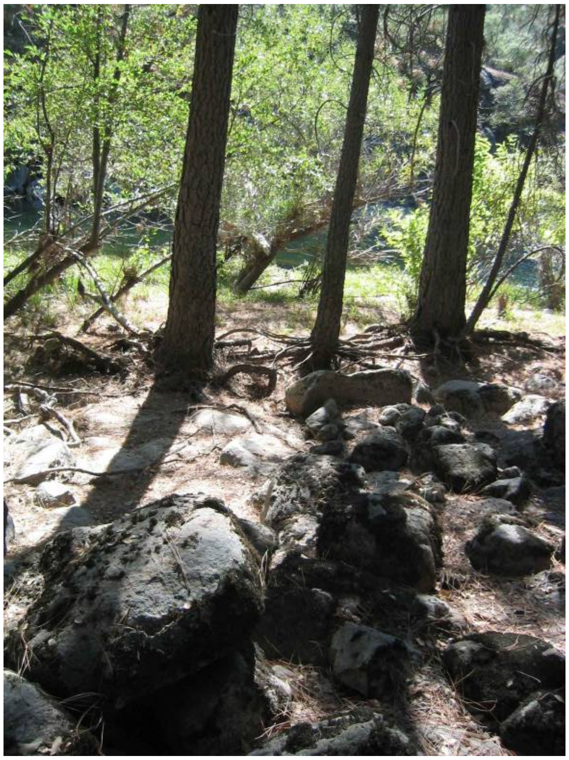
6.5.2 Water Temperature

Like Cherry Valley Dam, O’Shaughnessy Dam also reverses the seasonal water temperature regime in downstream reaches by releasing warmer than natural water in the winter, and colder than normal hypolimnial releases in the summer months (Appendix J). Winter release temperatures are likely 5-6º F warmer than what would occur without the dam in place, and summer release temperatures are likely 10-15º F cooler than what would naturally occur. As described for the Cherry Creek reach, the elimination of the snowmelt hydrograph in drier years and reduction in magnitude and duration during normal and wetter years likely increases spring and early summer temperatures in downstream reaches, such that the length of river downstream of the dam with preferable water temperatures is likely shorter than pre-dam conditions. The reduced stream length with preferable water temperatures could correspondingly reduce benthic macroinvertebrate production, reduce fish growth, and benefit exotic warm-water fish species.

6.5.3 Riparian Vegetation

Information about riparian vegetation specifically related to the upper Tuolumne River below O’Shaughnessy Dam is limited to the Yosemite National Park vegetation inventory and a nonnative plant inventory (TNC 1998, PRBO 2005). Both inventories, however, were very broad, and no local descriptions were included. The relationship of riparian vegetation dynamics along the Tuolumne River below the O’Shaughnessy Dam to substrate, topography and hydrologic environments is described based on qualitative observations made during 2006 field reconnaissance. Riparian woody plant encroachment trends are briefly discussed for the river segment near O'Shaughnessy Dam, but the focus in this reach is placed on riparian vegetation trends in Poopenaut Valley.

Figure 6-39: Riparian and Upland Vegetation Encroachment in the Historic Active Channel between Early Intake and Preston Falls. Note Lichens Growing on Boulders and Alder, Willow, and Ponderosa Pine Encroaching on Previously Active Alluvial Deposits, Indicating a Long Period of Boulder Inactivity, yet Sand has been Scoured from Root Crowns by 2006 High Flows (8,000 cfs).



Near the USGS gage downstream of the O'Shaughnessy Dam, the Tuolumne River is confined. Where alluvial deposits form, riparian woody plant species have encroached onto the bars along the summer water edge. Typical of other impaired streams in the Tuolumne River watershed, shiny willow and white alder have encroached along the low-water edge while ponderosa pine has encroached onto upper bar surfaces and floodplains (Figure 6-33). White alder is common, with individuals often growing on in-channel bars and also growing in bands along the summer low-water edge. A younger even-age band of alders is present, which presumably established in association with the 1997 flood.

Downstream of O'Shaughnessy Dam, the Tuolumne River enters Poopenaut Valley, where there is little or no bedrock confinement. The Poopenaut Valley has the highest richness of willow-related species of all stream reaches assessed for this study. On the valley floor, black cottonwood is common, which is unusual because it was rarely observed on other stream reaches assessed in this study. The valley has the highest abundance of black cottonwood in the Hetchy Reach, but most of the black cottonwood population grows in areas away from the main channel along small tributaries. Black cottonwood is not found in the dense thickets of willows lining the channel at the downstream end of the valley. Red willow and shiny willow are equally abundant. Dense thickets of young red and shiny willow (i.e., 15 yrs old) grow along the summer baseflow water edge within the valley (Figure 6-40). Ponderosa pine, white fir, cottonwood, white alder, red willow and shiny willow border the summer baseflow water edge at the upstream end of the valley. Two age classes of alder are evident at the upstream end of the valley, suggesting a shift in flow operations.

Figure 6-40: Riparian Vegetation Conditions in Poopenaut Valley. Note Woody Plants Grow in Dense Thickets along the Summer Water Edge at the Downstream End of Poopenaut Valley.

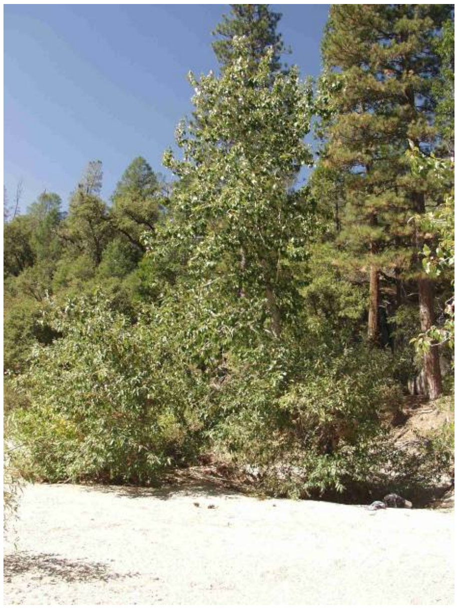
Meadows make up most of the valley floor and consist of wet and dry meadow areas (Figure 6-41). Wet meadows have a higher abundance of sedges and wetland grasses while dry meadows have more mesic grass species associated with them. Wet meadows are inundated for a portion of the year and exhibit wetland characteristics; dry meadows are typically inundated for short periods. Dry meadow grasses included some forage grasses indicating some historic grazing effects. The balance of wet and dry meadows is maintained by the annual pattern of groundwater recharge provided by streamflows in the mainstem and is susceptible to changes in annual groundwater dynamics. White fir and ponderosa pine species are beginning to encroach into the meadow. The encroachment of upland species into the meadows suggests a long-term reduction in the duration and magnitude of saturation in the valley. Although O'Shaughnessy Dam operations have altered the magnitude and duration of spring snowmelt runoff, the prolonged summer water table is still high enough to create soil moisture conditions that inhibit widespread conifer encroachment in the valley bottom.

A few individuals of Himalaya blackberry (*Rubus discolor*) were seen in Poopenaut Valley. Himalaya berry is ubiquitous in riparian systems throughout the state; however, the low numbers of individuals present in the valley makes eradication feasible. Himalaya berry could possible re-establish itself from sources upstream near the dam, but a large infestation could be inhibited in the valley through limited annual visits and plant removal.

During the 2006 field reconnaissance, the depositional history around a senescent single black cottonwood was assessed. The old black cottonwood was growing on a sand bar just upstream of Poopenaut Valley (Figure 6-42). The canopy of the cottonwood was scrappy and mechanically damaged, indicating the tree's old age. Based on its size and stature, the black cottonwood established on the sand bar either shortly before, or just after, O'Shaughnessy Dam was completed. The pattern of root whorls suggests that the tree has undergone at least four episodes of deposition that have since been scoured away by recent floods. The original root crown was easily exposed, and a marked transition from a fine grained sand to very coarse sand occurred where the cottonwood germinated and began growth (Figure 6-42).

Figure 6-41: Typical Wet and Dry Meadow Mosaic Found in Poopenaut Valley.

Figure 6-42: Senescent Black Cottonwood where a Brief Depositional History was Assessed. Note the Transition from Coarse to Fine Sand at the Root Crown where the Tree Originally Germinated.



Riparian vegetation in this reach is unusual when compared to other stream reaches assessed for this study. Black cottonwood is locally abundant along tributaries where presumably the snowmelt hydrograph is intact. The Poopenaut Valley is the only place visited with substantial numbers of black cottonwood. The Poopenaut Valley has the least confined valley width below Hetch-Hetchy which equated to the largest amount the off-channel wetland complexity. The summer water table is high, allowing shallow ponds and available soil moisture to persist well into the summer, and providing off-channel wetland conditions and creating wet and dry montane meadow habitats. Because the balance between wet and dry meadows and the inhibition of conifer encroachment is currently maintained by mainstem streamflows, vegetation in the Poopenaut valley is likely sensitive to subtle shifts in the timing, magnitude and duration of annual spring dam releases.

6.5.4 Analysis Species

Rainbow Trout

Fish species found in the Hetchy Reach include brown trout (non-native), rainbow trout, Sacramento sucker, California roach, and riffle sculpin (USFWS 1976, Vondracek 1985, USFWS 1992). Prior to fish stocking, the Hetchy Reach may have been the upstream limit of "native" rainbow trout in the Tuolumne River, since native trout apparently did not reach Hetch Hetchy Valley (elevation 3,600 ft) (Moyle et al. 1996). Rainbow trout and brown trout are the only species recorded upstream of Preston Falls (RM110), except for a single observation of California roach. Preston Falls is a natural barrier to upstream distribution of native freshwater fishes other than trout in this reach. Roach are common in Hetch Hetchy reservoir (M. Horvath, SFPUC, pers. comm.) and can enter the reach during spills from the reservoir (Bell et al. 1980). Brown trout (non-native) predominate in the uppermost portions of the reach but become proportionally less abundant in the downstream direction. Rainbow trout predominate in the lowermost reach, downstream of Preston Falls. Abundance of other native fishes from Preston Falls to Early Intake has not been quantified, but Moyle observed in 1986 that California roach were present only in low numbers in this reach (Moyle and Marchetti 1992). Early Intake Diversion Dam forms a barrier to upstream fish migration at the downstream end of the reach (USFWS 1976, Bell et al. 1980). Rainbow and brown trout have been observed aggregating at the base of the dam in fall (Lewis 1978). The effect of this barrier on fish populations upstream is not known. Fish can migrate downstream over Early Intake Dam during spills.

Several studies of trout habitat and abundance have been conducted in this reach, including two IFIM model studies, five fish abundance surveys, habitat mapping, benthic macroinvertebrate surveys, and temperature monitoring (Table 6-5). All of the trout studies listed in Table 6-5 divide the Hetchy Reach into five sub-reaches, as follows:

- O'Shaughnessy Sub-reach (2.7 miles) from the base of O'Shaughnessy Dam to the upstream end of Poopenaut Meadow;
- Poopenaut Valley Sub-reach (0.9 miles) from the upstream end of Poopenaut Meadow (at "Big Pool") to Tuolumne Gorge;
- Tuolumne Gorge Sub-reach (4.3 miles) from the downstream end of Poopenaut Meadow to Mather Pool
- Preston Falls Sub-reach (2 miles) from Mather Pool to Lower Preston Falls; and
- Early Intake Sub-reach (2.5 miles) from Lower Preston Falls to Kirkwood Powerhouse (0.5 miles upstream of Early Intake Diversion Dam).

The geomorphic characteristics of these sub-reaches are described in Section 6.6.1. Except in Poopenaut Valley, the Hetchy Reach is dominated by deep pools, cascades and pocket waters, which comprise 45.6%, 16.5%, and 20% of the total reach length, respectively (Figure 6-43). In Poopenaut Valley, the river channel is low-gradient and sand-bedded, and long-runs are the dominant habitat type. In this sub-reach, Poopenaut Meadow and shallow side channels that parallel the river through the meadow also provide extensive potential, shallow-inundated trout rearing habitat during high spring and summer flows. The predominance of brown trout in the upstream portions of the reach may be driven by lower water temperatures (e.g., Moyle and Marchetti 1992) or the prevalence of deep pool habitat in the upstream sub-reaches. Where rainbow and brown trout co-occur, they may compete for food and space but can coexist by occupying different locations and using different feeding strategies. Brown trout are usually found in pools feeding on bottom invertebrates and other fish, while rainbow trout are most likely to reside in riffles feeding on surface insects and drift (Moyle 2002). Riffles are uncommon in the Hetchy Reach, comprising only 2.3% of the total reach length. The USFWS (1976) concluded that riffle habitat, which is critical to spawning and rearing, is very limited in the reach and is sensitive to changes in flow magnitude.

The 1976 IFIM study focused exclusively on the effects of flow on trout habitat at five riffle transects (USFWS 1976).

Table 6-5: Fish Habitat and Abundance Surveys Available for Hetchy Reach of Tuolumne River.

Survey/Study	Comments	Source
IFIM/PHABSIM	Based on five riffle transects, calibrated for eight flows ranging from 35 cfs to 200 cfs 1968–1970.	USFWS 1976
	Based on 29 transects in six habitat types, calibrated for 25 cfs, 125 cfs, and 250 cfs 1987–1990	USFWS 1992
Habitat Mapping	From 1:3,684-scale aerial photographs taken in 1968 during a flow of 75 cfs.	Bell et al. 1980
	Field surveys conducted in spring 1988 during a flow of 60 cfs	USFWS 1992
Trout Abundance	Rotenone at four locations in 1970 and 1977	USFWS 1976, USFWS 1981
	Snorkel surveys in each of five subreaches, location stratified by habitat type (pool, run, riffle) totaling 12,572 ft (19.7% of the reach) in 1985 and 1988–1990	Vondracek 1985, USFWS 1990
Benthic Macroninvertebrate Biomass and Composition	Monthly Surber samples at five IFIM riffle transects spring through fall 1968, 1969, 1970	USFWS 1976
Water Temperature	Monitored nr Hetch Hetchy and above Early Intake (1989–2006)	USGS 2006

The USFWS estimates that the Hetchy Reach supports approximately 6,000–9,000 adult trout (Figure 6-44). The 1976 and 1977 surveys used mark-recapture methods to estimate abundance. The 1985 and 1988–1990 surveys all used the same snorkel methods and locations. The results of the snorkel surveys should be reasonably comparable, although confidence limits are not known. The snorkel surveys, however, are not directly comparable to the mark-recapture surveys, but results can be used to compare overall increases and decreases in trout population with caution (USFWS 1991).

Using the PHABSIM predictions (which do not include temperature), the USFWS (1992) concluded that “flows as low as 80 cfs would provide at least 90% of the maximum predicted area of adult trout habitat within the study reach,” and “flows as low as 20 to 30 cfs would provide at least 90% of maximum habitat for area predicted for juvenile rainbow and brown trout.” When temperature was considered, however, the USFWS (1992) concluded that temperature may be “the most critical habitat parameter influencing the trout population below Hetch Hetchy Reservoir” and recommended higher flows to maintain temperatures below 70^{o}F (USFWS 1992).

Figure 6-43: Habitat Types in the Hetchy Reach Mapped at 60 cfs in Spring 1988 (USFWS 1992).

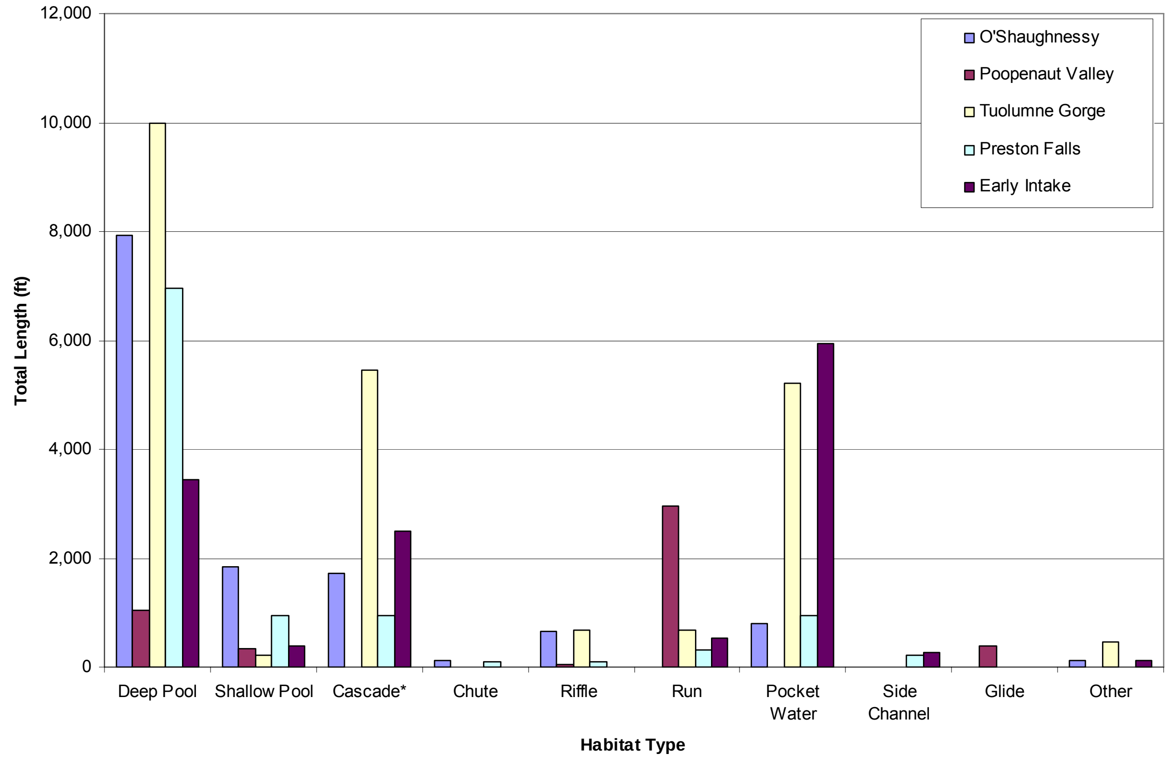
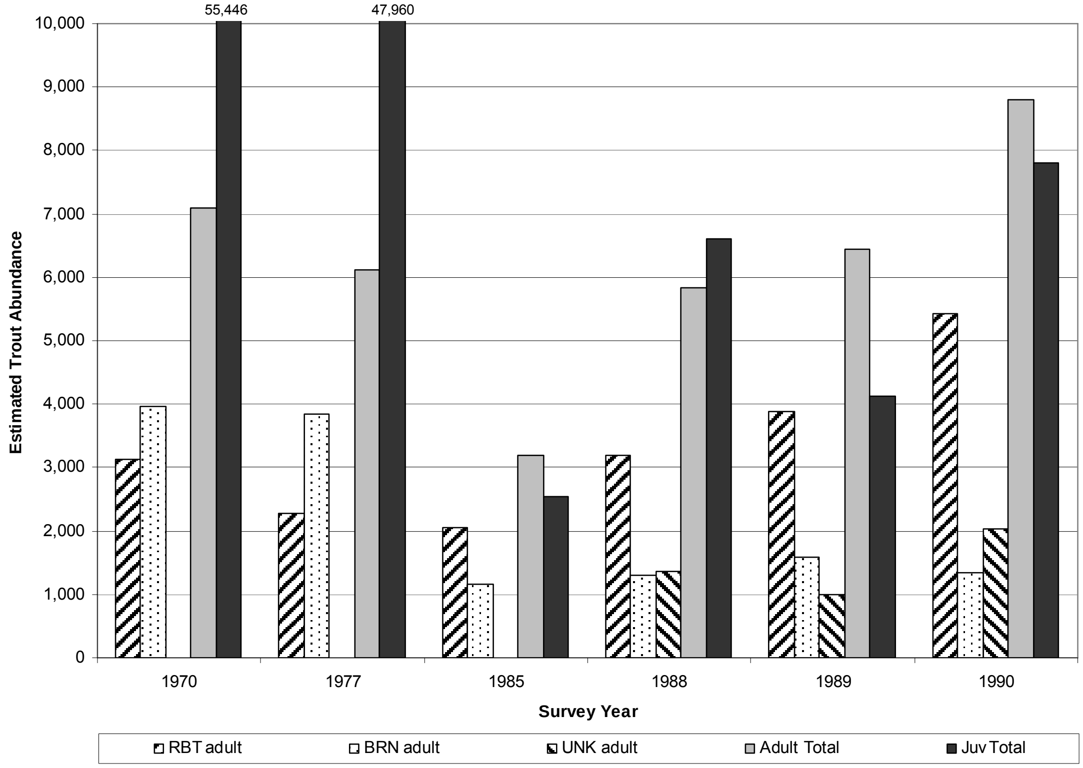


Figure 6-44: Trout Abundance in the Hetchy Reach – 1970, 1976, 1985, and 1988–1990.



Water temperature is likely an important factor limiting rainbow trout habitat and abundance in the lower Hetchy Reach. In some years, daily average and/or daily maximum water temperature exceeds optimal thresholds for adult and juvenile rainbow trout (Figure 6-45 and Figure 6-46). Since temperature monitoring began in 1989, average daily water temperature above Early Intake exceeded 68°F in nine of 17 years, including two wet runoff years, two normal runoff years, three dry runoff years, and two critically dry runoff years (Table 6-6). Maximum daily water temperature above Early Intake exceeded 68º F in 16 of 17 years (Table 6-7). Higher temperatures tend to occur in June, July, and August, and therefore probably have the greatest affect on juvenile and adult rainbow trout (Figure 4-6).

Table 6-6: Number of Days that Daily Average Water Temperature above Early Intake Exceeded 68°F.

Water Year	Water Year Type	Number of Days					
		April	May	June	July	Aug.	Sept.
1989	Normal	0	0 0		0 0		0
1990	Dry	0	0 0		9 0		0
1991	Dry	0	0 0		0 0		0
1992	Dry	0	7 7		4 0		0
1993	Wet	0	0 0		0 0		0
1994	Critically Dry	0	0 10		30 5		0
1995	Extremely Wet	0	0 0		0 0		0
1996	Wet	0	0	0 11	8		0
1997	Extremely Wet	0	0 0		0 0		0
1998	Extremely Wet	0	0 0		0 0		0
1999	Normal	0	0 0		0 0		0
2000	Normal	0	0 0		0 0		0
2001	Dry	0	0 1		3 0		0
2002	Normal	0	0	0 11	0		0
2003	Normal	0	0	0 19	0		0
2004	Dry	0	0	0 22	0		0
2005	Wet	0	0 0		4 0		0

Figure 6-45: Daily Average Water Temperature above Early Intake (1989-2005).

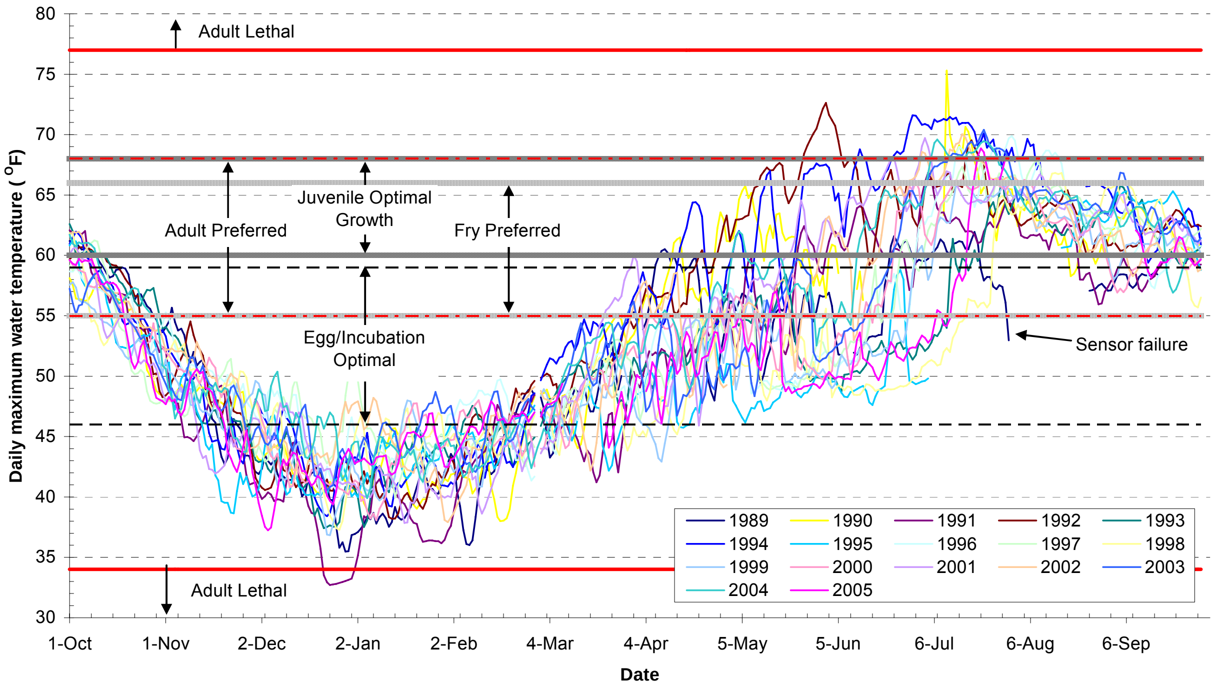


Figure 6-46: Daily Maximum Water Temperature above Early Intake (1989-2005).

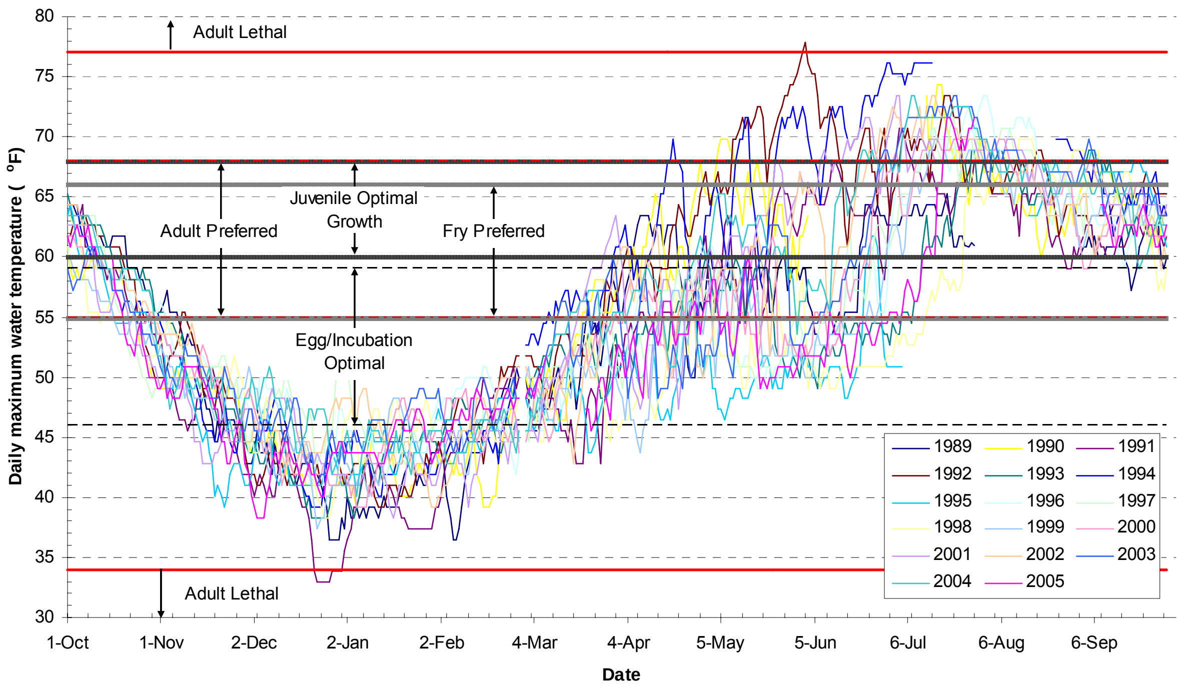


Table 6-7. Number of Days that Maximum Daily Water Temperature above Early Intake Exceeded 68° F.

Water Year	Water Year Type	Number of Days					
		April	May	June	July	Aug.	Sept.
1989	Normal	0	0 0		0 0		0
1990	Dry	0	0	0 11	0		0
1991	Dry	0	0 0		5 0		0
1992 Dry		0	23	17	19	2	0
1993	Wet	0	0 0		0 3		2
1994 Critically	Dry	1	12	25	14[a]	8[a] 1	
1995	Extremely Wet	0	0 0		0 0		2
1996 Wet		0	0	0	18	17	0
1997	Extremely Wet 0		0	0	15 16		0
1998	Extremely Wet	0	0 0		0 9		3
1999	Normal	0	0	0 11	4		0
2000	Normal	0	0	0 23	7		0
2001	Dry	0	0 14		18 9		0
2002	Normal	0	0	7 31	3		0
2003	Normal	0	0	2 30	7		4
2004	Dry	0	0	3 29	2		0
2005 Wet		0	0	0	11	0[a]	0

Footnote:

a. Sensor failed; therefore number of days with maximum temperature above 68° F is likely higher.

Foothill Yellow-legged Frog

No available studies or surveys for foothill yellow-legged frogs in this reach were identified during the course of this project, and surveys conducted for other target species did not record any foothill-yellow-legged frog observations. The presence or absence of this species in the reach, therefore, is not known. The reach is within the elevation range of the species, but potential breeding habitat (open cobble bars) is sparse.

The Poopenaut Valley provides an unusual opportunity to benefit amphibian breeding and rearing habitat area and quality in the upper Tuolumne River. Poopenaut Meadow contains “remarkably undeveloped low-elevation riparian and meadow communities” that are uncommon in the Sierra Nevada (NPS 2006). The ponds and wetlands in the valley are hydraulically connected to surface flow in the river. These ponds and wetlands could provide habitat for western toad (*Bufo boreas*), Pacific treefrog (*Pseudacris* [Hyla] *regilla*), and Yosemite toad (*Bufo canorus*). Because the ponds and wetlands dry up by late summer or early fall (presumably under pre-dam conditions also), potential habitat value for the endangered mountain yellow-legged frog (*Rana muscosa*), which has a multi-year larval stage, is limited. In addition to amphibians, the Poopenaut Valley wetlands and open-water support diverse bird and bat fauna (NPS 2006). Productivity from this wetland, transferred across the landscape by bats and other fauna, may also play a key role in supporting nearby terrestrial fauna (e.g., Pierson et al. 2000, Stillwater Sciences 2003).

Benthic Macroinvertebrates

The USFWS (1976) sampled benthic macroinvertebrates at five riffle locations from late spring through early fall in 1968, 1969, 1970, They concluded that benthic macroinvertebrate production in the reach was very low, possibly due to the “infertility of the water” and “sizeable and sudden changes in flow volume" (USFWS 1976). Analysis of trout gut contents made in conjunction with the invertebrate surveys noted the importance of terrestrial insects in the trout diet. Stomach content analysis of 34 brown and rainbow trout collected May 1970 identified Hymenoptera and Coleoptera as the main component of the trout diet.

6.6 Tuolumne River – Lumsden Reach

6.6.1 Geomorphology

Sources of geomorphic information for the Lumsden Reach of the Tuolumne River are few. The primary geomorphic information sources are USGS topographic maps, USGS digital elevation model (DEM), descriptions in the Clavey-Wards Ferry Project documents, rafting information websites, and our 2006 field reconnaissance. The Tuolumne River near Buck Meadows gaging station (USGS 11-283000) operated between 1910-1936, which captures a short period of flows prior to and after completion of O'Shaughnessy Dam, but does not capture the effect of Cherry Valley Dam and Holm Powerhouse. The combined effect of peak flow reduction from Cherry Valley Dam, Eleanor Lake Dam, and O'Shaughnessy Dam has certainly reduced the frequency of bed mobility, but the impact quickly decreases downstream of the Cherry Creek confluence as valley walls contribute sediment and unregulated tributaries contribute high flows and sediment. Flow fluctuation from Holm Powerhouse is a pronounced hydrologic effect of the project, yet probably is too small to cause significant geomorphic changes in the channel. One possible exception is an observation that gravel and cobble storage within the active channel was lower than expected immediately below Cherry Creek as well as at Lumsden Bridge. This may be a natural feature of larger rivers in a steep confined canyon, and not influenced by project operations, yet observations on similar unregulated rivers may be worthwhile.

The Tuolumne River profile shows a substantial inflection just downstream of the South Fork Tuolumne River (immediately downstream of Lumsden Bridge) where slope decreases from 2.1% to 0.7%. Upstream of this point, valley width is narrow and the channel is primarily boulder-bed with some individual alternate bars (Figure 2-5). Downstream of this point, valley width expands locally allowing boulder alternate bars to form (Figure 2-5) and some side channels and high flow scour channels. The bed surface in both reaches is typically composed of boulders (Figure 6-47). Overall, the project may have caused some geomorphic changes, such as slightly reduced storage of gravels and cobbles within the active channel, and perhaps slight simplification of channel margins, but these changes are likely subtle to non-existent.

Figure 6-47: Tuolumne River Immediately Downstream of Lumsden Bridge, Looking Upstream. Note Boulders with Few Gravels or Sand in Storage, and Compressed Riparian Vegetation Bands.

6.6.2 Riparian Vegetation

There was no information available about riparian vegetation specifically related to the lower Tuolumne River below the Cherry Creek Confluence. The relationship of riparian vegetation dynamics along the Tuolumne River below the Cherry Creek confluence to substrate, topography and hydrologic environments is described based on a qualitative observations made during a limited 2006 field reconnaissance.

Valley walls locally confine the river in this reach, but there are many areas where floodplains, point bars, and instream medial bars provide potential riparian vegetation establishment sites. Flow fluctuation seems to be the primary hydrologic control on riparian vegetation establishment at the upstream end of the reach (i.e., where reconnaissance surveys were conducted in 2006). When the snowmelt runoff peaks in an unregulated river (such as the Clavey River) diurnal flow fluctuations of 1-3 ft are typical and inhibit woody riparian plants from colonizing most channel deposits. As snowmelt recession continues into the early summer, diurnal fluctuations usually decrease in magnitude, and plants can colonize exposed substrate on point bars and other locations in and along the channel. In the Lumsden reach, releases from Holm Powerhouse effectively extend the extreme diurnal fluctuations typical of late spring and early summer throughout the entire growing season, thus preventing plant initiation within approximately 2-4 ft above summer baseflow elevation.

Fremont cottonwoods, alders, and ashes were the dominant woody riparian plants observed near Lumsden Bridge. The dominance of these species and the lack of other higher elevation species, such as black cottonwood, indicate a clear transition into lower elevation, foothill vegetation patterns. In the lower elevation region, rainfall hydrograph components become more important in riparian vegetation establishment and species composition as increased flows during fall and winter rainfall facilitate fall/winter seed dispersal.

Willow species richness near Lumsden Bridge was the lowest of any of the reaches assessed for this study, which probably results from the transition to foothill vegetation combined with the effects of flow fluctuation. Dusky willow was common, and arroyo willow was occasionally observed. Narrowleaf willow was expected to occur at the site but was absent, probably an effect of flow fluctuations. Narrowleaf willow disperses seeds in the summer, when flow fluctuations for power generation and recreation are greatest. Riparian vegetation structural diversity also was low on active channel deposits.

Daily fluctuations in water surface elevation during the growing season inhibit some herbaceous species from colonizing locations within the active channel where they typically grow. Releases from Holm Powerhouse vary local water surface elevations in this reach by 0.4-0.8 ft daily. This daily fluctuation in water surface prevents herbaceous perennial plants, such as Indian rhubarb, sedges, and grasses, from establishing on in-channel bars where they typically occur in unregulated or less regulated streams (e.g., Clavey River and Eleanor Creek).

Large stands of deer grass (*Muhlenbergia rigens*) were observed on floodplain surfaces near Lumsden Bridge (Figure 6-48). Deer grass is shade intolerant, and on most soil types deer grass stands rapidly revert to the surrounding dominant vegetation without the presence of frequent human or natural disturbance. The persistence of deer grass on floodplain surfaces suggests that the disturbance regime is frequent enough to prevent dense riparian stands from forming and shading out deer grass. The presence of deer grass also suggests that the inundation regime is capable of inhibiting conifer encroachment onto upper bars and floodplains

There was not a strong gradation in the bank locations where Ponderosa pine, white alder, Fremont cottonwood, and dusky willow grew (Figure 6-49). Conifers and riparian vegetation both established on pre-dam point bars and floodplains (i.e., upland and riparian plant species all have to grow in the same place). The lack of gradation in channel locations for the observed woody riparian species is consistent with observations and descriptions of riparian vegetation patterns along streams downstream of large storage reservoirs (i.e., the lower Tuolumne).

Figure 6-48: Dense Stands of Deer Grass Growing on the Upper Bar Surface near Lumsden Bridge.

Figure 6-49: Oregon Ash, White Alder and Ponderosa Pine at Lumsden Bridge Showing Lack of Species Gradation along Elevational Gradient.

6.6.3 Analysis Species

Rainbow Trout

Little information from past studies or surveys of rainbow trout or other fishes was found for the Lumsden Reach. Information acquired was limited to internal memoranda and interim reports provided by Tim Ford, Turlock Irrigation District for studies that were initiated for the proposed Ponderosa Project. The Ponderosa Project was abandoned with the designation of the Tuolumne River as Wild and Scenic, and the fish and wildlife studies were terminated. Extensive data were collected for these studies, including IFIM transect surveys, trout microhabitat observations, and fish abundance surveys. These data were never completely analyzed, but preliminary results are summarized in an internal memorandum to Turlock Irrigation District. Relevant findings are included in the information presented below. No current temperature data are available. Thermograph tapes from temperature monitoring in the 1970s are available and were scanned to electronic files as part of this study.

Within this reach, the Tuolumne River transitions to a semi-alluvial morphology, and cobble bars and riffles are extensive from about two miles downstream of Cherry Creek to Wards Ferry (see Section 6.7.1). Potential spawning and rearing area in this reach is extensive, but habitat area:flow relationships are not known. Spawning areas upstream of the South Fork Tuolumne River are limited to small patches of potentially suitable spawning substrate (Ford 1983). Also, inflow from Cherry Creek (i.e., releases from Holm Powerhouse) reduces water temperature in the upstream portion of the reach. Lewis (1978) noted that inflow from Cherry Creek reduced water temperature by 20^{o}F on some days. Temperature of water released from Holm Powerhouse was 50-55^{o}F (Lewis 1978).

Fish fauna in the Lumsden Reach includes rainbow trout, brown trout (non-native), California roach, Sacramento sucker, Sacramento pikeminnow, hardhead (*Mylpharodon conocephalus*), riffle sculpin, Coho salmon (stocked), Chinook salmon (stocked), and kokanee (stocked) (USFS 1976). Coho salmon have been reported migrating as far upstream as Early Intake Diversion Dam. The USFS suspects that Tuichub (*Siphateles bicolor*) and western speckled dace (*Rhinichthys osculus*) may also occur in the reach (USFS 1976). In letters of comment received during the Wild and Scenic River designation process, one local biologist reported the occurrence of non-native smallmouth bass (*Micropterus salmoides*) and green sunfish in the Lumsden Reach downstream of Clavey Falls. Presumably, the Clavey Falls is a barrier to upstream migration of these fishes, if they are in fact present in the downstream end of the reach.

During helicopters surveys of the Lumsden Reach in October 1983, Ford (1983) reported observing very few fish, except some schools of suckers with up to 150 individuals downstream of the Clavey River confluence. No redds or salmon carcasses were observed during this single survey, nor were concentrations of fish identifiable as trout (although some unidentified fish could have been trout or salmon). In electrofishing surveys conducted at 18 sites in this reach for the Ponderosa Project, relative species abundance was suckers>trout>squawfish downstream of the Clavey River and trout>squawfish>suckers upstream of the South Fork Tuolumne River (TID, unpublished data). The shift in relative abundance is likely due to cooler water temperatures in the upstream portion of the reach.

Fish residing in this reach are subject to daily flow fluctuations released for power generation and recreation (see Section 5). The magnitude change in flow stage and velocity during flow fluctuations has not been quantified, but could have substantial effects on fish behavior, spawning success, and food web productivity.

The fisheries study group for the Ponderosa Project made observations of fish behavioral response to flow fluctuations in the reach (TID, unpublished data). Sacramento suckers, Sacramento pikeminnow, and rainbow trout were observed during high flows (~1,200 cfs) and low flows (~300 cfs) in September 1984. Suckers were less active during high flows than low flows. As flow increased, suckers first increased swimming activity, then hid behind structures and in eddies, then reduced activity and moved closer to the stream bottom. At low flows, suckers came off the bottom and grazed, coursing back and forth laterally across the channel. Pikeminnows either remained in the channel and roved near the channel bottom or retreated to eddies during high flows. Rainbow trout continued to feed during high flows, but were washed downstream off runs and riffles into pool heads. During high flows, trout were 3-6 ft off the bottom feeding at pool heads. At low flows, trout moved higher off the streambed and closer to the riffle. With increasing flow, trout increased tailbeats to hold station. As flow velocity continued to increase, trout moved to eddy fences or closer to substrate.

Foothill Yellow-legged Frog

No available studies or surveys for foothill yellow-legged frogs or other amphibians in the Lumsden Reach were identified during the course of this project. The presence or absence of this species in the reach, therefore, is not known. The reach is within the elevation range of the species, and populations are known to occur in tributaries to this reach. Moreover, side channels and extensive alluvial bars present in this reach offer abundant potential oviposition and rearing habitat for this species. Eggs and tadpoles in this reach, however, would be vulnerable to desiccation and scour during fluctuating flows throughout the breeding and rearing season (e.g., Lind et al. 1996).

Benthic Macroinvertebrates

Numerous benthic macroinvertebrate samples were collected throughout the reach as part of a study to assess the effects of flow fluctuation for the Ponderosa Project. The study was not completed, and many of these samples were never analyzed (Fields 1984). Preliminary findings from completed analyses were as follows:

- Species diversity (richness) downstream of Early Intake Reservoir to Wards Ferry was moderate overall but low when compared to sites above Early Intake in the tributaries to the mainstem, probably due to hypolimnial releases from Holm Powerhouse;
- Plecoptera (stoneflies) and Elmidae (riffle beetles) were notably absent from the samples in the Lumsden Reach, which could be an indicator of environmental stress; and
- benthic macroinvertebrate abundance was low at all sites in the reach.

Chapter 7 Proposed Monitoring Actions

General hypotheses of potential project effects on geomorphic and ecological conditions in the study reaches were described in Section 6, and are summarized in matrix form in Appendix L. Additional hydrologic analyses, field reconnaissance, and internal discussion have expanded and refined these hypotheses, adding spatial and topical specificity, and support recommendations for testing these hypotheses. Each hypothesis is an important product in the study plan process illustrated in Figure 4-1. These hypotheses summarize current thinking on project-induced impacts, which guides future study plan development to: 1) evaluate (test) high priority hypotheses, 2) quantify relationships between project operations and ecosystem responses, and 3) if needed, guide analyses that will inform management actions to reduce project-induced impacts and improve ecosystem function. For brevity, these hypotheses and study plan recommendations are provided in matrix form in Appendix M for all project reaches.

From this large matrix, hypothesized project-induced effects on ecosystem function must be prioritized. Prioritization should be based largely on two central criteria: 1) has a substantial change in river ecosystem function due to the project been identified? and 2) based on our experience, can operational changes improve these functions? Using these criteria, the information needed can be extracted to test high priority hypotheses and recommend work plan actions to address those information needs.

7.1 High Priority Study Plan Recommendations

7.1.1 Recommendation 1: Evaluate Fish and Amphibian Presence, Abundance, and Age-Size Class Distribution

Hypotheses addressed:

- Fish are present in all study reaches, although species composition, abundance and age class structure differs among the reaches based on water temperatures, available habitat area, and magnitude of flow fluctuation.
- Foothill yellow-legged frogs potentially breed and inhabit in all study reaches, though habitat appears most extensive in the Upper Cherry Reach (low gradient portion), Eleanor Creek (low gradient portion), and Lumsden Reaches.
- Poopenaut Valley off-channel wetlands and side channels potentially support diverse amphibian fauna, but reproductive success is limited in drier years by premature dewatering of these habitats.

Proposed Methods: Snorkel surveys to establish fish presence/absence using methods of Vondracek (1985), and amphibian surveys to establish presence/absence using methods of USFWS (unpublished data) for foothill yellow-legged frog. Re-occupy Tuolumne River sites surveyed by Vondracek in 1985 and USFWS in 1988-1990, re-occupy Cherry Creek and Eleanor Creek sites surveyed by Moyle and Baltz in 1981. Conduct data collection in same reaches where habitat assessment is performed. Compare as applicable to data on Clavey River.

Proposed Species: Rainbow trout, brown trout, California roach, Sacramento sucker, smallmouth and largemouth bass, and other non-native species.

High priority locations:

<u>Tuolumne River</u>

- Between O'Shaughnessy Dam and Poopenaut Valley.
- In Poopenaut Valley.
- Between Poopenaut Valley and Early Intake.
- In Lumsden Reach immediately downstream of Cherry Creek confluence.

Eleanor Creek

- In moderate gradient reach between Eleanor Dam and ¾ miles downstream of dam.
- In high gradient reach upstream of Cherry Creek confluence.

Cherry Creek

- In low gradient reach between Cherry Valley Dam and 2 miles downstream of dam.
- In high gradient reach upstream of Eleanor Creek confluence.
- In high gradient reach downstream of Eleanor Creek confluence and upstream of Holm Powerhouse.
- Between Holm Powerhouse and the Tuolumne River confluence.

Clavey River

- At Cottonwood Bar study site downstream of Cottonwood Bridge (1NO4).
- At Lower Bridge Bar downstream of 1NO1 Bridge.

Medium priority locations:

Tuolumne River

- Between Early Intake and Cherry Creek confluence (flow often augmented in this reach from excess water discharged from Kirkwood Powerhouse).
- In Lumsden Reach immediately downstream of South Fork Tuolumne River confluence near Lumsden Bridge.

Reliance on other information: Would benefit from ortho-rectified aerial photographs to precisely locate sampling boundaries and observation location.

7.1.2 Recommendation 2: Quantify Relationship Between Flow, Temperature, and Habitat

Hypotheses addressed:

- Reductions in snowmelt hydrograph directly reduce physical habitat availability, and increased water temperatures further reduce habitat quantity and quality for native fish and amphibians.
- Rapid curtailment of spring releases/spills strands juvenile fish, desiccates amphibian oviposition and rearing sites, and reduces benthic macroinvertebrate production (i.e., secondary production and food web support).
- Increased summer baseflows reduce water temperatures close to the dams and increase summer trout habitat downstream of O'Shaughnessy Dam and Cherry Valley Dam.

Proposed Methods: Expert Habitat Mapping (EHM), because estimating flow-habitat relationships using 1-D and 2-D hydraulic modeling may not be appropriate for complex channel morphology found in most priority study reaches.

Proposed Species: Rainbow trout, brown trout, Sacramento sucker, California roach, benthic macroinvertebrates, Foothill yellow-legged frog.

High priority locations:

Tuolumne River

- Poopenaut Valley.
- O'Shaughnessy Dam to Poopenaut Valley.
- Poopenaut Valley to Early Intake.

- Early Intake to Cherry Creek confluence (flow often augmented in this reach from excess water discharged from Kirkwood Powerhouse).
- Lumsden Reach immediately downstream of Cherry Creek confluence.
- Lumsden Reach immediately downstream of South Fork Tuolumne River confluence (flow fluctuations dampening increases downstream of Holm Powerhouse)

Eleanor Creek

- High gradient reach ¾ mile downstream of Eleanor Dam to the confluence with Cherry Creek.

Cherry Creek

- Low gradient reach from Cherry Valley Dam downstream two miles from the dam.
- High gradient reach from two miles downstream of Cherry Valley Dam to the Eleanor Creek confluence.
- High gradient reach from Holm Powerhouse to the confluence of the Tuolumne River (seasonally large daily flow fluctuations from Holm Powerhouse.

Clavey River

- Cottonwood Bridge Bar study site (1 mile downstream of 1NO4 Bridge) as comparative stream to Hetch Hetchy Project streams.

Medium priority locations:

Eleanor Creek

- Moderate gradient reach from Eleanor Dam downstream ¾ mile from the dam (best habitat is downstream of this reach).

Cherry Creek

- High gradient reach from the Eleanor Creek confluence to Holm Powerhouse (flow reductions partially mitigated by tributaries and contributions from Eleanor Creek).

Clavey River

- Lower Bridge Bar study site (1 mile downstream of 1NO1 Bridge) as comparative stream to Hetch Hetchy Project streams (water temperatures sometimes too warm for salmonids in this reach).

Reliance on other information: EHM requires low altitude aerial photographs; assessing habitat availability due to temperature requires temperature model and/or thermograph network.

7.1.3 Recommendation 3: Evaluate Water Temperatures

Hypotheses addressed:

- In years with reduced snowmelt hydrograph, water temperatures increase in late spring and early summer, reducing habitat quantity and quality.
- Increased summer baseflows decreases water temperatures close to the dam in late summer and early fall, increasing habitat quantity and quality.
- Flow fluctuations from Holm Powerhouse in the summer greatly reduce summer and fall water temperatures in the Holm and Lumsden reaches, and also cause large-scale daily changes in water temperature.
- Under unimpaired conditions, pools stratified during low summer baseflow periods, providing thermal refugia for salmonids in deep pools. Depending on pool location, higher post-dam summer baseflows could cause mixing of the pools, eliminating thermal refugia.

Proposed Methods: Complete Mike Deas water temperature model, and expand to other reaches as illustrated below. Establish water temperature monitoring network (continuous thermographs, but not real-time) needed to support model development and calibration. Install continuous recording Tidbits or Stowaway thermographs in a vertical profile in selected deep pools

Proposed Species: Rainbow trout, Sacramento sucker, California roach, benthic macroinvertebrates, Foothill yellow-legged frog.

High priority locations:

Tuolumne River

- Temperature model and thermograph monitoring from O'Shaughnessy Dam to Cherry Creek confluence (Hetchy Reach).
- Temperature model and thermograph monitoring on Lumsden Reach from Cherry Creek confluence to Wards Ferry.
- Temperature monitoring above Hetch Hetchy Reservoir (USGS now doing this monitoring).

Eleanor Creek

- Temperature model and thermograph monitoring over the entire reach.
- Vertical temperature profiles to document hypolimnion layer and compare to outlet works (supplement Moyle data).

Cherry Creek

- Temperature model and thermograph monitoring over the entire reach.
- Temperature monitoring above Cherry Valley Reservoir.

Clavey River

- Continue continuous temperature monitoring at Cottonwood Bridge Bar study site (1 mile downstream of 1NO4 Bridge) and 1NO1 Bridge for comparisons with streams regulated by the Hetch Hetchy Project.

Medium priority locations:

Tuolumne River

- Lumsden Reach downstream of the Clavey River confluence.

Reliance on other information: Temperature modeling requires thermograph network for development and calibration; temperature model needs channel geometry obtained from LIDAR or other sources.

7.1.4 Recommendation 4: Evaluate Geomorphic and Woody Riparian Vegetation Processes

Hypotheses addressed:

- Reduced magnitude and frequency of high flows, combined with reduced sediment supply, has reduced the magnitude and frequency of bed mobilization and transport.
- Reduced magnitude and frequency of high flows has allowed riparian and upland vegetation encroachment into the low flow channel, further reducing bed mobilization on channel margins and bar features, allowing fine sediment deposition along channel margins, and reducing complex channel margin habitats needed for juvenile fish and amphibian habitat.
- The change in timing, duration, and recession rate associated with project operations has reduced the number of riparian plant species, shifted the dominance of certain woody plant species, and simplified riparian structural diversity.

- Flow fluctuations in lower Cherry Creek and the Tuolumne River below Cherry Creek have reduced riparian plant species richness and vegetation structural complexity within the low water channel and compressed the riparian corridor into a narrow zone above the active channel.
- Shallow groundwater dynamics within and between water years maintains the balance between wet and dry meadows with the riparian corridor and inhibits conifers from encroaching into these meadows.

Proposed Methods:

- Determine bed mobility thresholds in a variety of alluvial features important as fish and amphibian habitat using a combination of bed mobility modeling approaches (e.g., Barta and Wilcock 2000) and empirical approaches (e.g., tracer rocks).
- To develop a better understanding of how vegetation has evolved within the riparian corridor under pre-dam and contemporary regulated conditions, determine ages of encroaching riparian and upland vegetation and apply a riparian initiation model to varying geomorphic surfaces and hydrographs, relating encroaching vegetation to historic and contemporary hydrology, and relating vegetation to geomorphic surfaces as documented by the cross section surveys.
- Document preferential channel locations where a broad range of riparian plant species establish using cross sections and band transect surveys in reaches with daily flow fluctuations and similar reaches without.
- To develop a better understanding of the relationship between wet and dry meadow patterns as they relate to shallow ground water in the Poopenaut Valley, combine cross sections and band transects located in wet and dry meadows near locations where ground water is evaluated to document species composition and changes in composition.

Proposed Species: White alder, black cottonwood, ponderosa pine, a variety of willow species, and dominant herbaceous species.

High priority locations:

<u>Tuolumne River</u>

- Immediately upstream of Hetch Hetchy Reservoir to document unimpaired conditions
- Between O'Shaughnessy Dam and Poopenaut Valley.
- Within Poopenaut Valley (focus historic channel analysis in this reach).
- Between Poopenaut Valley and Early Intake.
- In Lumsden Reach immediately downstream of South Fork Tuolumne River confluence near Lumsden Bridge.

<u>Cherry Creek</u>

- In low gradient reach between Cherry Valley Dam and 2 miles downstream of dam.
- In high gradient reach upstream of Eleanor Creek confluence.

<u>Clavey River</u>

- Immediately downstream of Cottonwood Bridge (1NO4).

Medium priority locations:

<u>Tuolumne River</u>

- In Lumsden Reach immediately downstream of Cherry Creek confluence.

<u>Eleanor Creek</u>

- In high gradient reach upstream of Cherry Creek confluence.

Clavey River

- Immediately downstream of 1N01 Bridge.

Reliance on other information: Requires cross sections to be surveyed, and pebble counts to be collected in alluvial features. Bed mobility modeling would benefit from improved valley slope measurements from LIDAR data.

7.1.5 Recommendation 5: Evaluate Sediment Budget

Hypotheses addressed:

- Cherry Valley and O'Shaughnessy dams have eliminated sediment supply to downstream reaches from upstream sources, causing bed coarsening and reducing bed mobility frequency.
- Sediment storage on Cherry Creek has remained in approximate balance due to reduced high flow regime (reduced sediment transport capacity).
- Eleanor Dam has not changed sediment supply to the downstream reach because the pre-dam Lake Eleanor was a natural sediment trap.
- Sediment storage on Eleanor Creek has remained in approximate balance due to reduced high flow regime (reduced sediment transport capacity).
- Sediment storage available for mobilization on the Tuolumne River upstream of Poopenaut Valley has decreased. Although the sediment transport capacity has been reduced, the reduction in sediment supply has likely been greater than the reduction in sediment transport capacity such that storage has decreased.
- Sediment storage available for mobilization on the Tuolumne River within Poopenaut Valley has likely decreased, yet changes in storage and grain size may still be modest because large amounts of sand are still stored in the channel.

Proposed Methods: Identify sediment sources immediately downstream of the dam and qualitatively estimate sediment yield in order to compare to transport capacity. Install representative cross sections. Apply various flow regimes through cross sections using a sediment transport equation to assess change in sediment budget, and to assess how operational changes may alter the sediment budget.

Proposed Species: Not Applicable.

High priority locations:

Tuolumne River

- Reach between O'Shaughnessy Dam and Poopenaut Valley (gravel/cobble bed stream).
- Reach within Poopenaut Valley (small gravel and sand bed stream).

Cherry Creek

- Low gradient reach from Cherry Valley dam downstream two miles to the beginning of the high gradient confined reach.

Medium priority locations:

Tuolumne River

- Reach between Poopenaut Valley and Early Intake.

Reliance on other information: Slopes for computing hydraulics would be obtained from LIDAR topographic information.

7.1.6 Recommendation 6: Evaluate Groundwater, Side-Channel, and Wetland Dynamics in Poopenaut Valley

Hypotheses addressed:

- Off-channel wetland and side-channels are connected via shallow groundwater table to surface flow in the mainstem Tuolumne River.
- Reductions in spring snowmelt hydrograph and summer baseflows has reduced frequency and duration of wetting from mainstem high flows, and may have changed timing of wetting from mainstem high flows.

Proposed Methods: NPS staff establish cross section through south bank side channel, mainstem Tuolumne River channel, and north bank wetland, then install staff plates and at least one piezometer on the transect. Install continuous stage recorders on the mainstem, in piezometers, and in the wetland to evaluate hydraulic connectivity and correlate lateral groundwater stages during high flow events.

Proposed Species: Amphibians, fry and juvenile salmonid rearing.

High priority locations:

<u>Tuolumne River</u>

- Poopenaut Valley.

Reliance on other information: Streamflow data (currently collected by USGS immediately upstream).

7.1.7 Recommendation 7: Obtain New Aerial Photographs

Hypotheses addressed: None (provides data to test hypotheses listed above)

Proposed Methods: Low altitude orthorectified photographs with at least 0.5' pixel resolution.

Proposed Species: Not Applicable.

High priority locations:

<u>Tuolumne River</u>

- O'Shaughnessy Dam downstream to Wards Ferry.

<u>Eleanor Creek</u>

- Eleanor Dam to the Cherry Creek confluence.

<u>Cherry Creek</u>

- Cherry Valley Dam to the Tuolumne River confluence.

<u>Clavey River</u>

- Cottonwood Bridge (1N04) downstream 2.5 miles to capture habitat mapping reach.

Medium priority locations:

<u>Clavey River</u>

- Cottonwood Bridge (1N04) to the Tuolumne River confluence.

Application to hypothesis testing: Provides basemaps for flow-habitat assessment, geomorphic assessment, and historic channel analysis in Poopenaut Valley.

7.1.8 Recommendation 8: Supplement Streamflow Gaging Network

Hypotheses addressed: None (provides data to test hypotheses listed above)

Proposed Methods: Short-term method is to install continuous stage recorder (pressure transducer and datalogger) and staff plates, long-term method is for USGS to install real-time gaging station and cableway.

Proposed Species: Not applicable.

High priority locations:

Tuolumne River

- Re-establish the Tuolumne River near Buck Meadows gaging station near Lumsden Bridge downstream of the South Fork Tuolumne River. This location will provide accurate flow information for habitat and geomorphic threshold study plans, and may also benefit the rafting community.

Clavey River

- Re-establish the Clavey River near Buck Meadows gaging station at the 1NO1 Bridge to allow habitat assessment and geomorphic thresholds measured on an unregulated "control" stream to be compared to measurements on streams regulated by the Hetch Hetchy project. This gage is also one of the few on unregulated streams that have a long period of record. Re-establishing the gage will improve our ability to relate watershed changes to unregulated flood recurrence.

Application to hypothesis testing: Provides flow data to relate habitat assessments and geomorphic thresholds.

7.1.9 Recommendation 9: Document Topography along Stream Corridors

Hypotheses addressed: None (supports other hypotheses)

Proposed Methods: Laser Detection and Ranging (LIDAR) ground topography conducted at same time as aerial photo flight to provide 1 ft contour accuracy within the 50 year floodway corridor.

Proposed Species: Not applicable.

High priority locations:

Tuolumne River

- O'Shaughnessy Dam to Wards Ferry.

Eleanor Creek

- Eleanor Dam to Cherry Creek.

Cherry Creek

- Cherry Valley Dam to Tuolumne River confluence.

Medium priority locations:

Clavey River

- Cottonwood Bridge (1N04 Bridge) to Tuolumne River confluence.

Application to hypothesis testing: Provides topography for air photo ortho-rectification, provides channel geometry for temperature model, and provides accurate valley gradient slopes at study sites for hydraulic calculations.

7.2 Summary

As additional information is collected and discussed with stakeholders and collaborators, and more is learned about the Tuolumne River, Cherry Creek, and Eleanor Creek ecosystems, these hypotheses and study plans will evolve. Many hypotheses will be supported over time, some may be revised or refined based on the additional information gathered by this effort, some may be proved wrong, and new hypotheses may emerge. The ultimate goal of hypotheses testing is to synthesize former investigations and new data into a quantitative understanding that will enable the SFPUC to adjust operations and improve river ecosystem conditions.

Chapter 8 References

Ashton, D.T., Lind, A.J., and K.E. Shlick. 1997. *Foothill Yellow-Legged Frog (*Rana boylii*) Natural History*. Redwood Science Lab, Pacific Southwest Research Station, USDA Forest Service. Arcata, California. www.krisweb.com/biblio/gen_usfs_ashtonetal_1997_frog.pdf

Bair, J. 2003. Current trends in low water encroachment by riparian hardwoods along the Trinity River, California. Pages 190-194 in P.M. Faber (ed.), *California Riparian Systems: Processes and Floodplains Management, Ecology, and Restoration*. Riparian Joint Habitat Venture, Sacramento, California.

Baltz, D.M. and P.B. Moyle. 1984. Segregation by species and size classes of rainbow trout, *Salmo gairdneri*, and Sacramento sucker, *Catostomus occidentalis*, in three California Streams. *Environmental Biology of Fishes* 10: 101-110.

Barbour, M.T., Gerritsen, J., Snyder, B.D., and J.B. Stribling. 1999. *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish.* Second Edition. EPA 841-B-99-002. Office of Water, U.S. Environmental Protection Agency, Washington, D.C.

Bell, M., Royce, W., Ridenhour, R., and R. Lewis. 1980. *Evaluation of Tuolumne River Fishery with the Canyon Power Project*. Prepared for the San Francisco Public Utilities Commission, San Francisco, California.

Bettinger, T.L. and L.C. Fitzpatrick. 1979. Physiological and ecological correlates of preferred temperature in fish. *American Zoologist* 19: 319-329.

Bradley, C. and D.G. Smith. 1984. Meandering channel response to altered flow regime: Milk River, Alberta and Montana. *Water Resources Research* 20(12): 1913-1920.

Erman, N. 1996. Status of aquatic invertebrates. Pages 987-1008 in *Sierra Nevada Ecosystem Project: Final Report to Congress, Vol. II.* University of California Davis, Centers for Water and Wildland Resources, Davis, California.

Euliss, N.H. and G.A Swanson. 1989. Improved self-cleaning for processing benthic samples. *California Fish and Game* 75(2): 127-128.

Federal Energy Regulatory Commission (FERC). 1994. *Draft Environmental Impact Statement, Clavey River Project (FERC 10081-002)*. Federal Energy Regulatory Commission, Office of Hydropower Licensing & Turlock Irrigation District, Turlock, California.

Fields, W.C., Jr. 1984. *The Benthos of the Tuolumne River and Selected Tributaries*. Hydrozoology, P.O. Box 682, Newcastle, California.

Ford, T. 1983. *Helicopter Flight with Fishery Consultants over the Clavey-Wards Ferry Area*. Internal Memorandum, Turlock Irrigation District, Turlock, California.

Gore, J.A., Layzer, J.B., and J. Mead. 2001. Macroinvertebrate instream flow studies after 20 years: A role in stream management and restoration. *Regulated Rivers: Research & Management* 17: 527-542.

Horvath, M. 2006. Personal communication regarding the distribution of California roach in the Hetch Hetchy reach of the Tuolumne River. San Francisco Public Utilities Commission.

Hubbs, C.L. and O.L. Wallis. 1948. The native fish fauna of Yosemite National Park and its preservation. *Yosemite Nature Notes* 27(12): 131-144.

Huber, K. 2004. *A Tale of Two Valleys*. Yosemite Association, Portola, California.

Hupp, C.R. and W.R. Osterkamp. 1996. Riparian vegetation and fluvial geomorphic processes. *Geomorphology* 14: 277-295.

Hynes, H.B.N. 1970. *Ecology of Running Waters*. University of Toronto Press, Toronto, Canada.

Institute for River Ecosystems (IRE). 1994. *Developing a Maintenance Flow Methodology: A Sample Plan for Steep Bedrock-Controlled Sierra Rivers*. Report #IRE-08-91-01, Humboldt State University, Arcata, California.

Jennings, M.R. 1996. Status of amphibians. Pages 921-944 in *Sierra Nevada Ecosystem Project: Final Report to Congress, Vol. II.* University of California Davis, Centers for Water and Wildland Resources, Davis, California.

Jennings, M.R. and M.P. Hayes. 1994. *Amphibian and Reptile Species of Special Concern in California*. Final Report No. 8023. Prepared for the California Department of Fish and Game, Inland Fisheries Department, Rancho Cordova, California.

Knight, N.J. 1985. *Microhabitats and Temperature Requirements of Hardhead (*Mylopharadon concephalus) *and Sacramento Squawfish* (Ptychocheilus grandis)*, with Notes for Some Other Native California Stream Fishes.* Ph.D. Thesis, University of California, Davis.

Kondolf, G.M. and P.R. Wilcock. 1996. The flushing flow problem: Defining and evaluating objectives. *Water Resources Research* 32(8): 2589-2599.

Lewis, R.C. 1978. *Tuolumne River Flow Study Report – 1978.* Final report prepared for U.S. Fish and Wildlife Service, Sacramento, California.

Lind, A.J. 2004. *Foothill Yellow-legged Frog (*Rana boylii*) Envirogram Documentation for Monitoring and Risk Analyses*. Redwood Sciences Laboratory, Pacific Southwest Research Station, USDA Forest Service, Arcata, California.

Lind, A.J., Welsh, H.J., and R.A. Wilson. 1996. The effects of a dam on breeding habitat and egg survival of the foothill yellow-legged frog (*Rana boylii*) in northwestern California. *Herpetological Review* 27(2): 62-67.

Lundquist, J.D., Dettinger, M.D., and D.R. Cayan. 2005. Snow-fed streamflow timing at different basin scales: Case study of the Tuolumne River above Hetch Hetchy, Yosemite, California. *Water Resources Research* 41, W07005, doi:10.1029/2004WR003933.

Lytle, D.A. and N.L. Poff. 2004. Adaptation to natural flow regimes. *Trends in Ecology and Evolution* 19(2): 94-100.

Mahoney, J.M. and S.B. Rood. 1998. Streamflow requirements for cottonwood seedling recruitment - an integrative model. *Wetlands* 18(4): 634-645.

McBain & Trush, Inc. 2006. *Pulse Flow Guidelines: Managing the Annual Snowmelt Hydrograph and Winter Floods in Regulated Boulder-Bedrock Sierra Nevada Rivers (DRAFT).* California Energy Commission, PIER Energy-Related Environmental Research, Publication # not yet assigned.

McBain & Trush, Inc., and RMC Environmental. 2006. *Upper Tuolumne River: Available Data Sources, Field Work Plan, and Initial Hydrology Analysis*. Technical Memorandum prepared for San Francisco Public Utilities Commission, San Francisco, California.

McBain, S. and B. Trush. 2004. Attributes of bedrock Sierra Nevada ecosystems. *Stream Notes*, USDA Forest Service, Stream Systems Technology Center, Ft. Collins, Colorado.

McBain & Trush, Inc. 2006. Bank positions of willow, white alder, bigleaf maple, and conifers at Cherry Creek. Unpublished data.

Moyle, P.B. 2002. *Inland Fishes of California*. University of California Press, Berkeley, California.

Moyle, P., Yoshiyama, R., and R. Knapp. 1996. Status of Fish and Fisheries. Pages 953-973 in *Sierra Nevada Ecosystem Project: Final Report to Congress, Vol. II*. University of California Davis, Centers for Water and Wildland Resources, Davis, California.

Moyle, P.B. and M. Marchetti. 1992. *Temperature requirements of rainbow trout and brown trout in relation to flows between O'Shaughnessy Dam and Early Intake on the Tuolumne River, California*. Unpublished manuscript.

Moyle, P. and D. Baltz. 1981. *Fisheries Evaluation of Lake Eleanor and Eleanor and Cherry Creeks*. University of California, Davis.

Naiman, R.J., Bunn, S.E., Nilsson, C., Petts, G.E., Pinay, G., and L.C. Thompson. 2002. Legitimizing fluvial ecosystems as users of water: an overview. *Environmental Management* 30(4): 455-467.

Nilsson, C. and M. Svedmark. 2002. Basic principles and ecological consequences of changing water regimes: Riparian plant communities. *Environmental Management* 30(4): 468-480.

National Park Service (NPS). 2006. *Tuolumne Wild and Scenic River Outstandingly Remarkable Values Draft Report*. Yosemite National Park, California.

Pelzman, R.J. 1973. *Causes and Possible Prevention of Riparian Plant Encroachment on Anadromous Fish Habitat*. California Department of Fish and Game, The Resources Agency, Environmental Services Branch Administrative Report 73-1.

Pierson, E.D., Rainey W.E., and C.J. Corben. 2000. *Seasonal Patterns of Bat Distribution along an Altitudinal Gradient in the Sierra Nevada*. Report to California State University at Sacramento Foundation, Yosemite Association, and Yosemite Fund, California.

Platt, J. 1964. Strong Inference. *Science* 146(3642): 347-352.

Point Reyes Bird Observatory (PRBO). 2005. *Non-native Vascular Plant Inventory of Riparian Areas in Yosemite National Park, California*. Final Report submitted to Yosemite National Park and Sierra Nevada Inventory and Monitoring Network. PRBO Contribution #1335. Petaluma, California.

Quine, W.V.O. and J. Ullian 1988. Hypothesis. Pages 246-256 in E.D. Klemke, R. Hollinger, and A.D. Kline, editors. *Introductory Readings on the Philosophy of Science*. Prometheus Books, Amherst, New York.

Raleigh, R.F., Hickman, T., Solomon, R.C., and P.C. Nelson. 1984. *Habitat Suitability Information: Rainbow Trout*. USFWS FWS/OBS-82/10.60.

Russell, I.C. 1902. *River Development as Illustrated by the Rivers of North America*. G.P. Putnam and Sons, New York.

Ruttner, F. 1963. *Fundamentals of Limnology*. Third Edition. Translated by Frey, D.G. and F.E.J. Frey. University of Toronto Press, Toronto, Canada.

Seltenrich, A. and C. Pool. 2002. *A Standardized Approach for Habitat Assessments and Visual Encounter Surveys for the Foothill Yellow-legged Frog (*Rana boylii*)*. Pacific Gas and Electric Company.

Snider, W.M. and A. Linden. 1981. *Trout Growth in California Streams*. California Dept. of Fish & Game, Administrative Report 81-1, Sacramento, California.

Stark, E. 2002. *Effects of Water Level Fluctuations on Benthic Macroinvertebrates in the Hanford Reach, Columbia River*. Masters Thesis. University of Idaho, Moscow.

Stillwater Sciences, Rainey, Pierson, Corben, and Power. 2003. *Sacramento River Ecological Indicators Pilot Study*. Prepared for The Nature Conservancy, Chico, California.

Stillwater Sciences. 2002. *Merced River Corridor Restoration Plan.* Stillwater Sciences, Berkeley, California.

The Nature Conservancy (TNC). 1998. *An Environmentally-Driven Approach to Vegetation Sampling and Mapping at Yosemite National Park*. Prepared for the United States Department of the Interior and the National Park Service.

Turlock Irrigation District (TID). Electro-fishing surveys for proposed Ponderosa project. Unpublished data.

Trush, W.J., McBain, S., and L.B. Leopold. 2000. Attributes of an alluvial river and their relation to water policy and management. *Proceedings of the National Academy of Science* 97(22): 11858-11863.

U.S. Forest Service (USFS). 1988. *Tuolumne Wild and Scenic River Management Plan*. Pacific Southwest Region, Stanislaus National Forest, Sonora, California.

USFS. 2001. Yellow-legged frog surveys on Clavey River. Unpublished data.

U.S. Fish and Wildlife Service (USFWS). 1992. *Instream Flow Requirements for Rainbow and Brown Trout in the Tuolumne River between O'Shaughnessy Dam and Early Intake (Rough Draft)*. U.S. Fish and Wildlife Service, Sacramento, California.

USFWS. 1991. *Hetch Hetchy Fishery Investigation Tuolumne River, California 1990 Progress Report.* U.S. Fish and Wildlife Service, Fish and Wildlife Enhancement, Sacramento, California.

USFWS. 1990. *Hetch Hetchy Fishery Investigation Tuolumne River, California 1989 Progress Report.* U.S. Fish and Wildlife Service, Fish and Wildlife Enhancement, Sacramento, California.

USFWS. 1981. *Environmental Assessment Tuolumne River Flow Schedule Revision (Canyon Power Project*). U.S. Fish and Wildlife Service, Region 1. Portland, Oregon.

USFWS. 1976. *Tuolumne River Flow Study: Canyon Power Project, California*. U.S. Fish and Wildlife Service, Portland, Oregon.

U.S. Geological Survey (USGS). 2006. Daily average streamflow data. Available at: http://waterdata.usgs.gov/ca/nwis/sw

USGS. 1918. *Surface Water Supply of the United States 1916*, Part XI Pacific Slope Basins in California, Water Supply Paper 441, Washington DC.

Vondracek, B. 1985. *Tuolumne Fish Population Survey*. Report to U.S. Fish and Wildlife Service, Sacramento, California.

Washington State Department of Ecology. 2002. *Evaluating Standards for Protecting Aquatic Life in Washington's Surface Water Quality Standards: Temperature Criteria*. Draft Discussion Paper and Literature Summary. Publ. No. 00-10-070, Prepared by: Water Quality Program, Washington State Department of Ecology, Watershed Management Section, Olympia, Washington.

Whipple, K.X., Hancock, G.S., and R.S. Anderson. 2000. River incision into bedrock: Mechanics and relative efficacy of plucking, abrasion, and cavitation. *GSA Bulletin* 112(3): 490-503.

Wildland Resources Center (1996). *Status of the Sierra Nevada Vol. 3*; Assessments, Commissioned Reports, and Background information. University of California, Davis.

Young, J. and C. Young 1992. *Seeds of Woody Plants of North America*. Dioscorides Press, Portland, Oregon.

Zweifel, R.G. 1955. Ecology, distribution, and systematics of frogs of the *Rana boylii* group. *University of California Publications in Zoology* 54: 207-292.

9 Appendices

Appendix A: Daily average hydrographs for Tuolumne River near Hetch Hetchy below O'Shaughnessy Dam (USGS 11-276500) for Water Years 1911-2005.

Appendix B: Daily average hydrographs for Eleanor Creek near Hetch Hetchy below Lake Eleanor Dam (USGS 11-278000) for Water Years 1910-2005.

Appendix C: Daily average hydrographs for Cherry Creek near Hetch Hetchy below Cherry Valley Dam (USGS 11-277000) for Water Years 1910-2005.

Appendix D: 15-minute stage and discharge plots for each month in Water Year 2004 (DRY) and 2005 (WET) for Cherry Creek near Early Intake above Holm Powerhouse (USGS 11-278300) and Cherry Creek below Holm Powerhouse (USGS 11-278400). Simulated 15-minute discharge plots for each month in Water Year 2004 and 2005 for Tuolumne River below Cherry Creek confluence.

Appendix E: Daily average streamflows and water temperatures for Tuolumne River near Hetch Hetchy (USGS 11-276500) and above Early Intake (USGS 11-276600).

Appendix F: Daily average streamflows and water temperatures for Cherry Creek below Cherry Valley Dam (USGS 11-277300) for Water Years 2006 – 2007).

Appendix G: Daily average streamflows and water temperatures for Cherry Creek downstream of Cherry Valley Dam. McBain & Trush thermograph UCD2 May – Sept. 2006.

Appendix H: Daily average streamflows and water temperatures for Cherry Creek below Dion R Holm Powerhouse (USGS 11-278400) Water Years 2006-2007.

Appendix I: Daily average streamflows and water temperatures for Eleanor Creek near Hetch Hetchy (USGS 11-278000) Water Years 2006-2007.

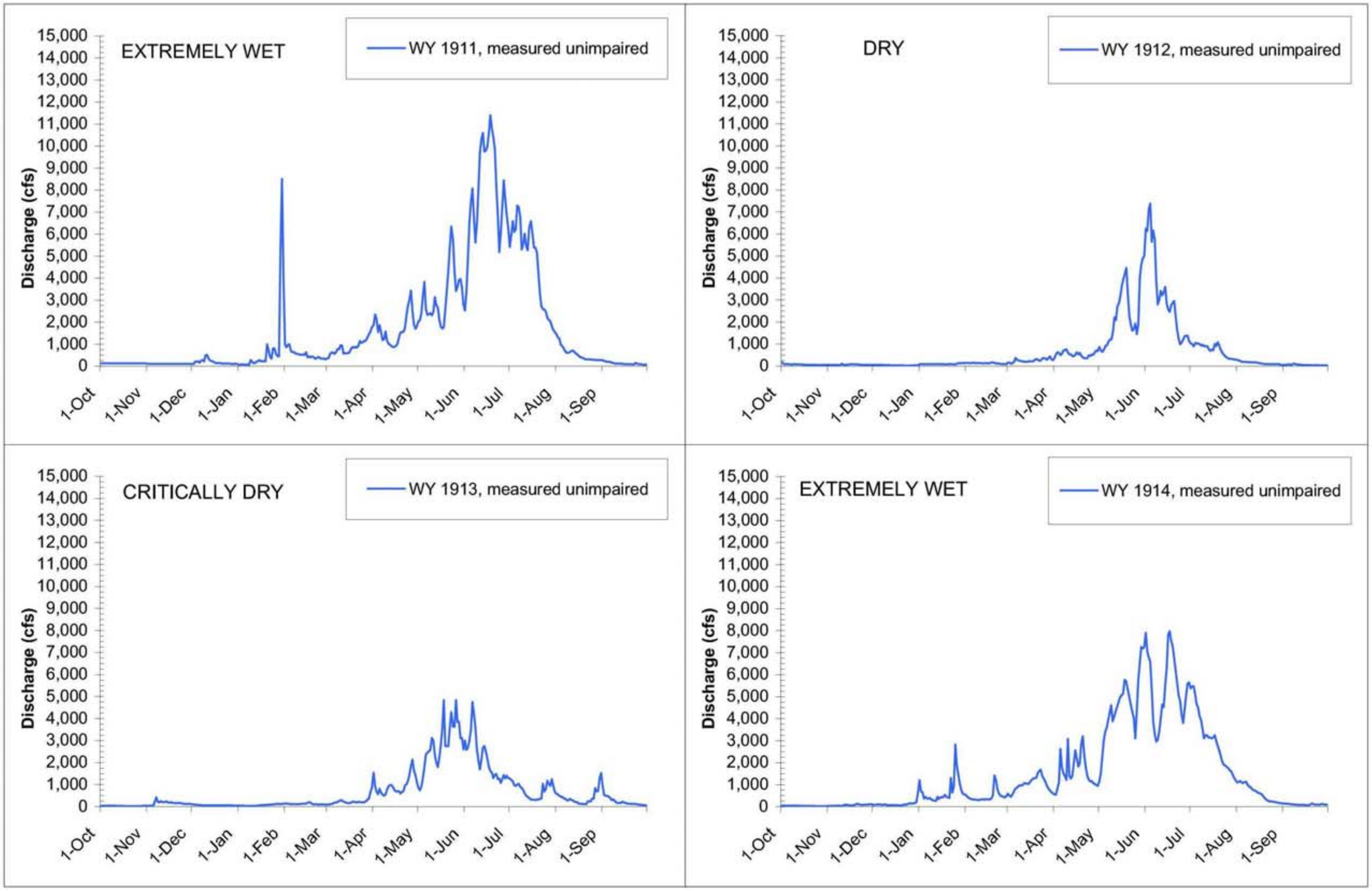
Appendix J: Daily average streamflows and water temperatures for Tuolumne River at the Grand Canyon of the Tuolumne above Hetch Hetchy (USGS 11-274790) Oct. 24, 2006 – Jan. 11, 2007.

Appendix K: Daily average streamflows and water temperatures for Clavey River at 1N01 Bridge (M&T gage) Feb. 23, 2005 – Sept. 15, 2006.

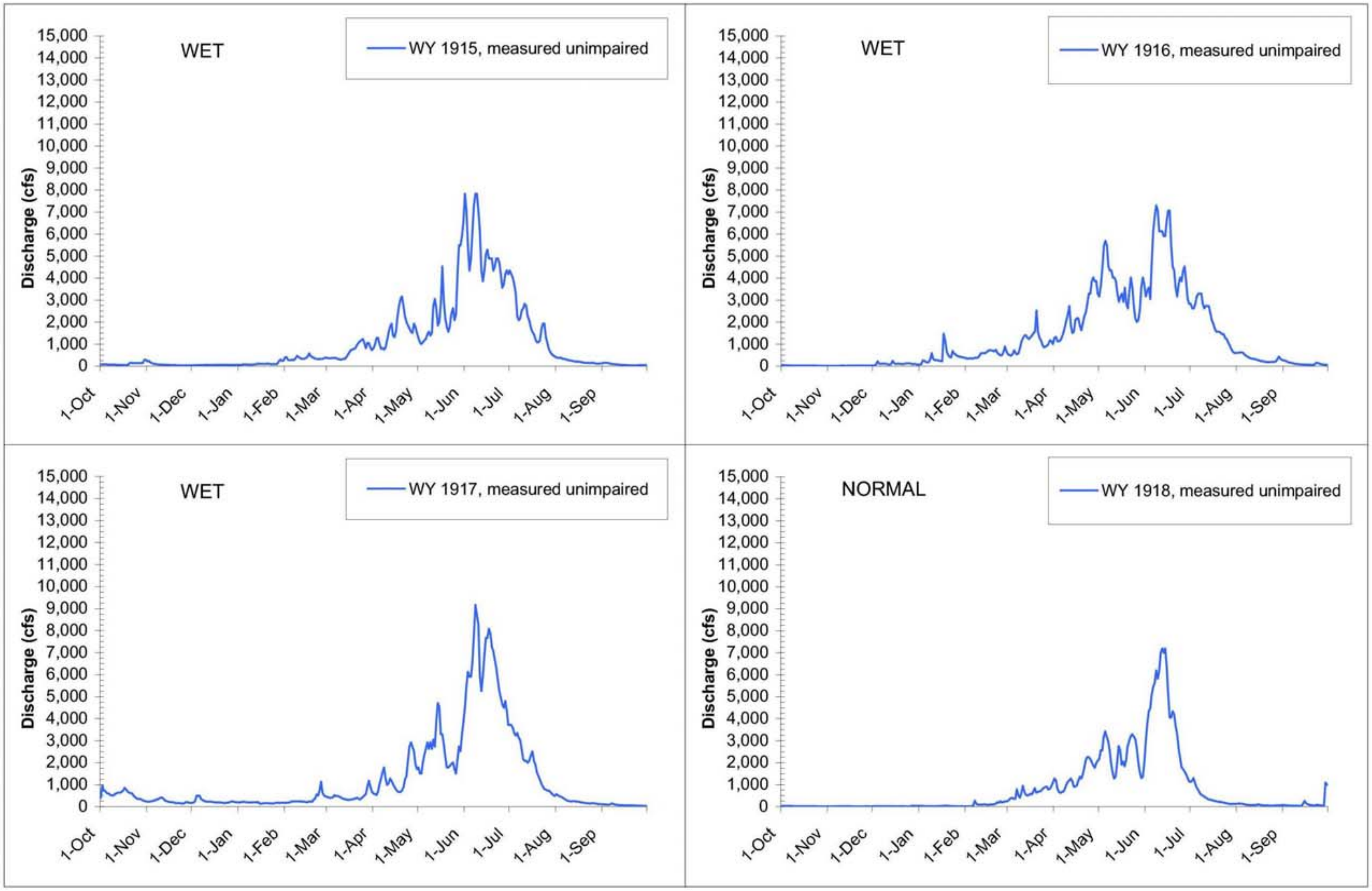
Appendix L: Hypotheses of Potential Project Effects on Geomorphic and Ecological Conditions in the Study Reaches).

Appendix M: Summary of Reach-Scale Study Plan Recommendations for Eleanor Creek, Cherry Creek, and Tuolumne River to Evaluate Hypotheses of Project Induced/Influenced Negative Impacts and Provide Recommendations on Improved Operations to Reduce Negative Impacts.

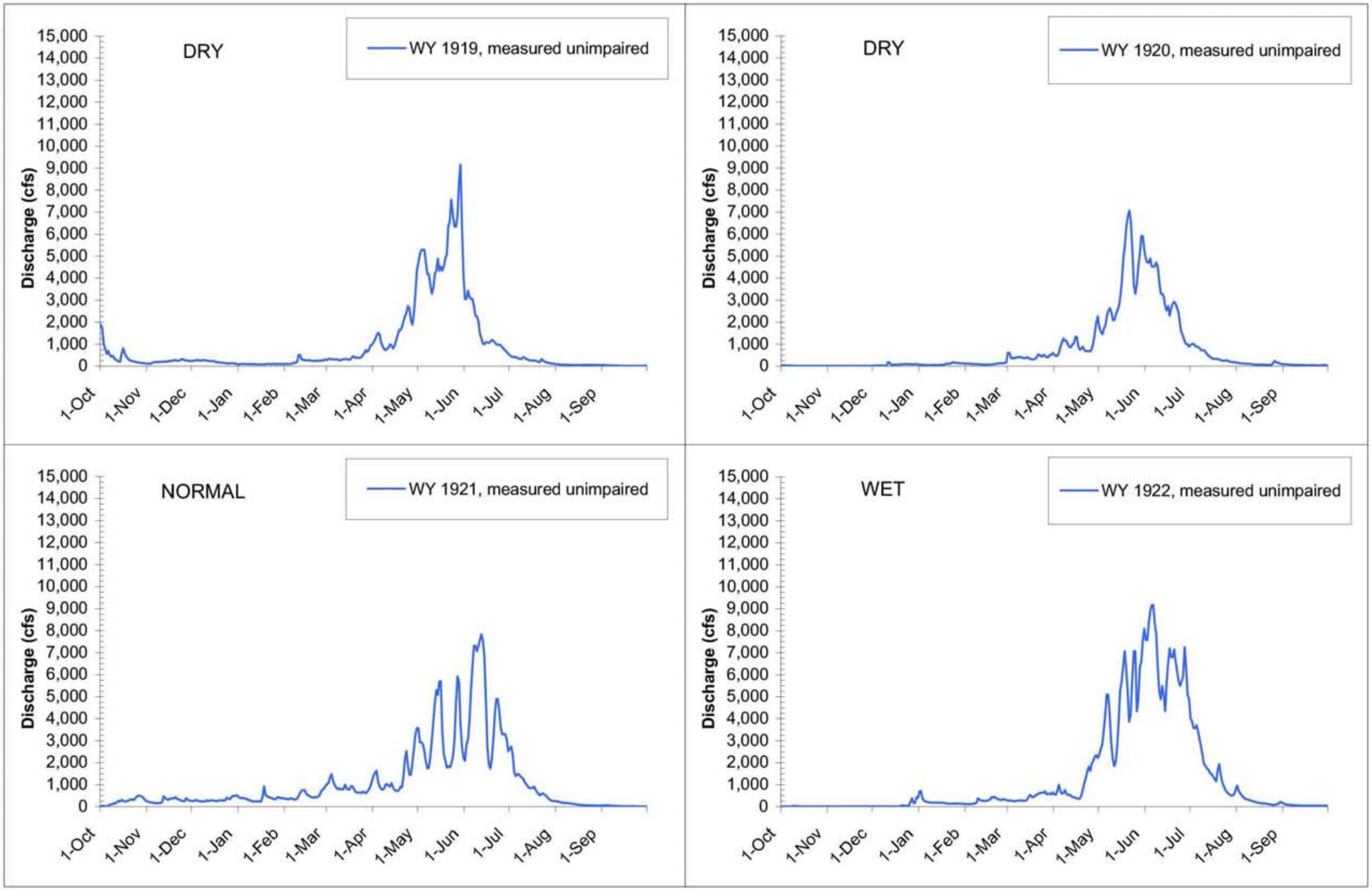
Appendix A: Daily average hydrographs for Tuolumne River near Hetch Hetchy below O'Shaughnessy Dam (USGS 11-276500) for Water Years 1911-2005.



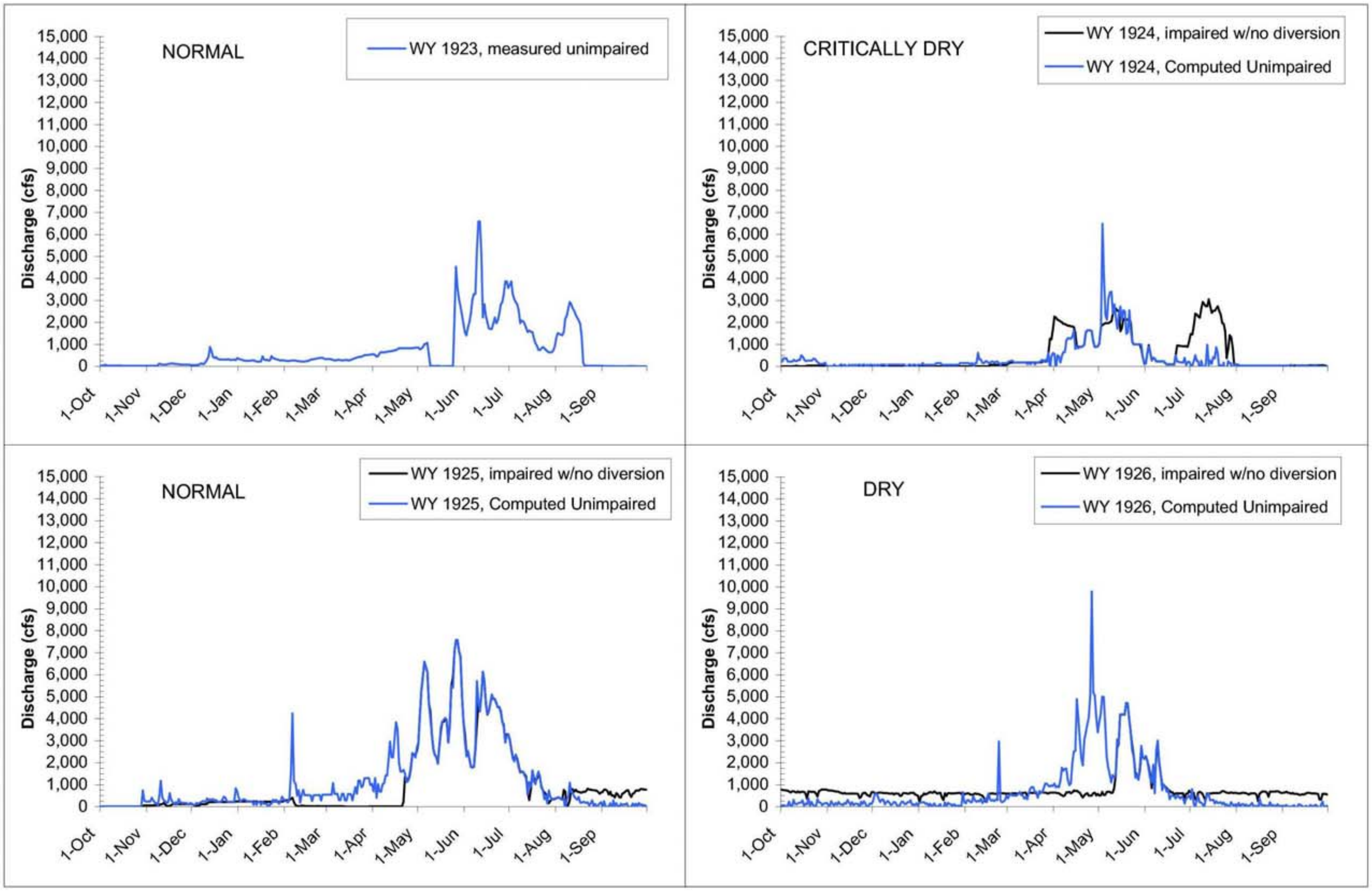
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



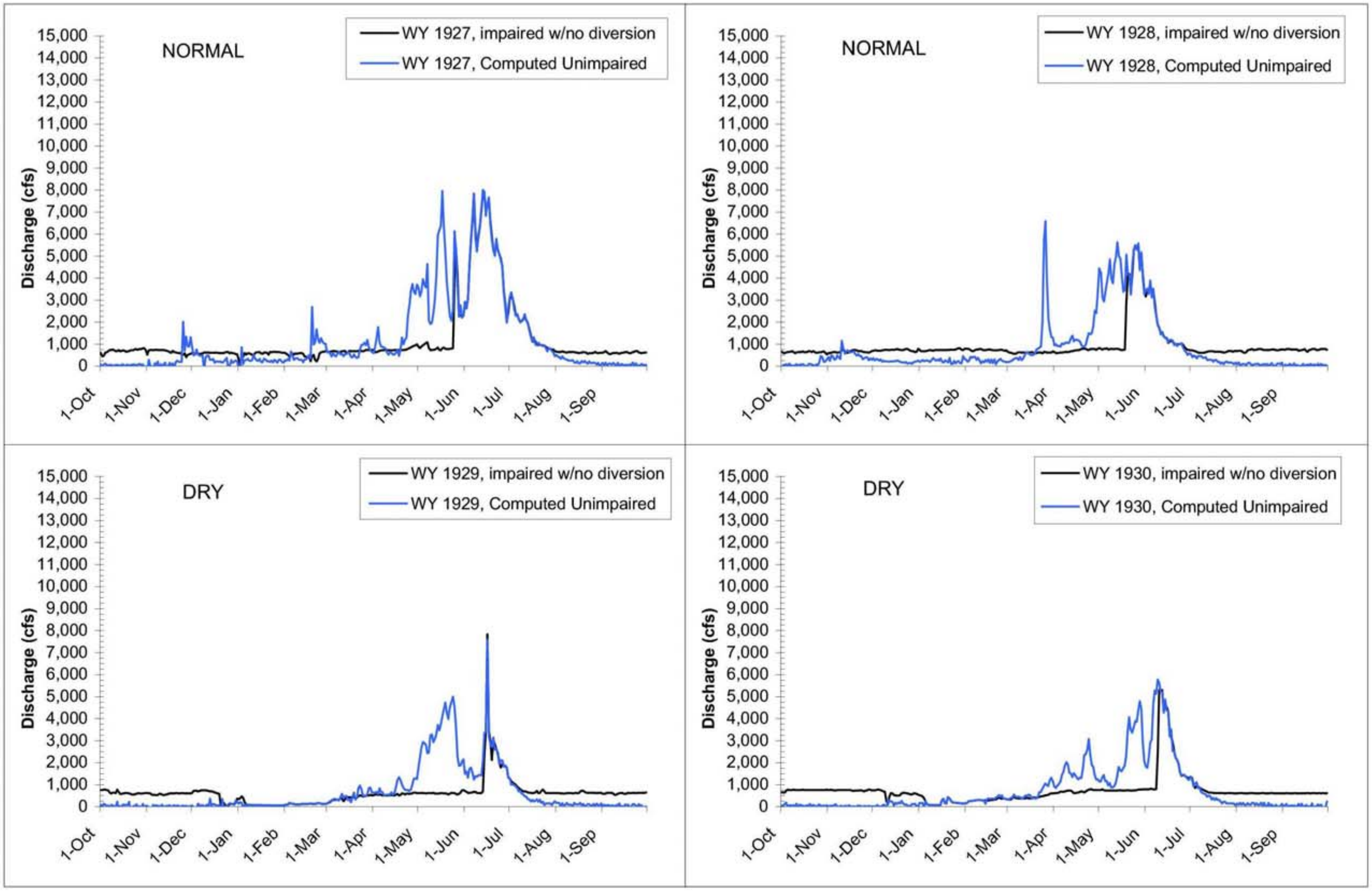
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



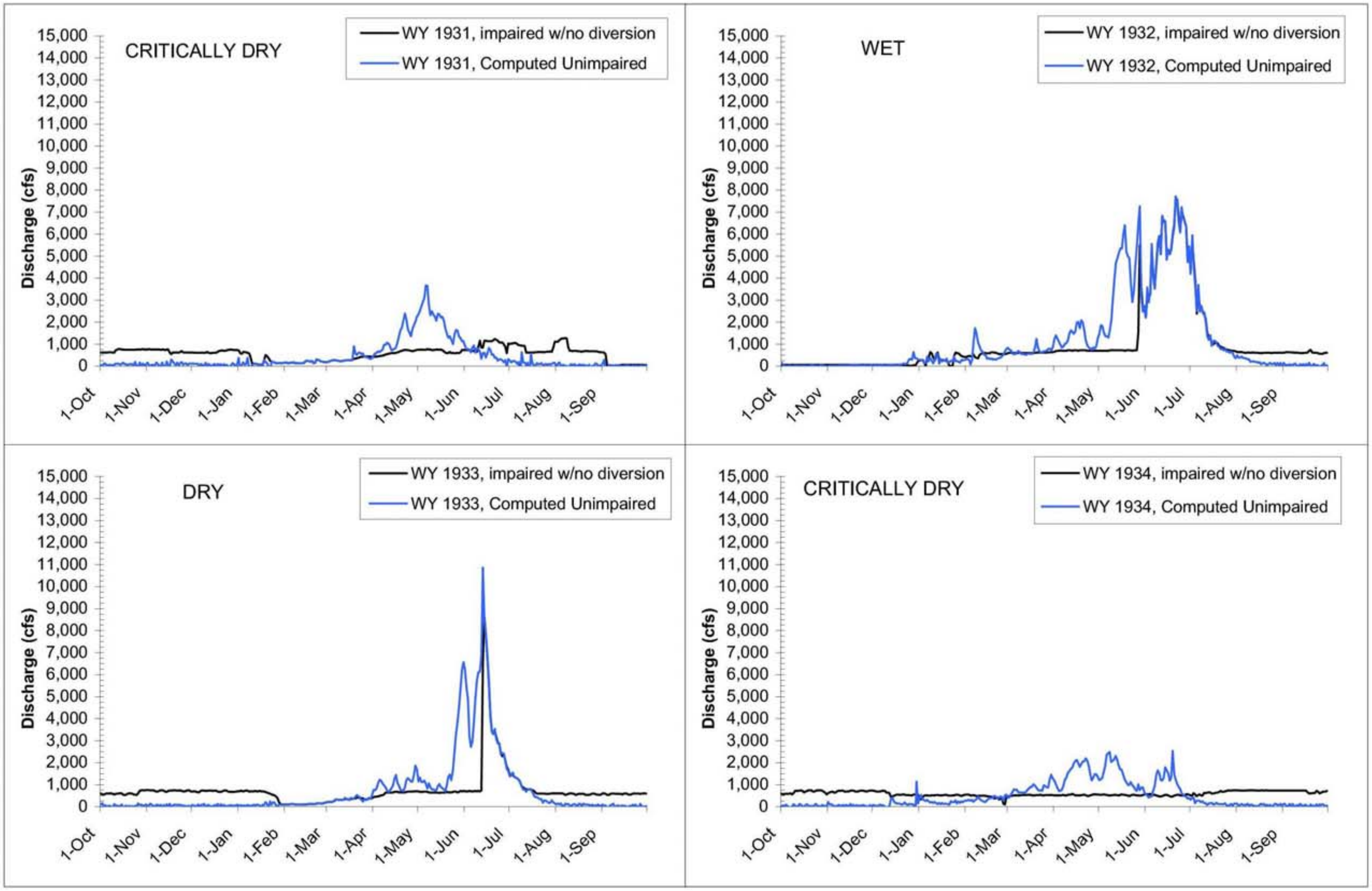
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



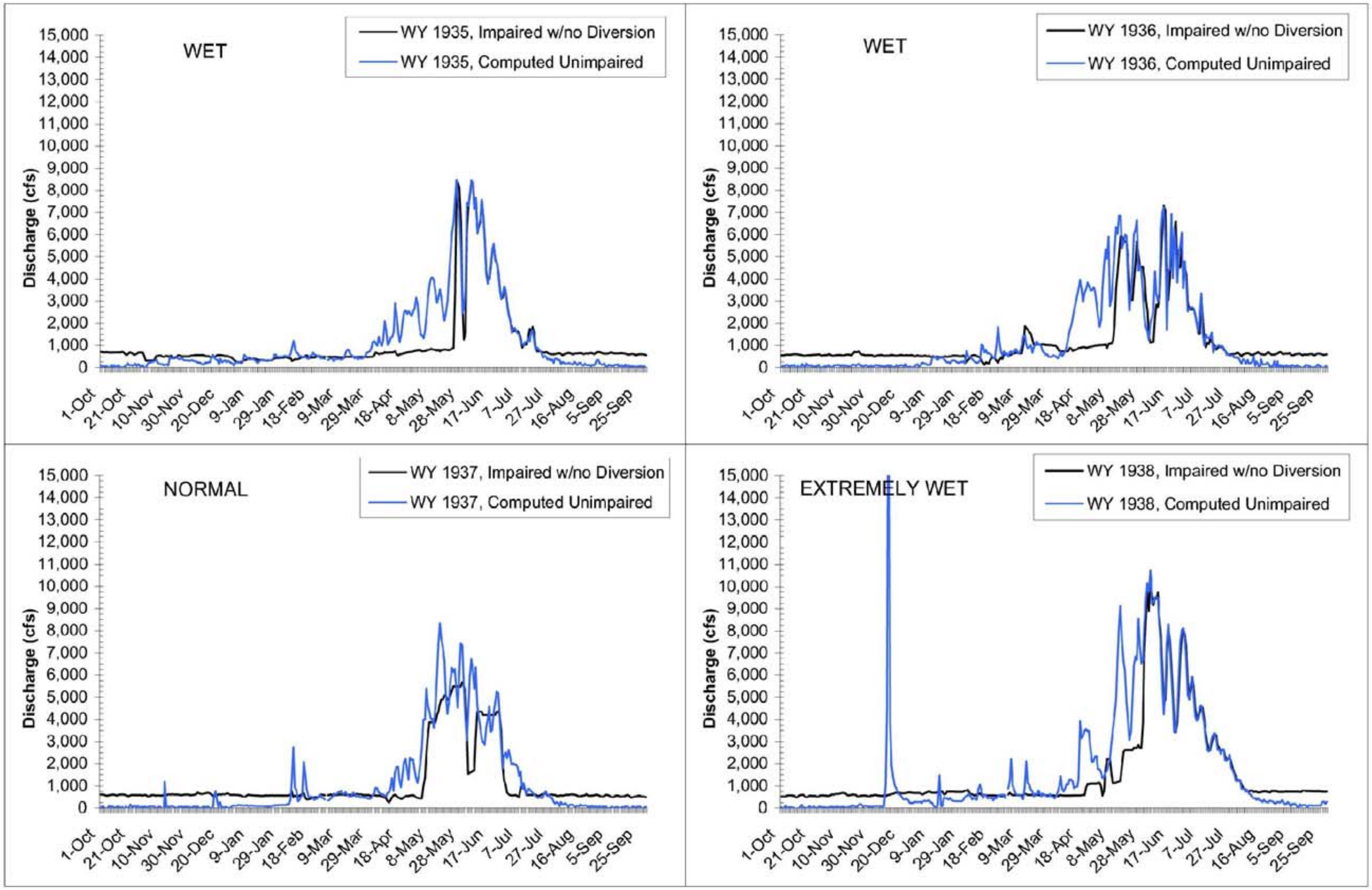
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



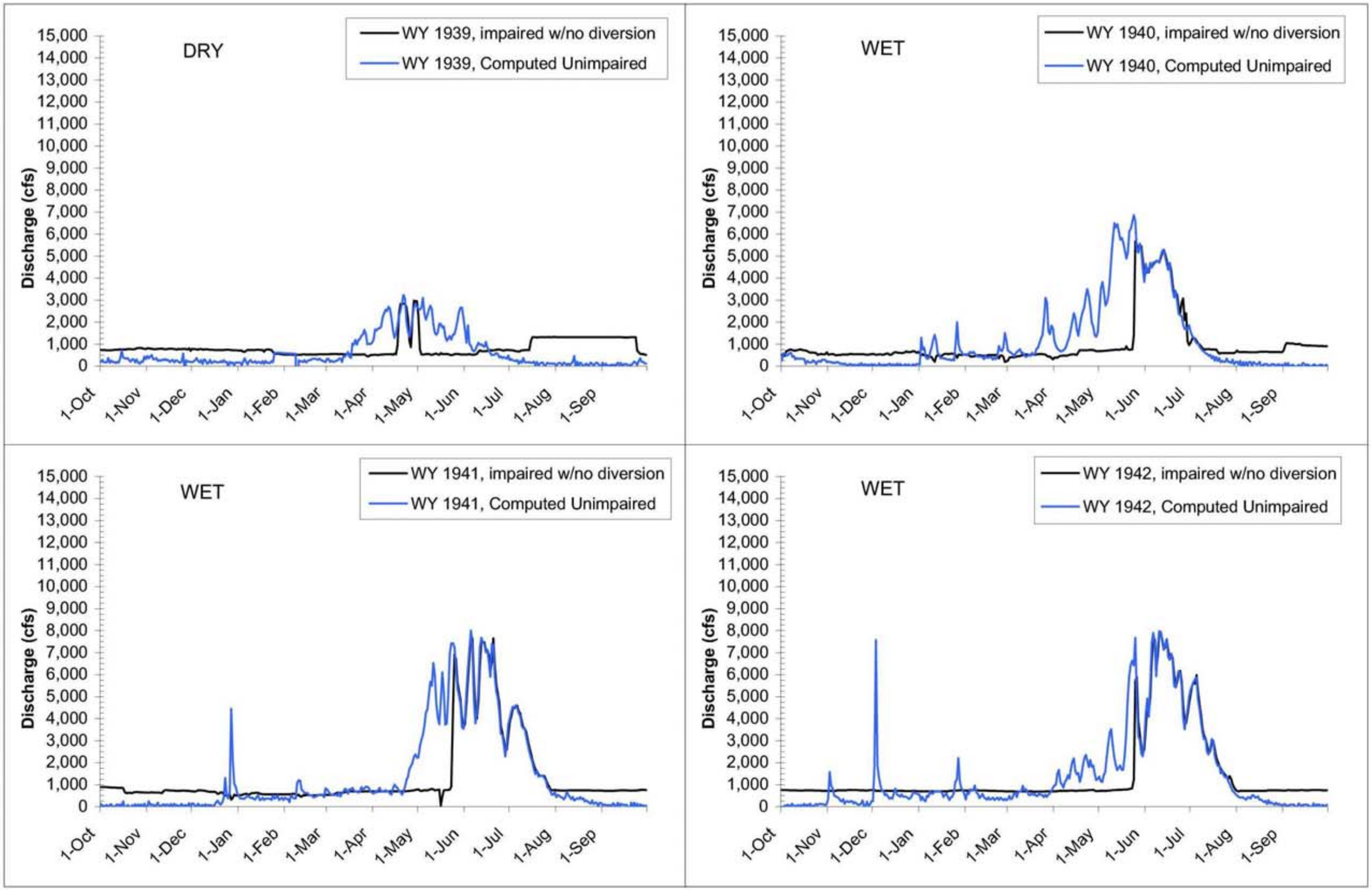
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



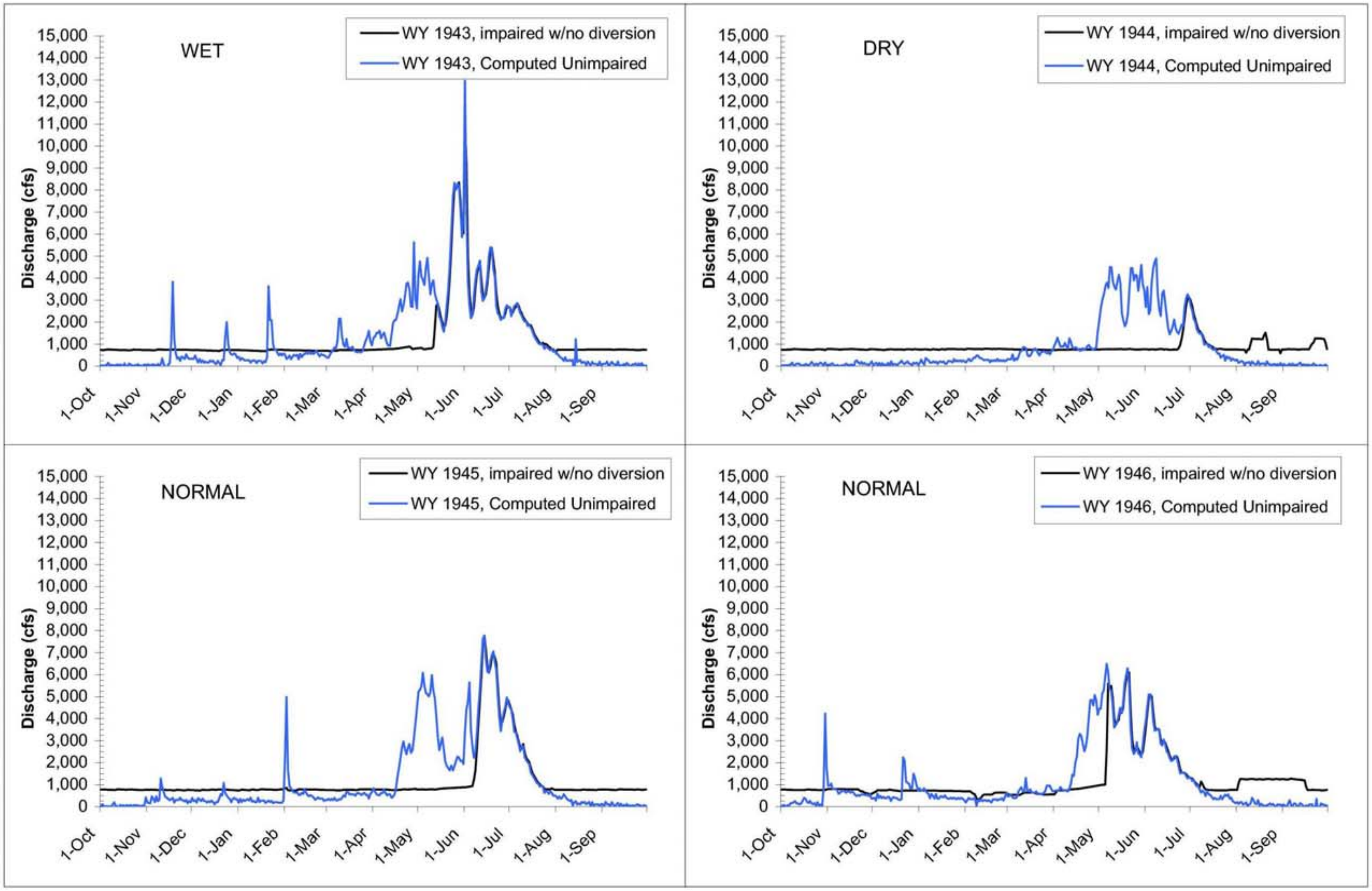
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



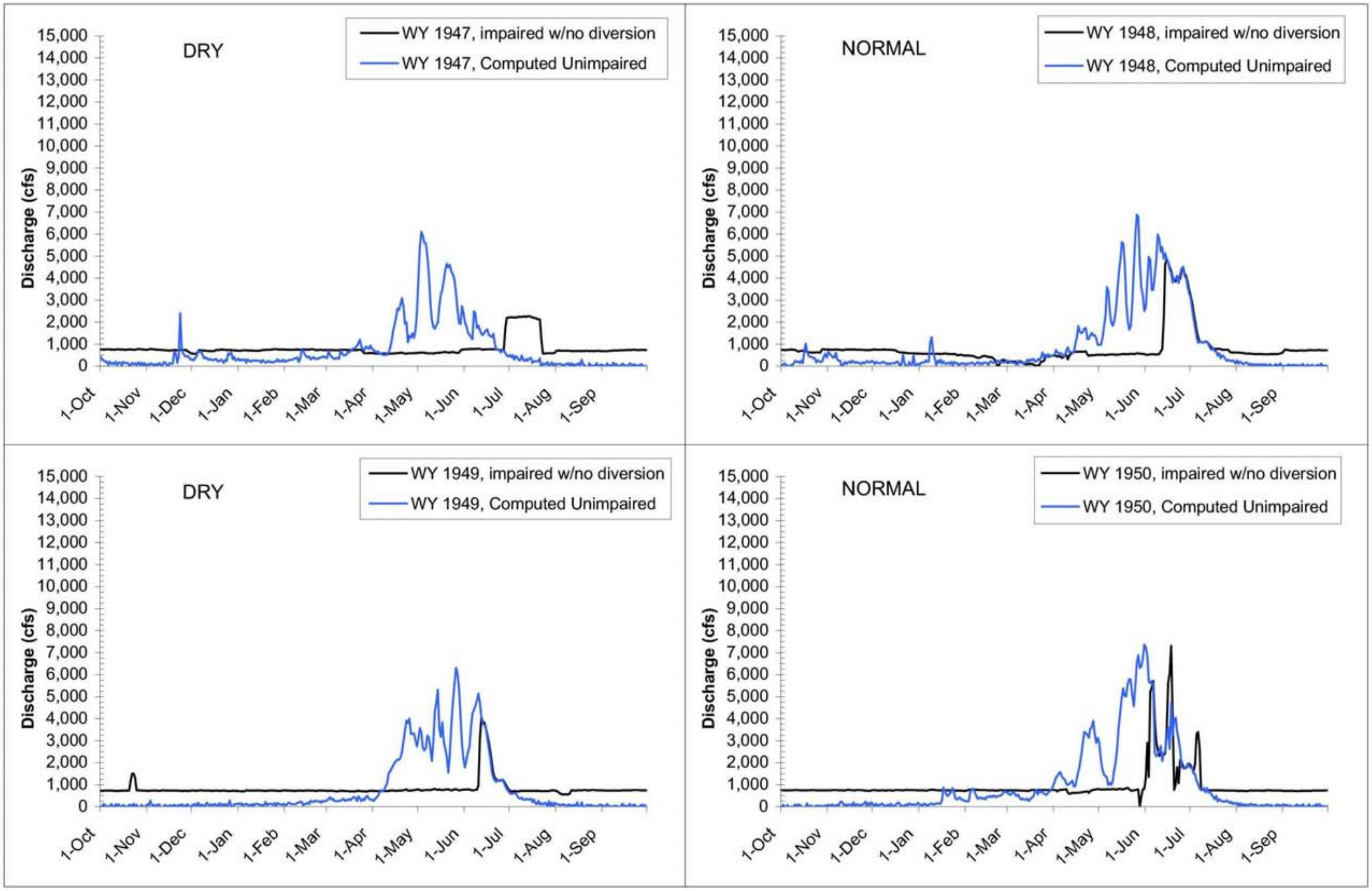
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



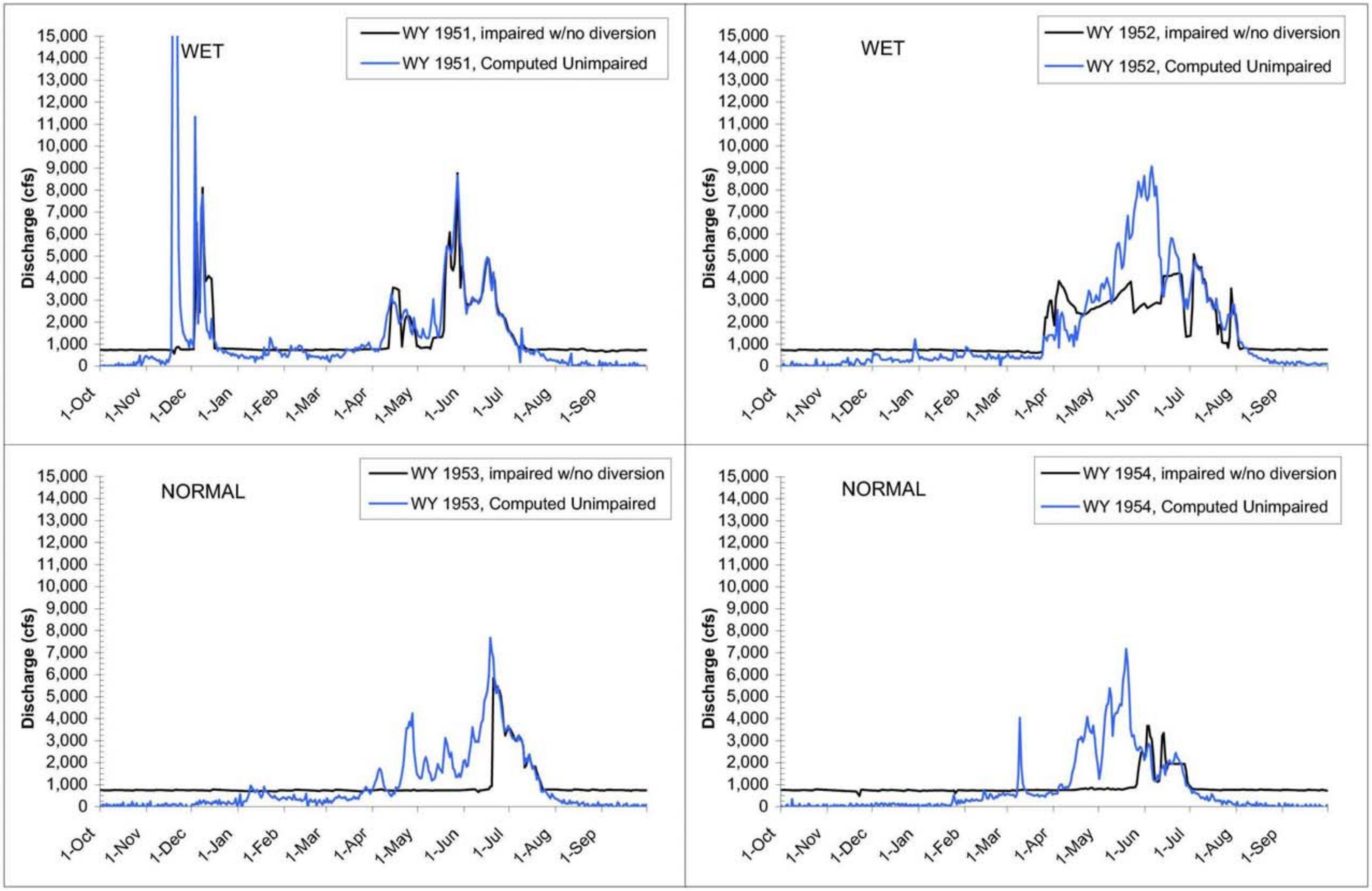
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



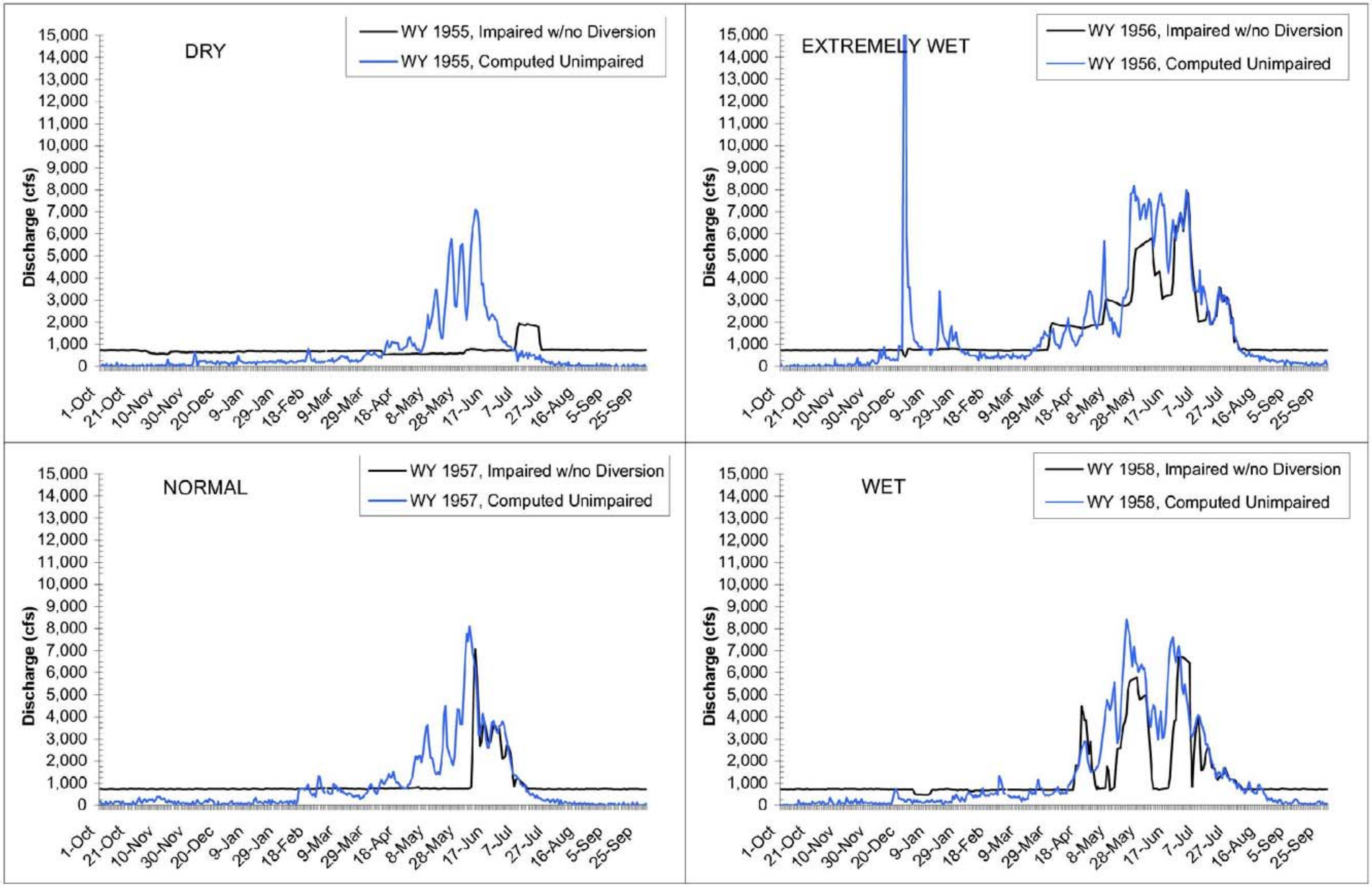
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



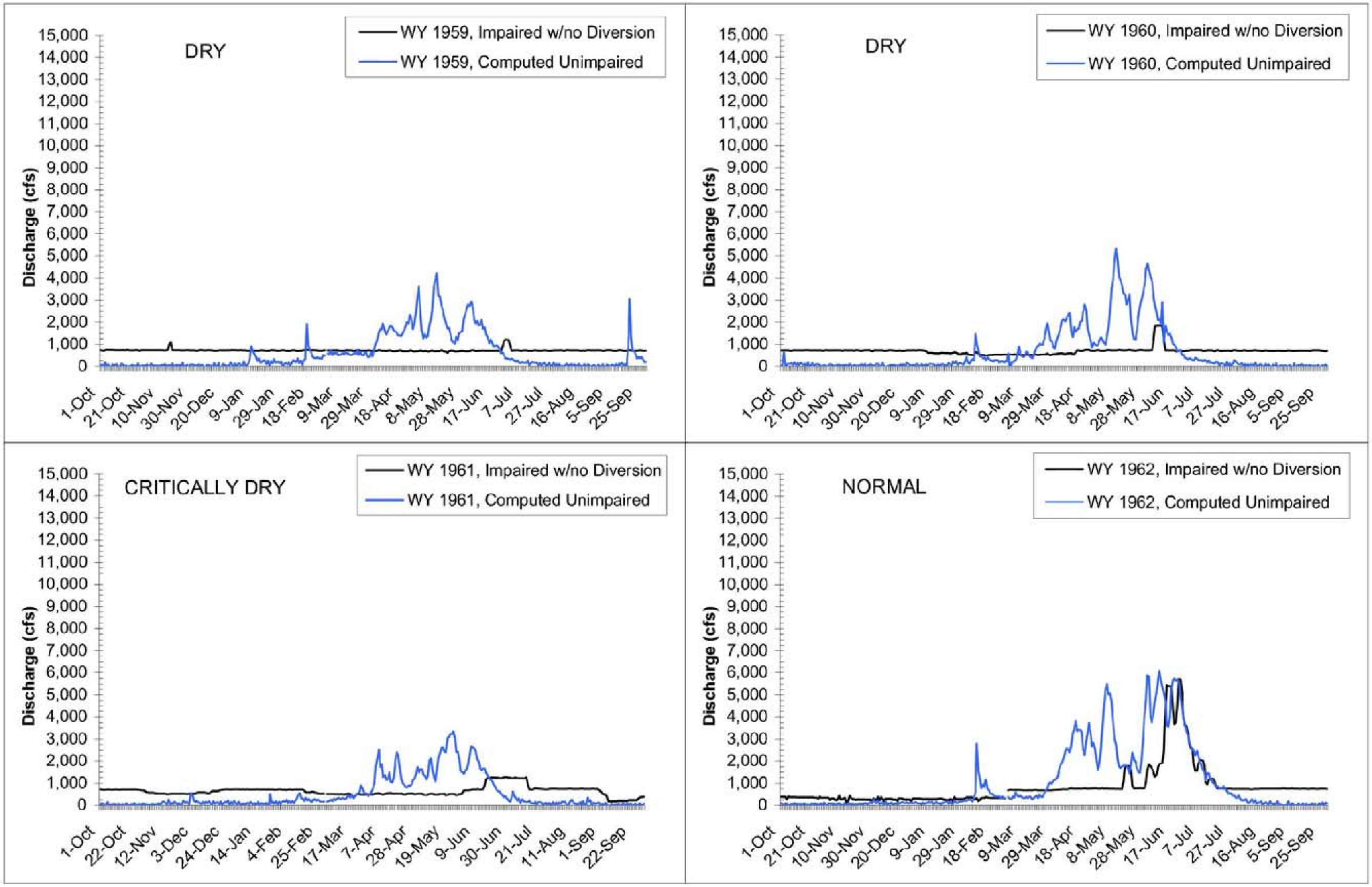
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



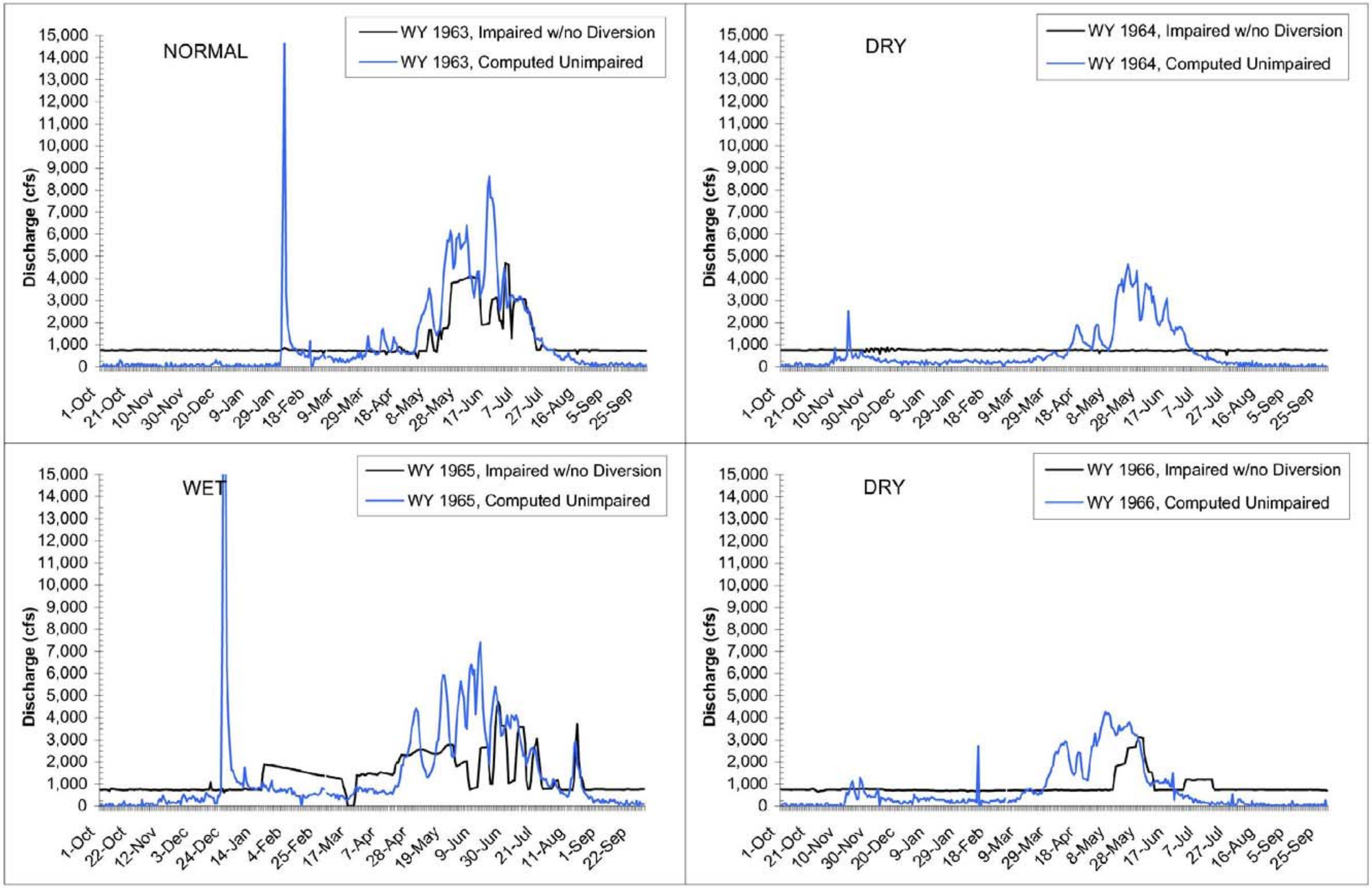
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



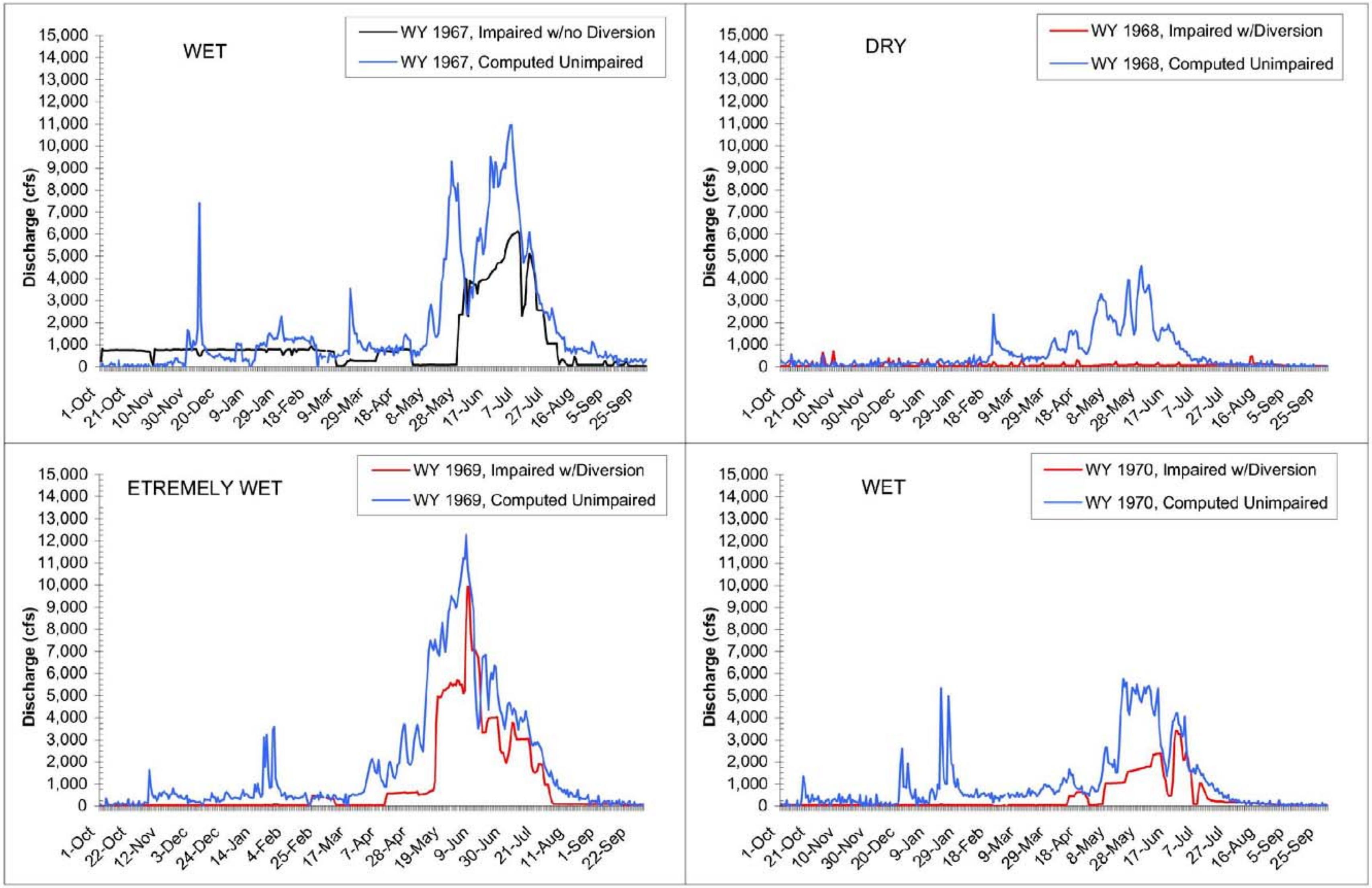
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



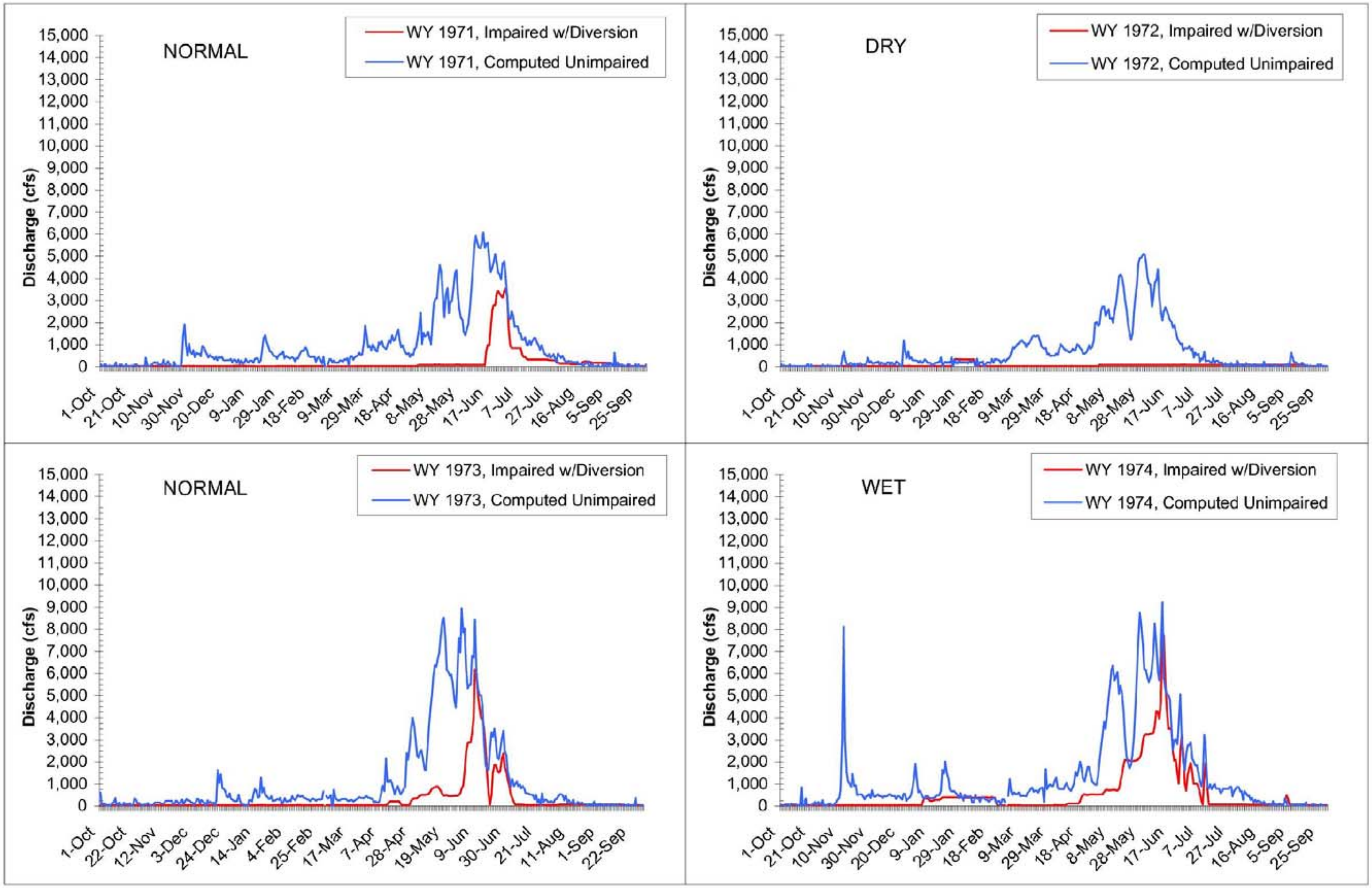
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



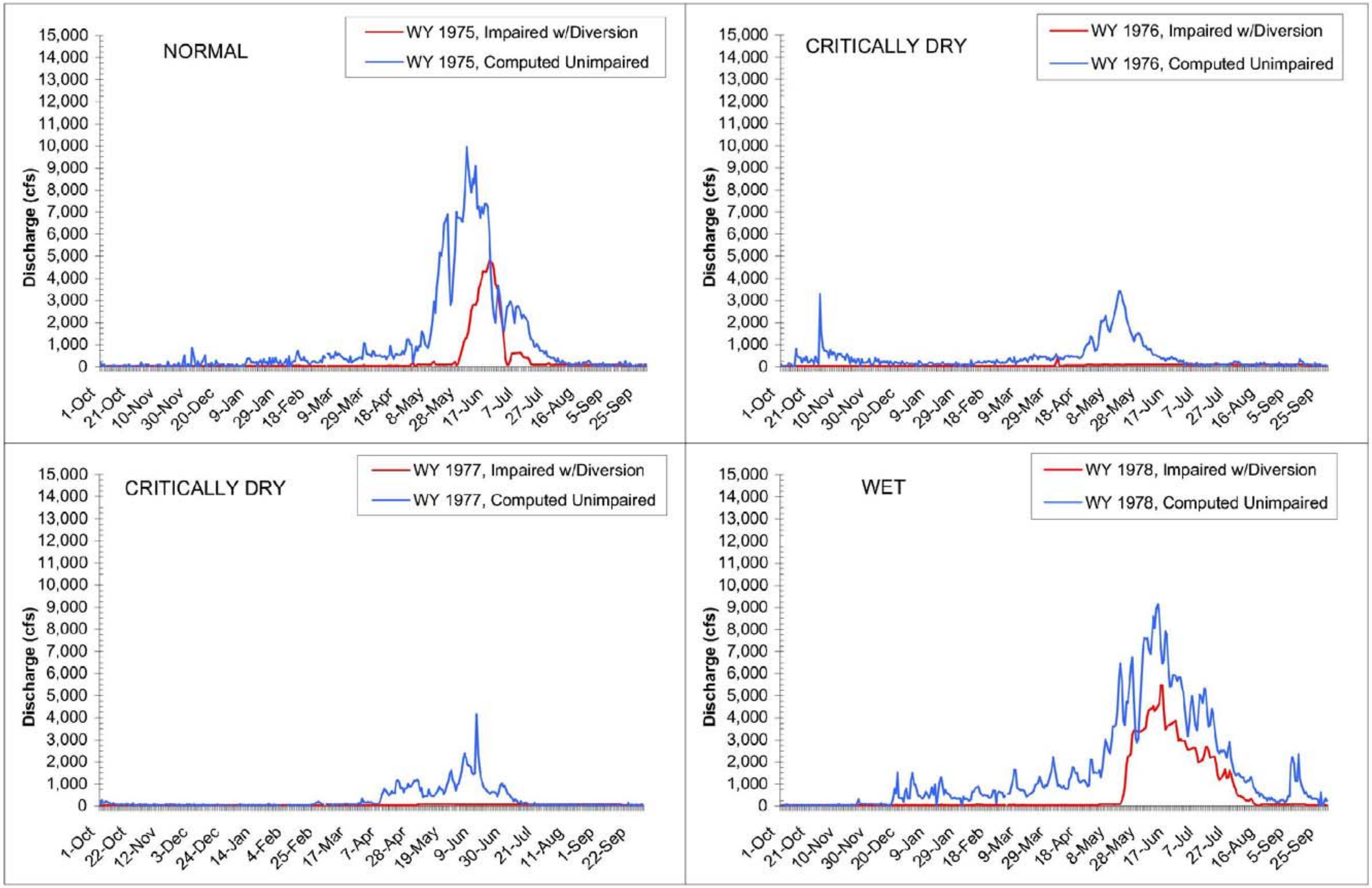
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



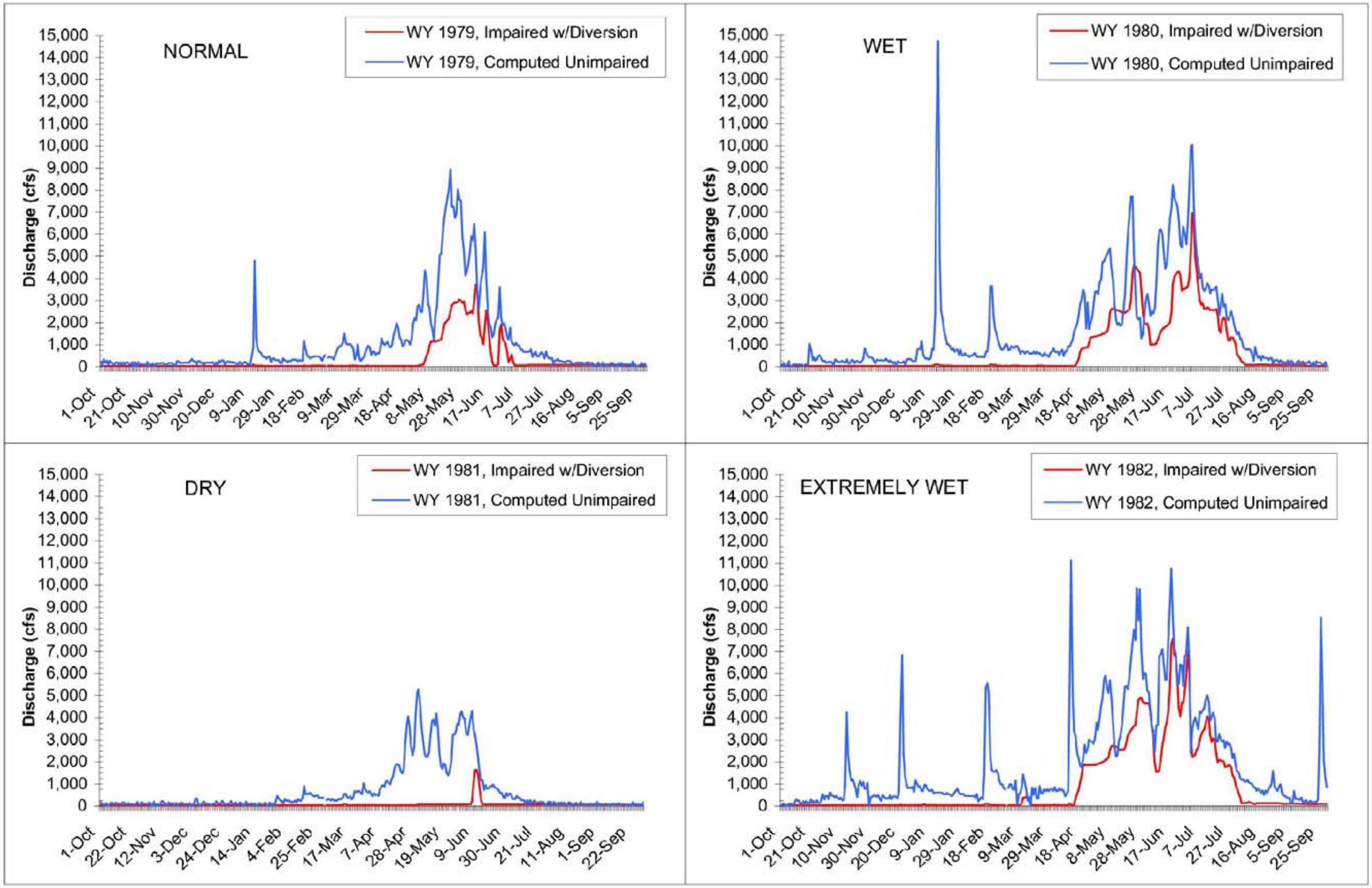
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



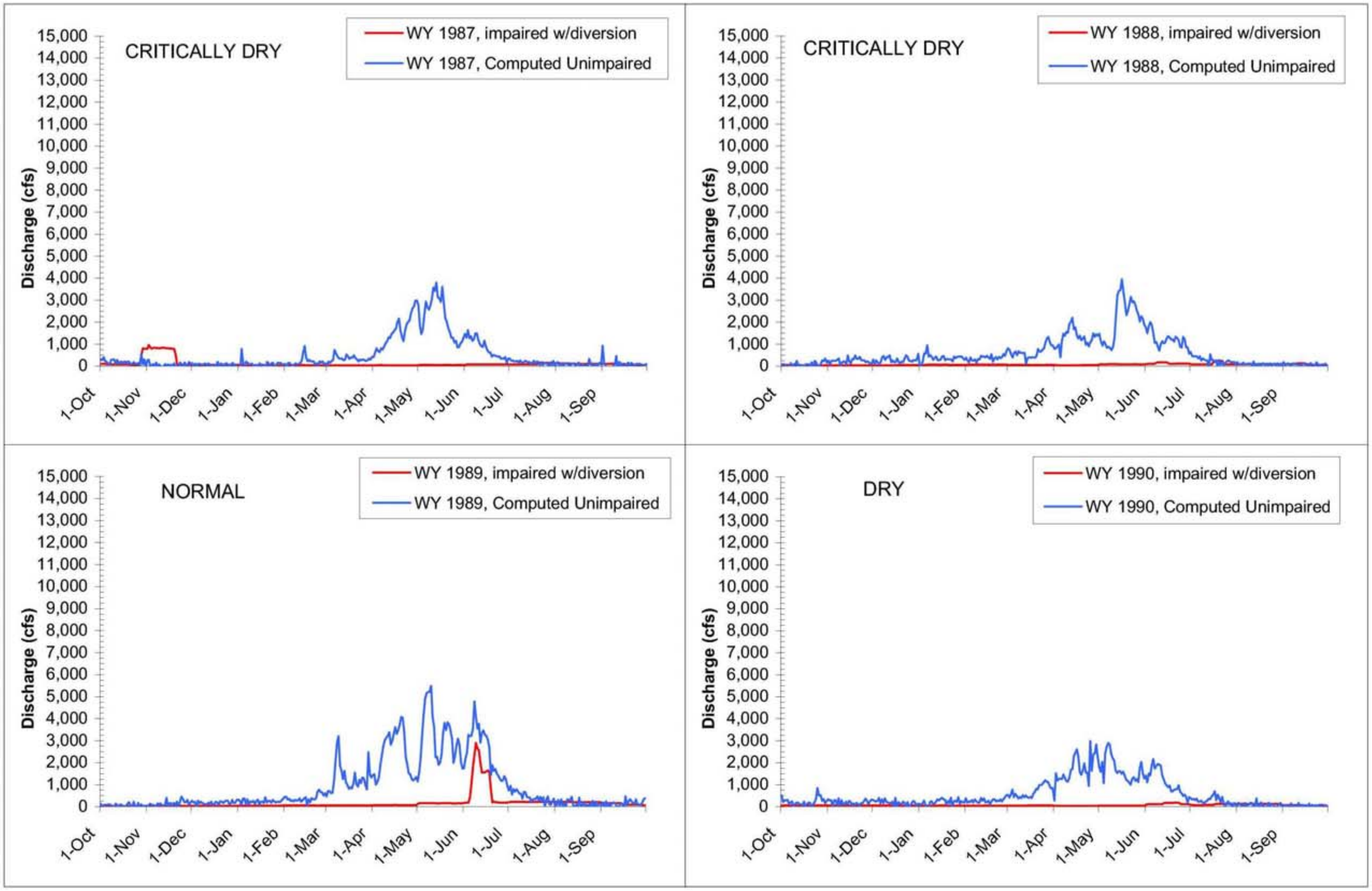
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



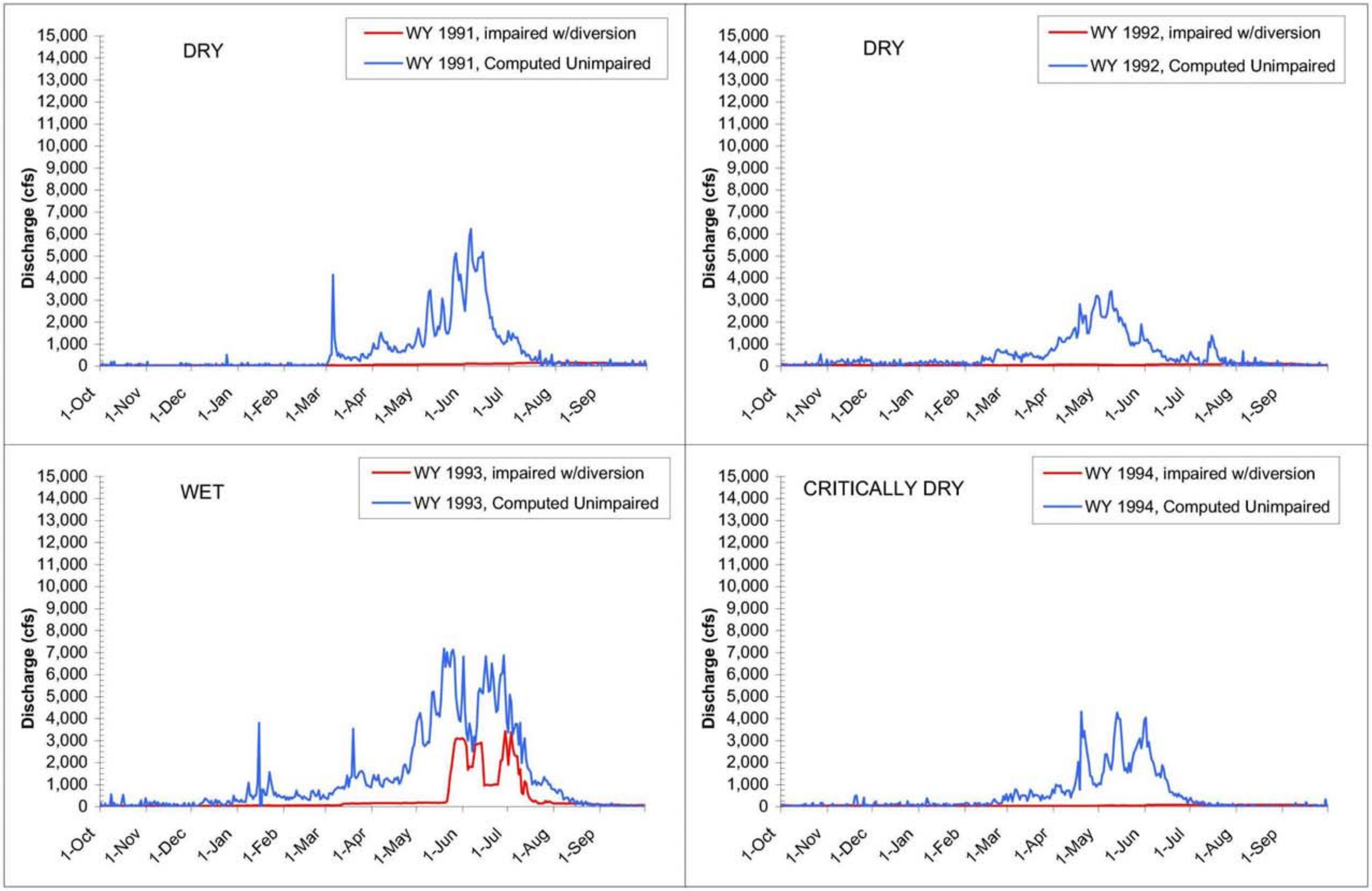
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



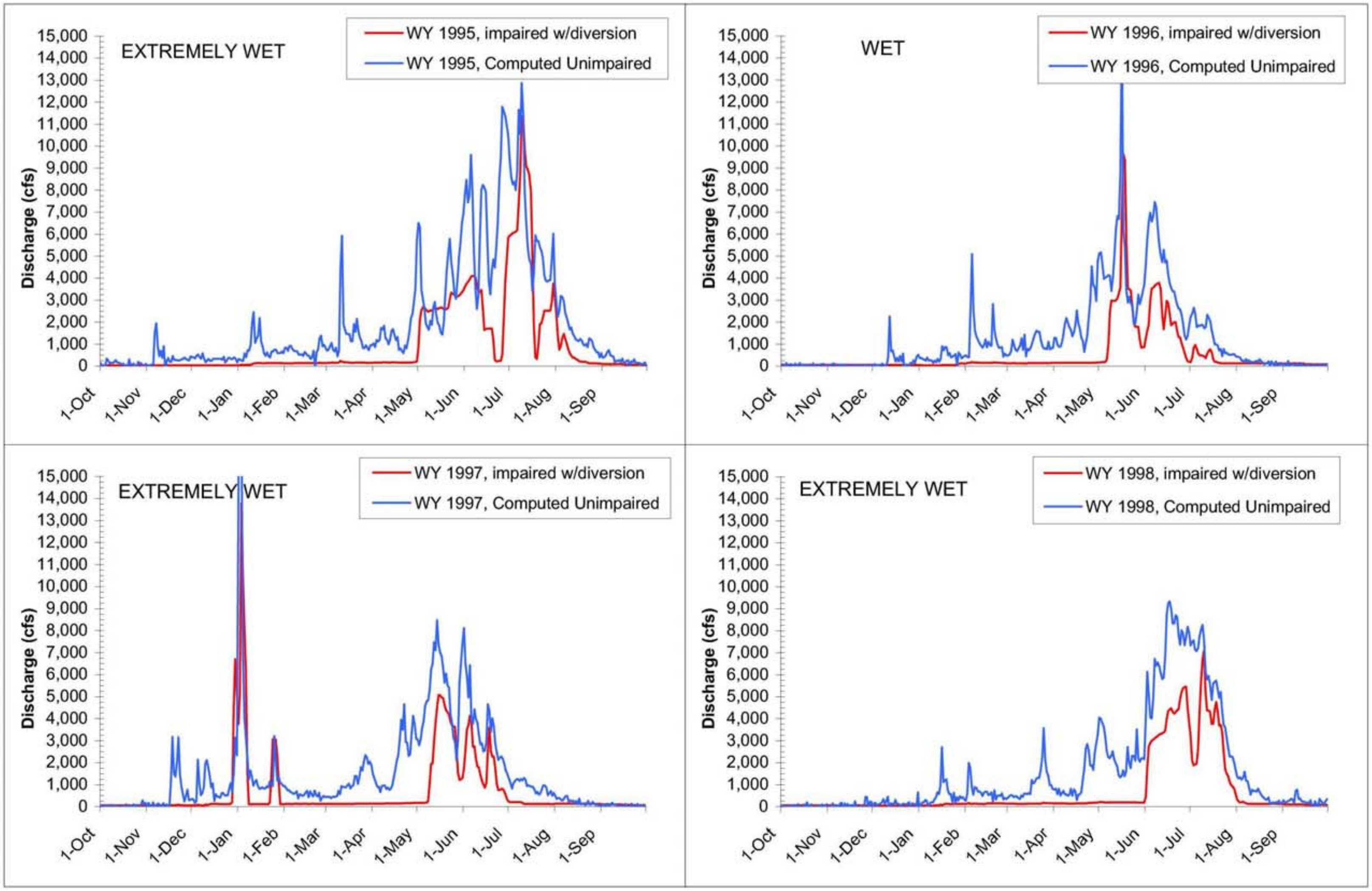
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



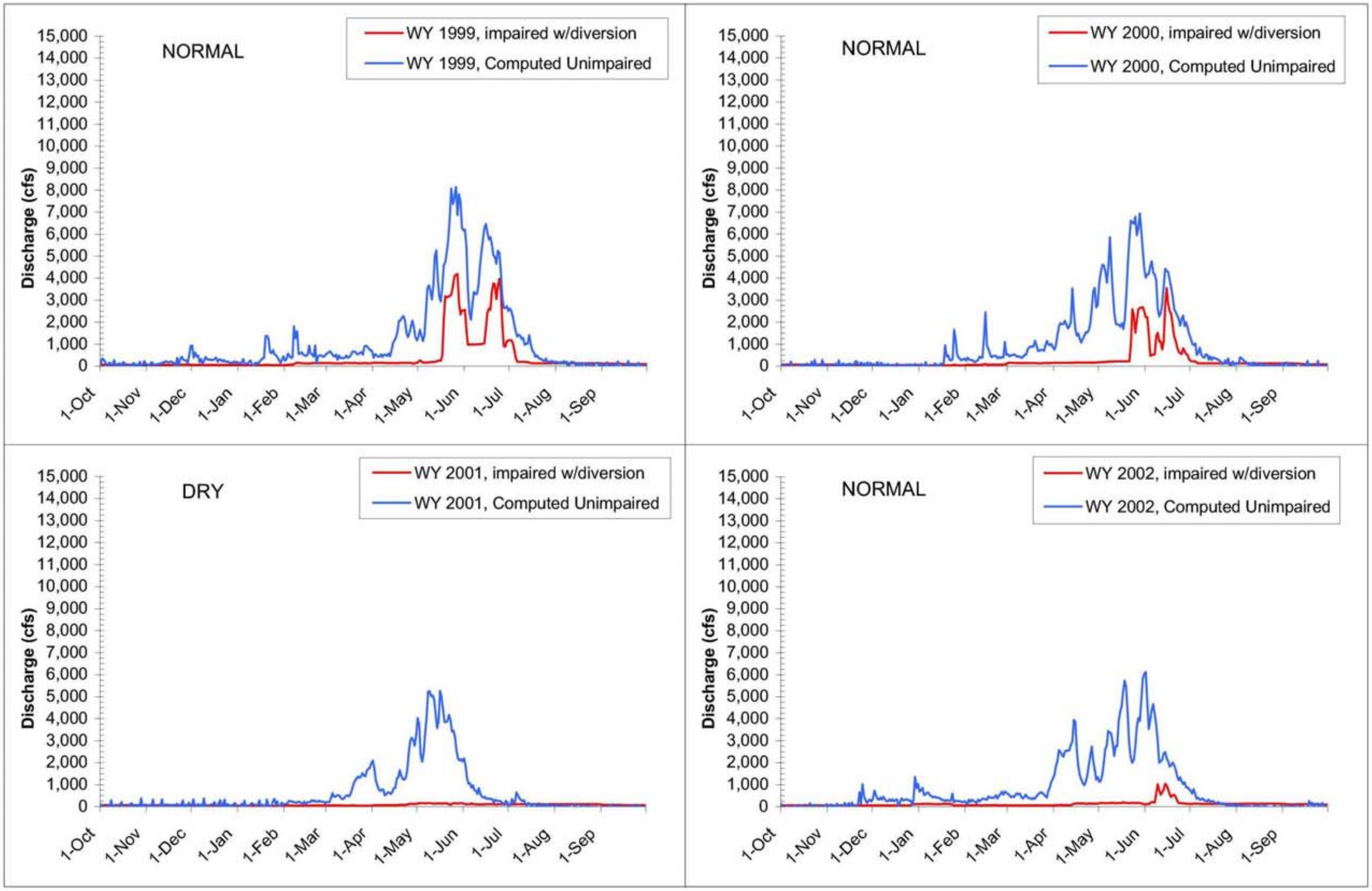
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



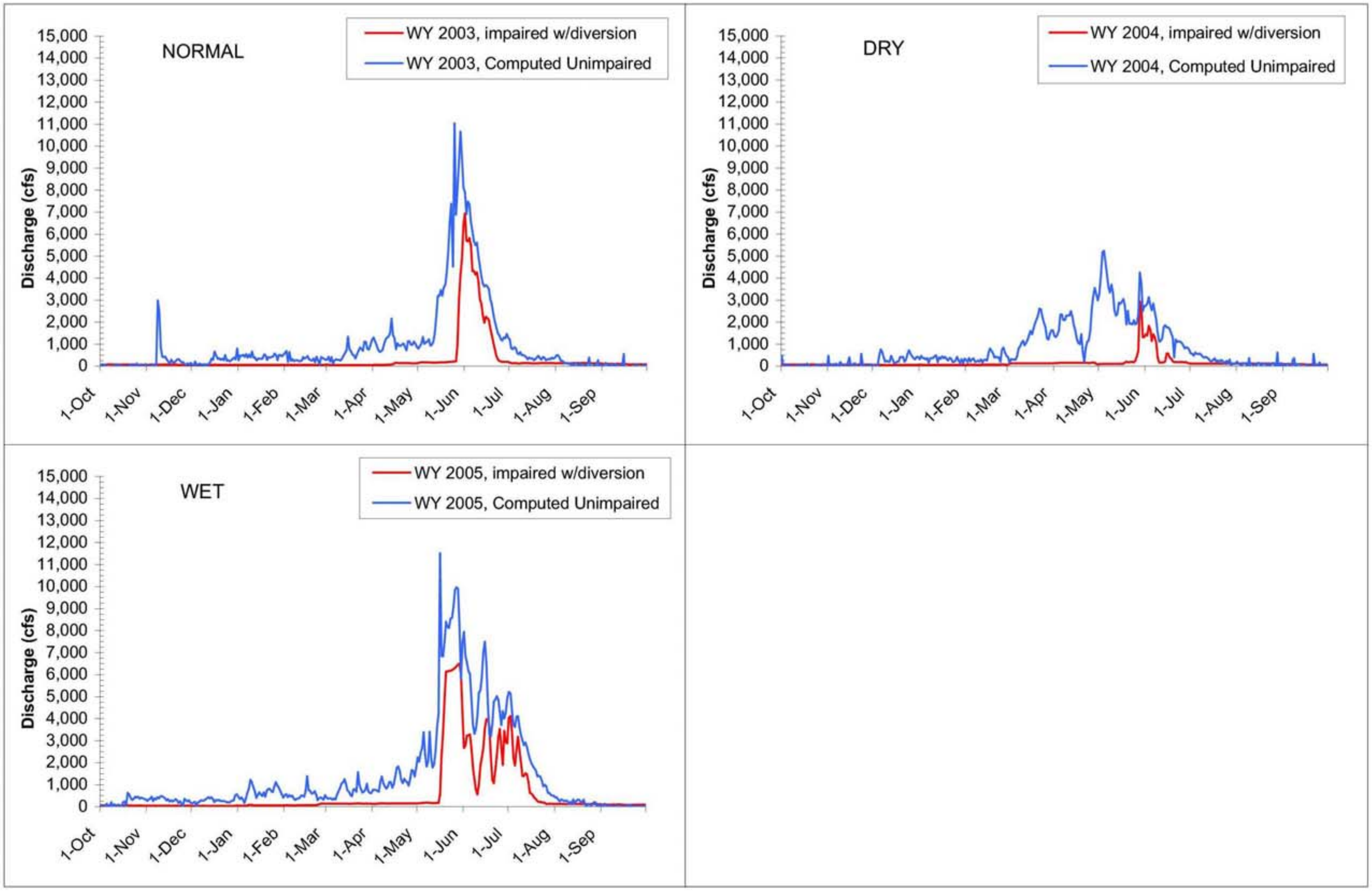
Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)



Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)

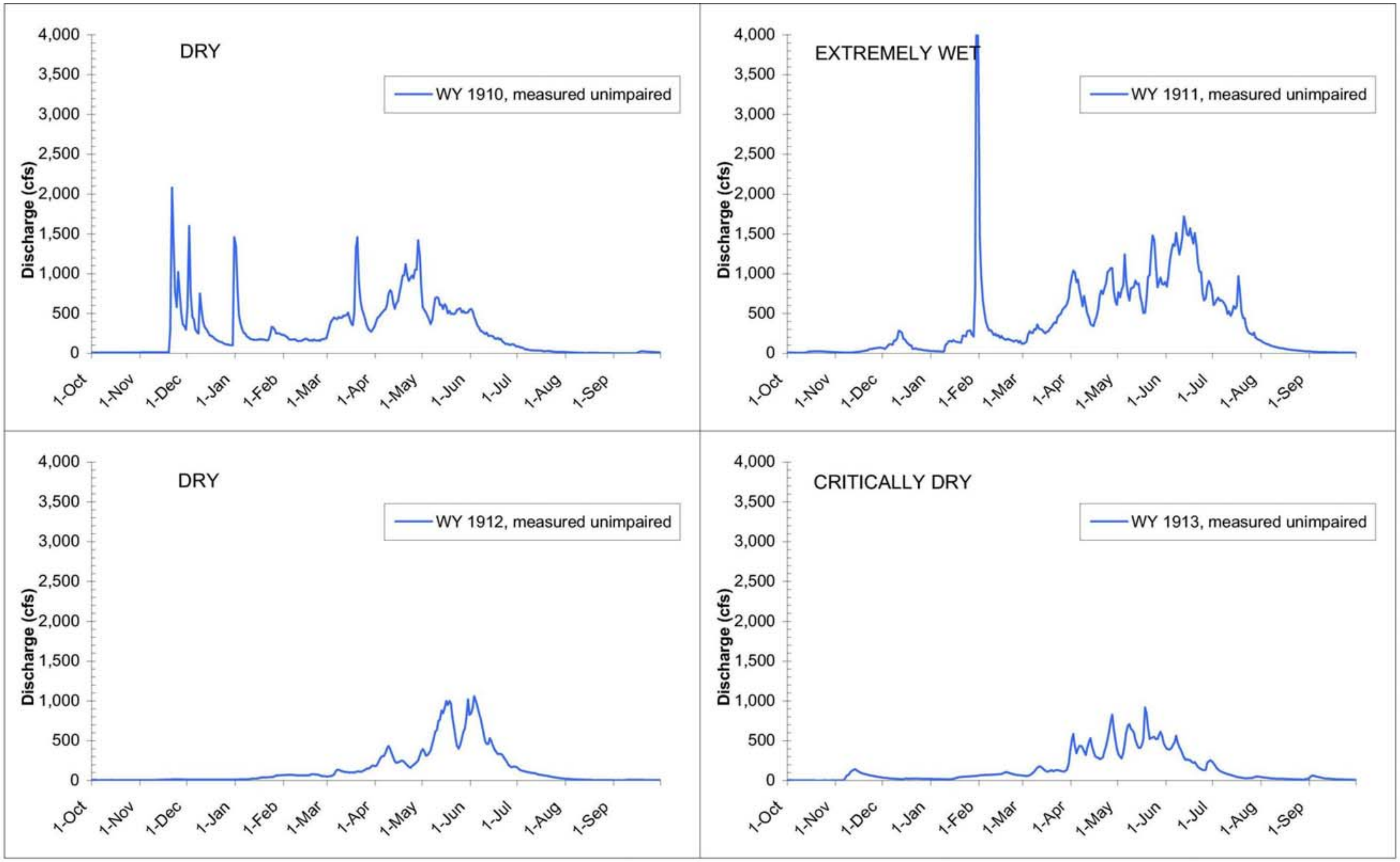


Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)

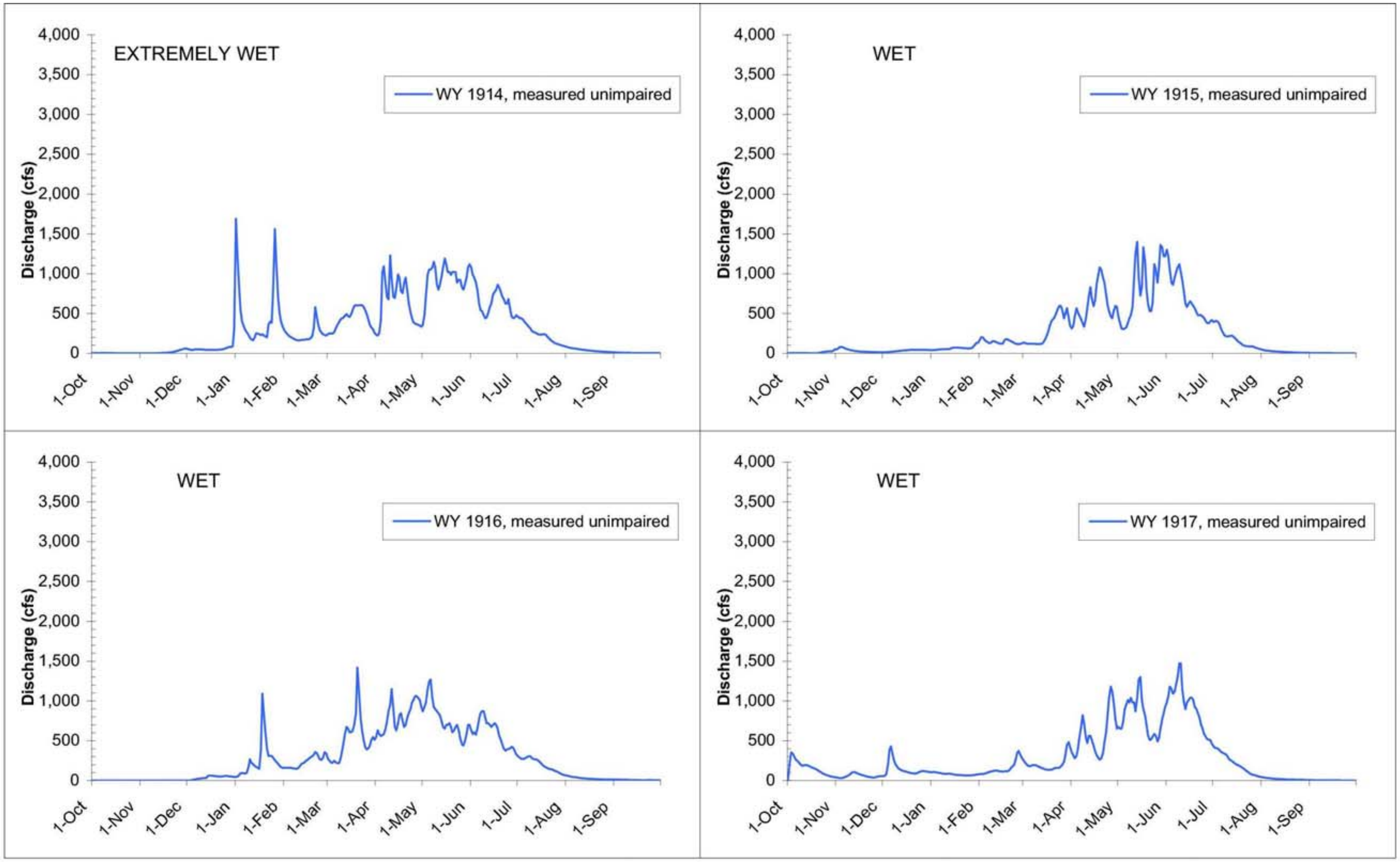


Tuolumne River nr Hetch Hetchy, CA (USGS Stn 11-276500)

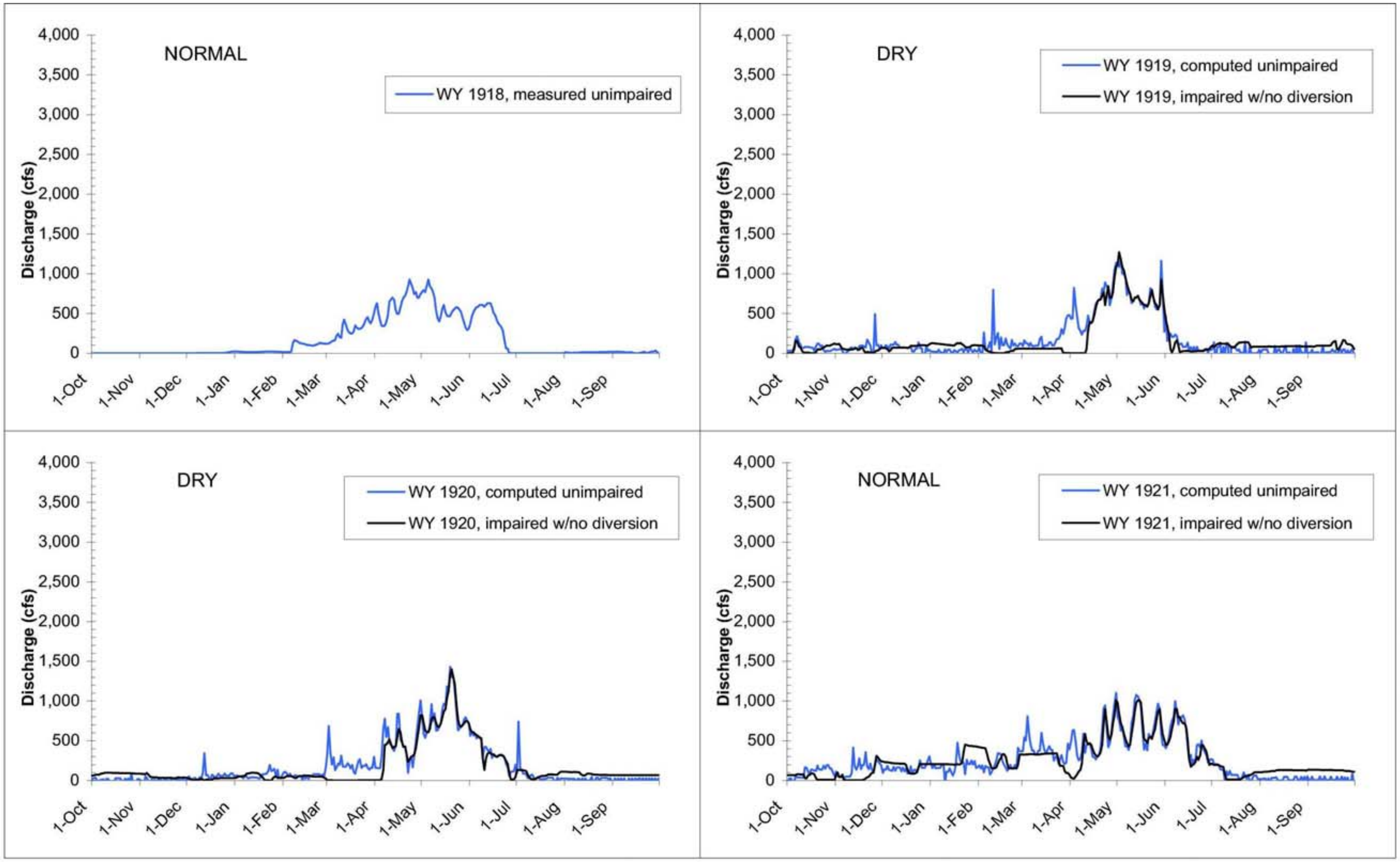
Appendix B: Daily average hydrographs for Eleanor Creek near Hetch Hetchy below Lake Eleanor Dam (USGS 11-278000) for Water Years 1910-2005.



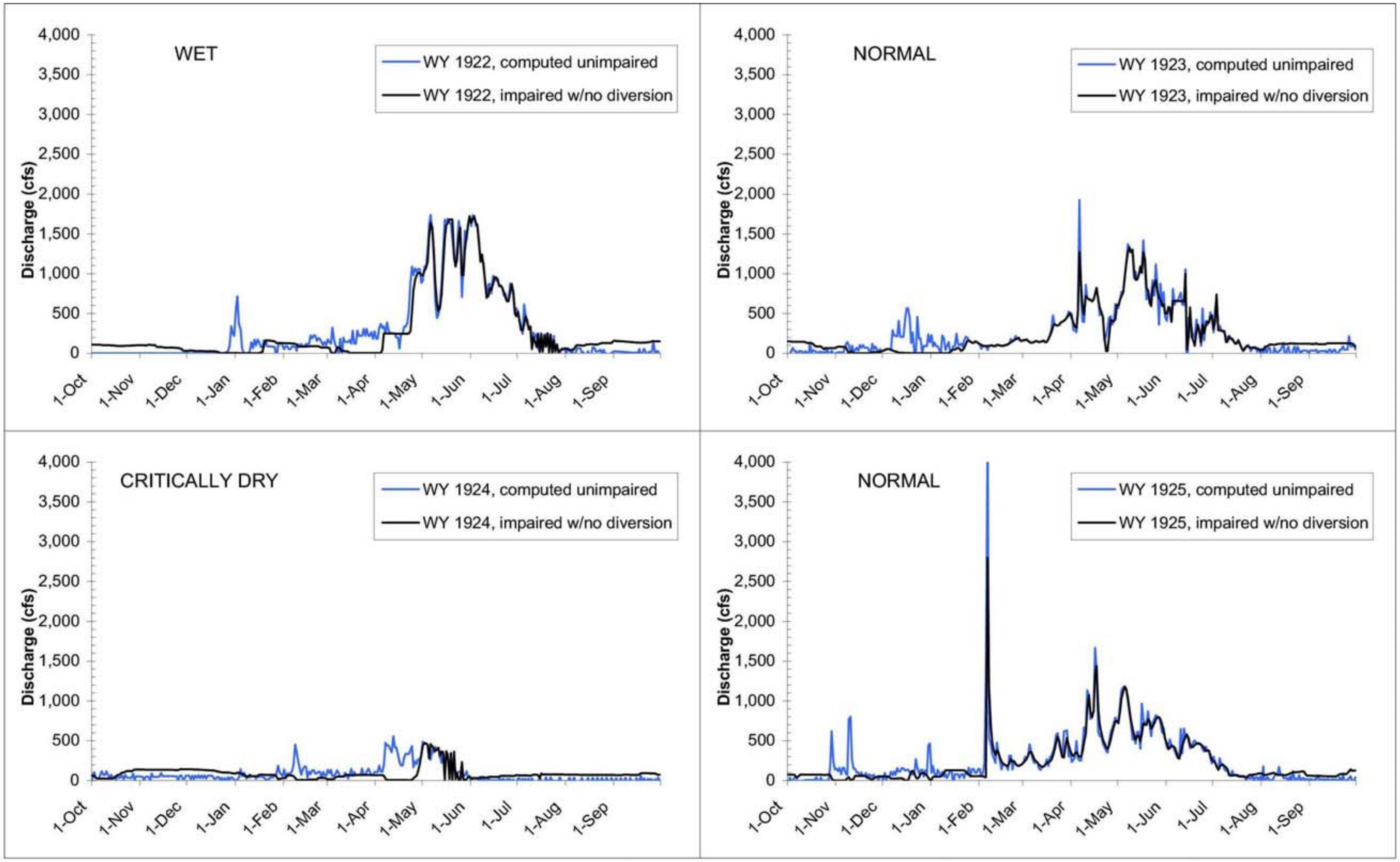
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



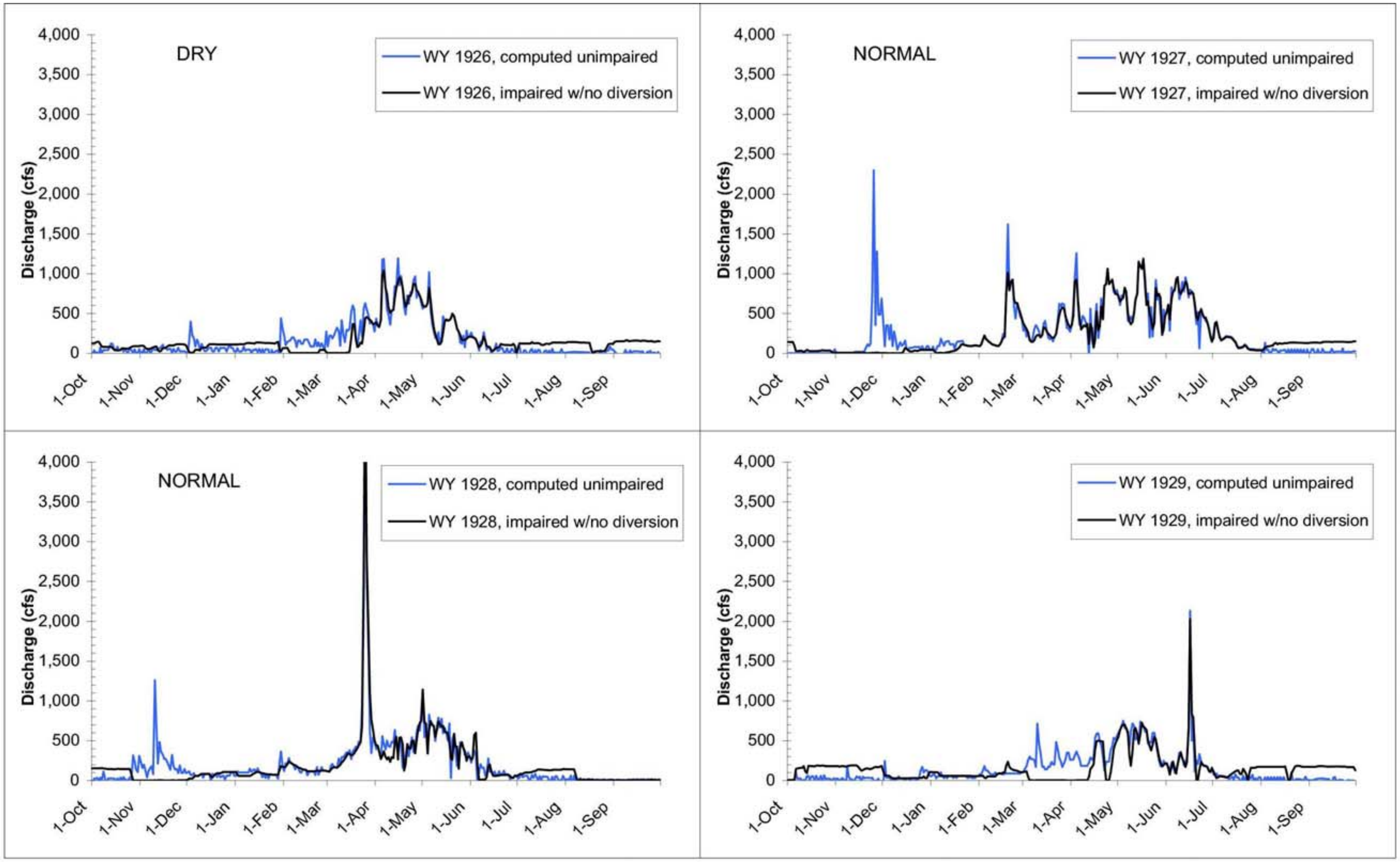
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



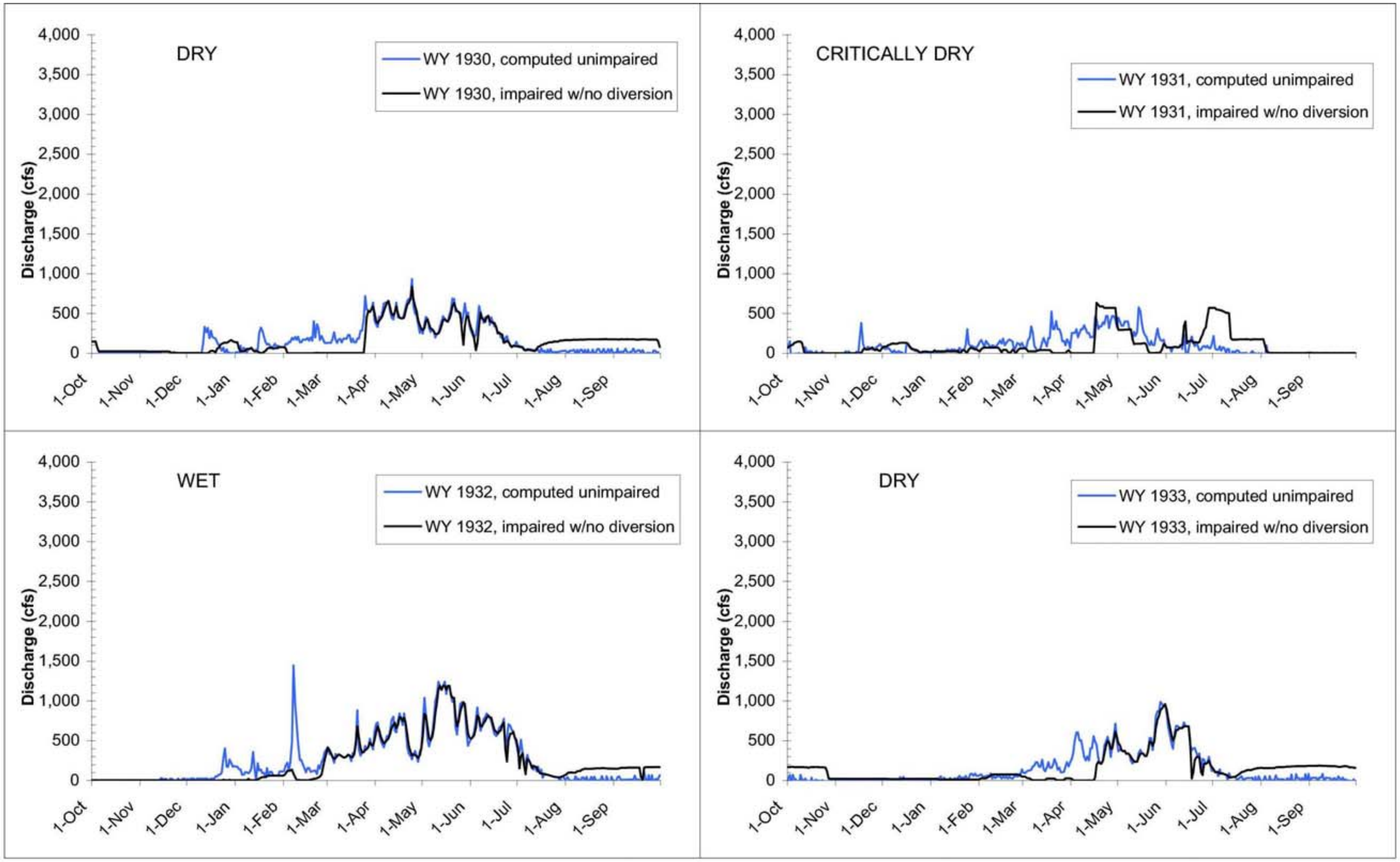
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



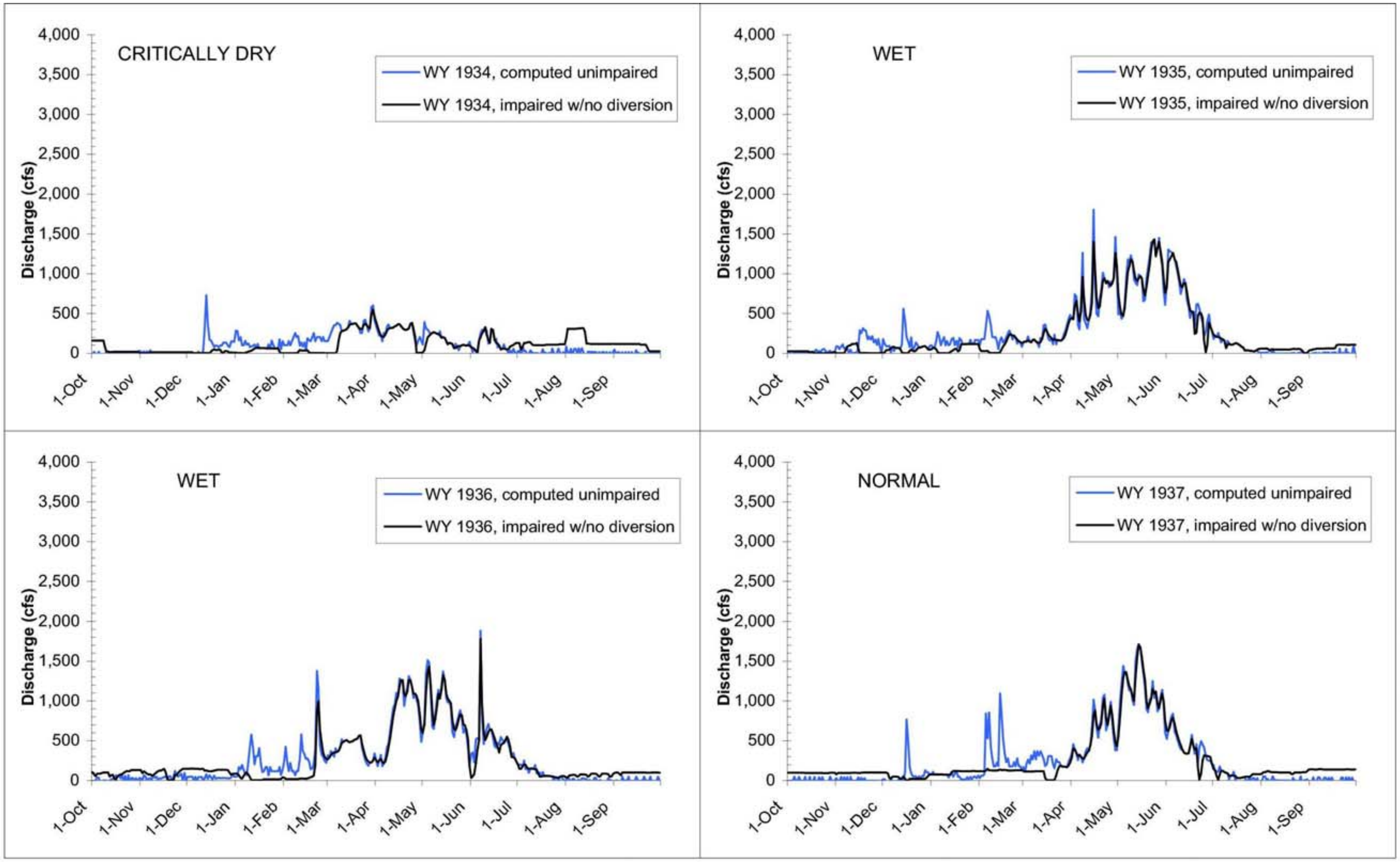
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



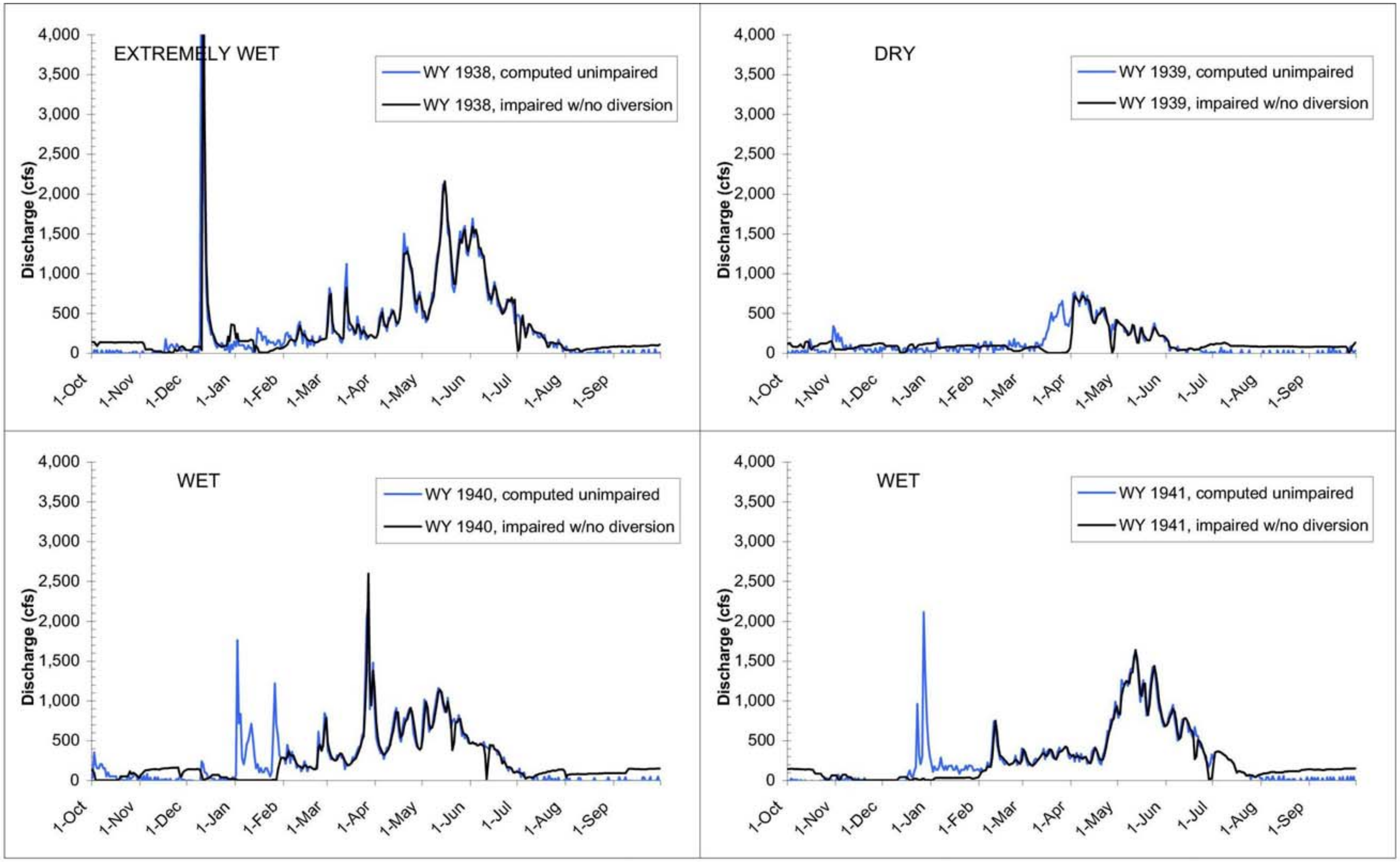
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



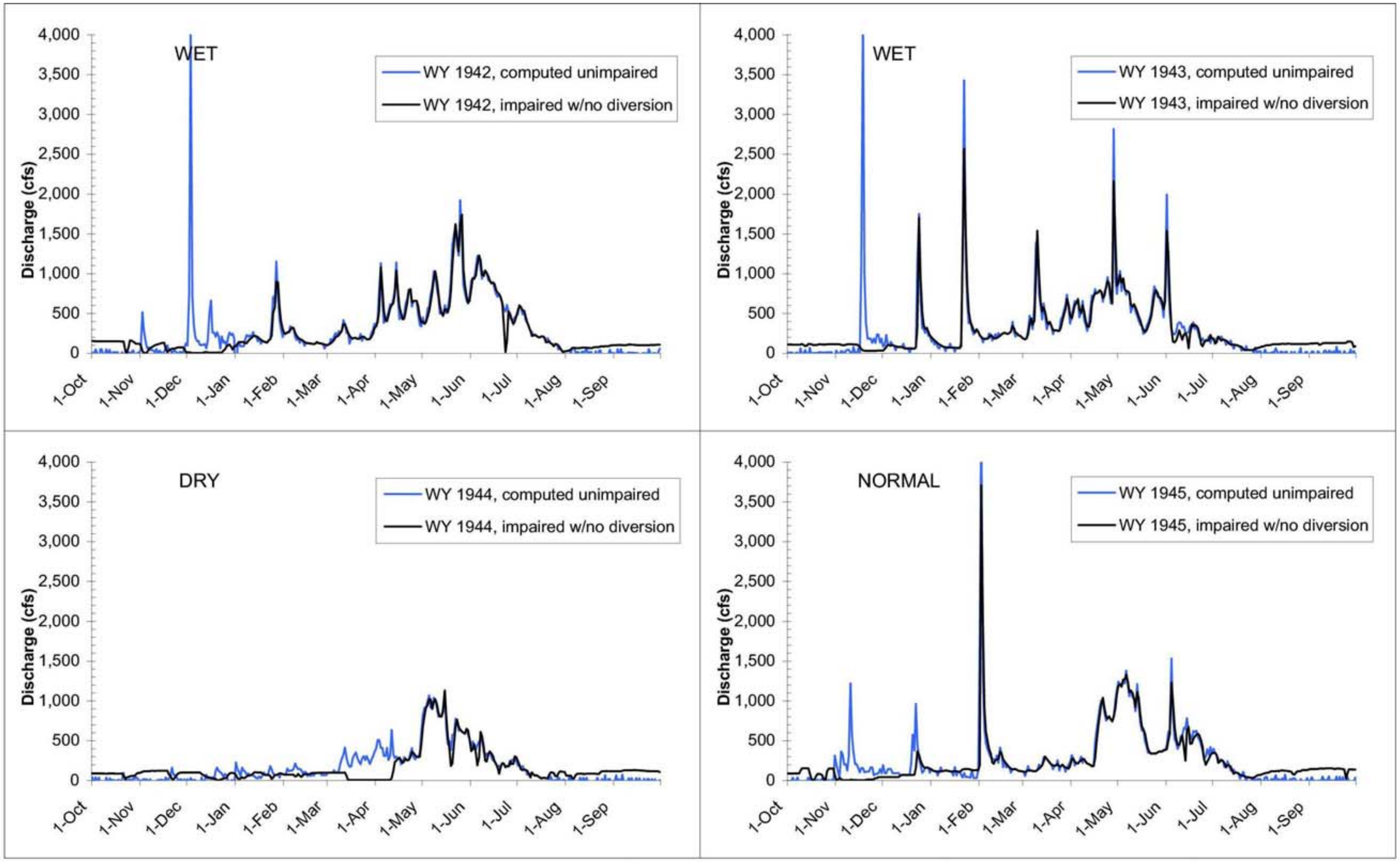
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



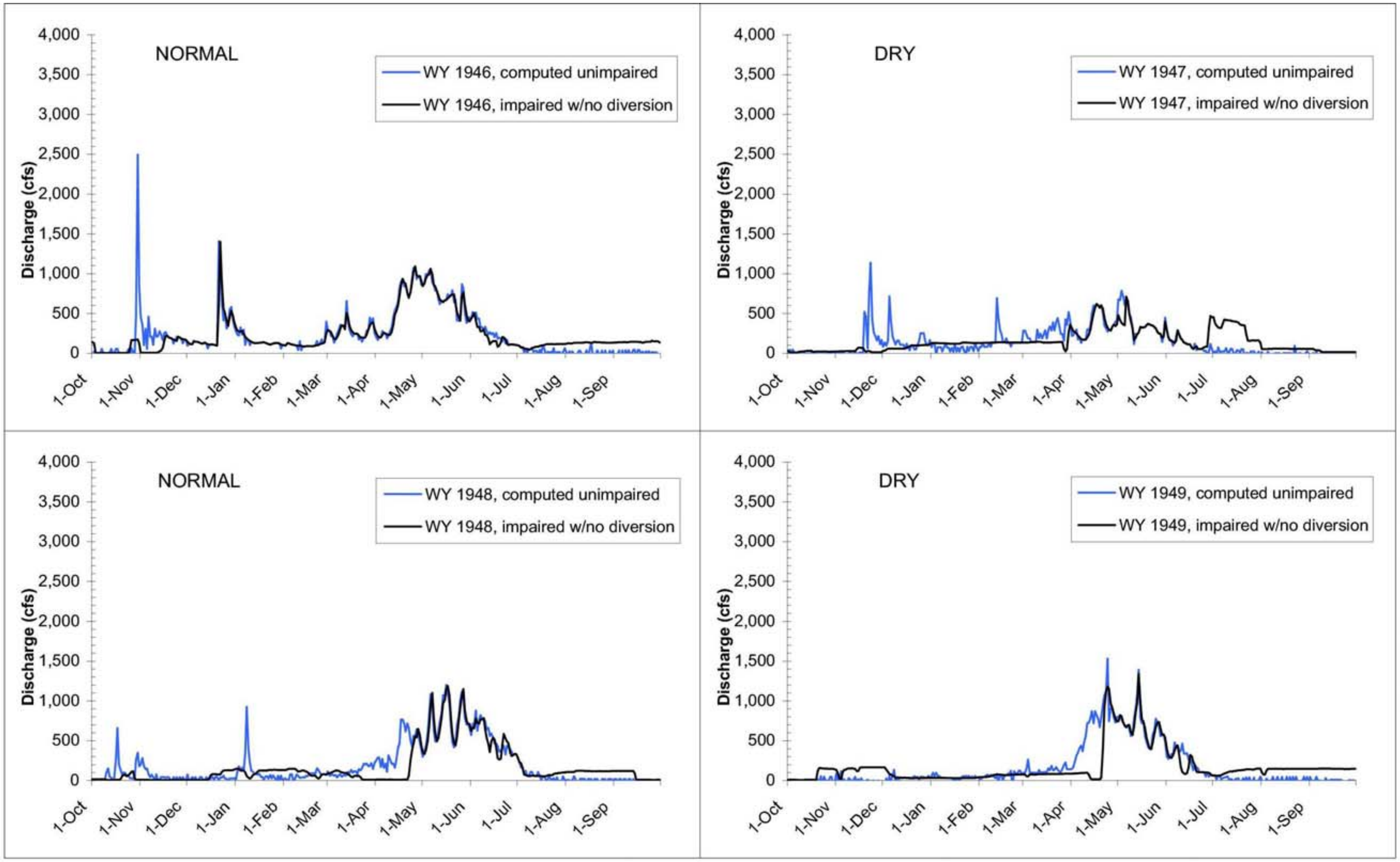
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



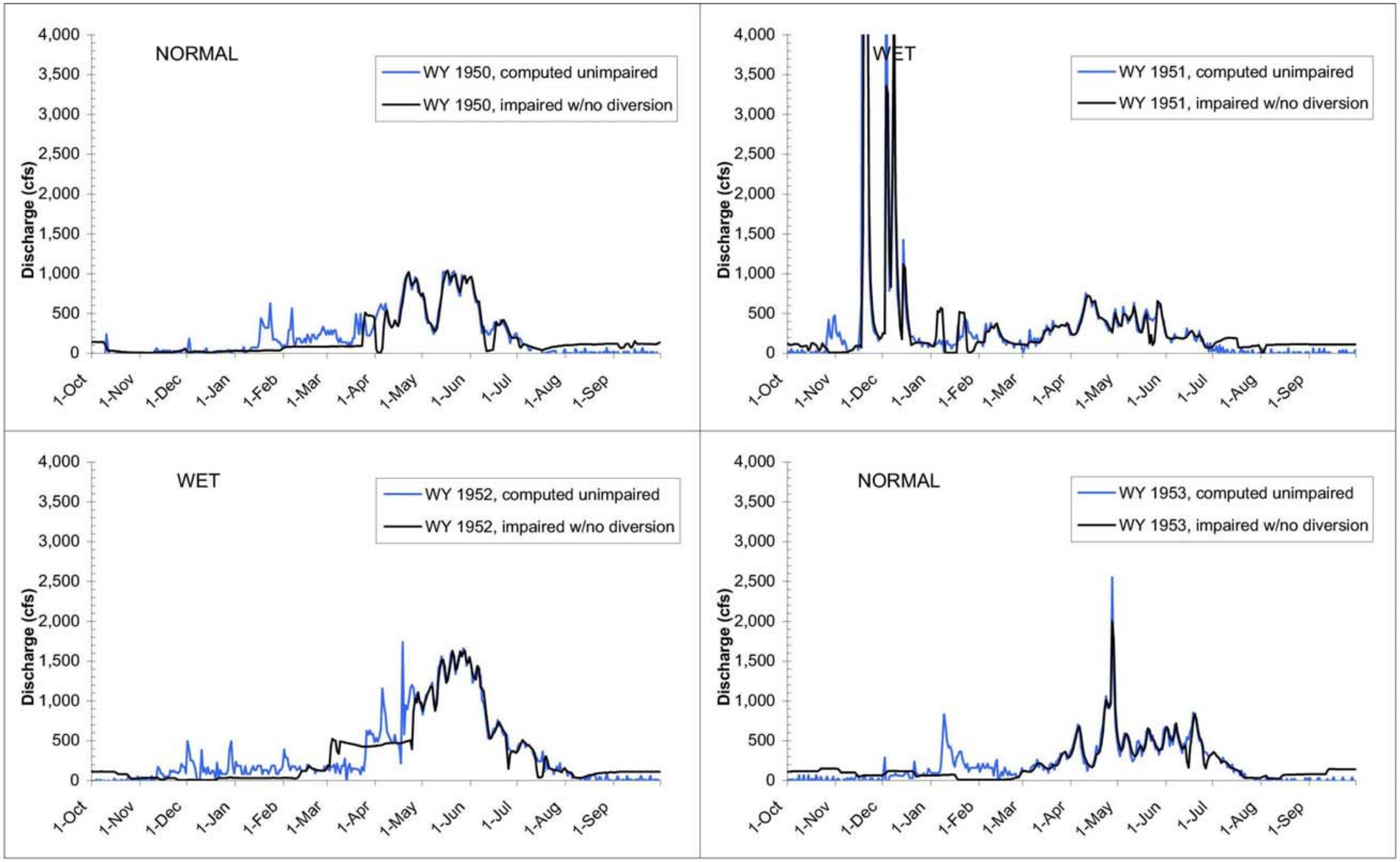
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



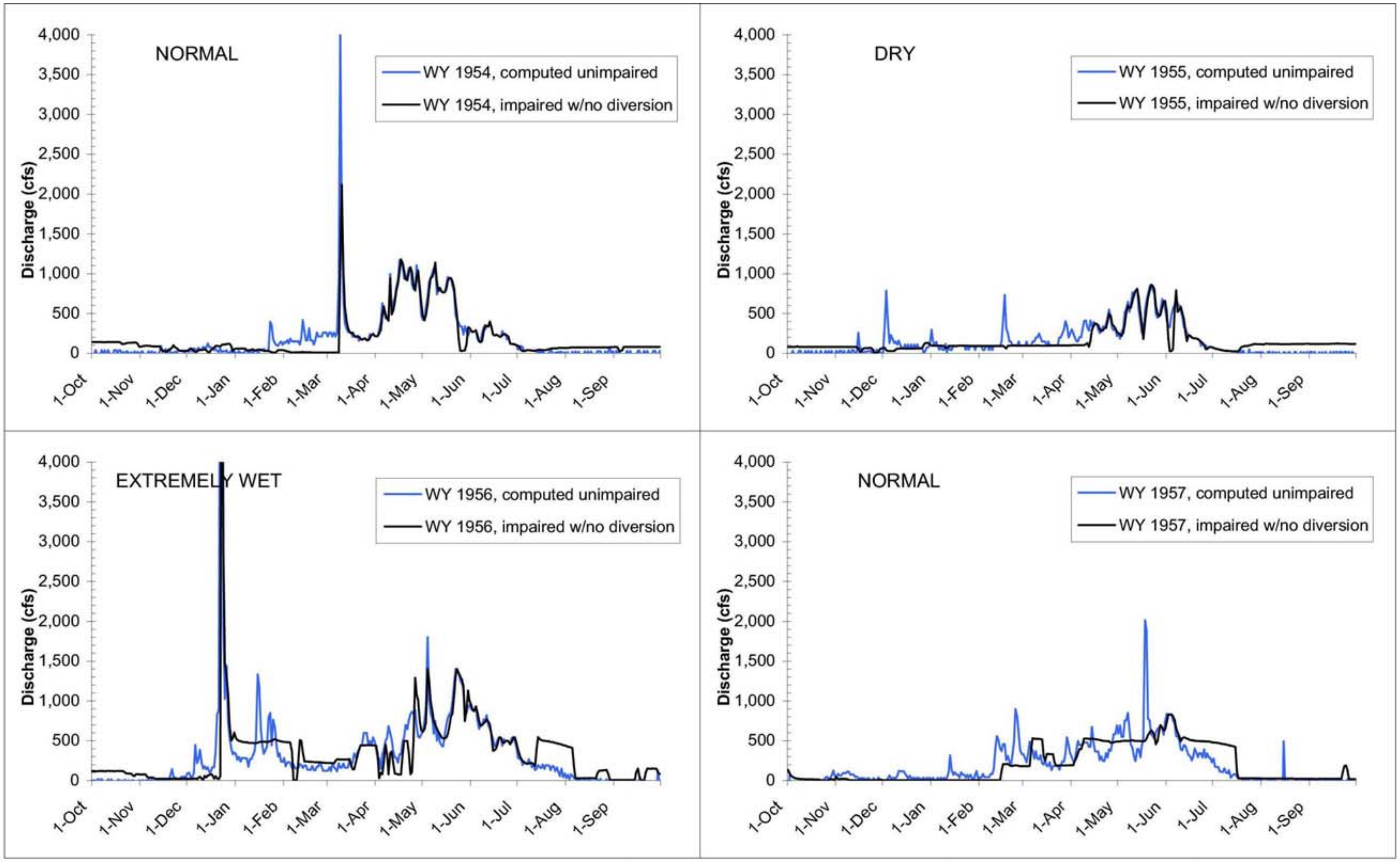
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



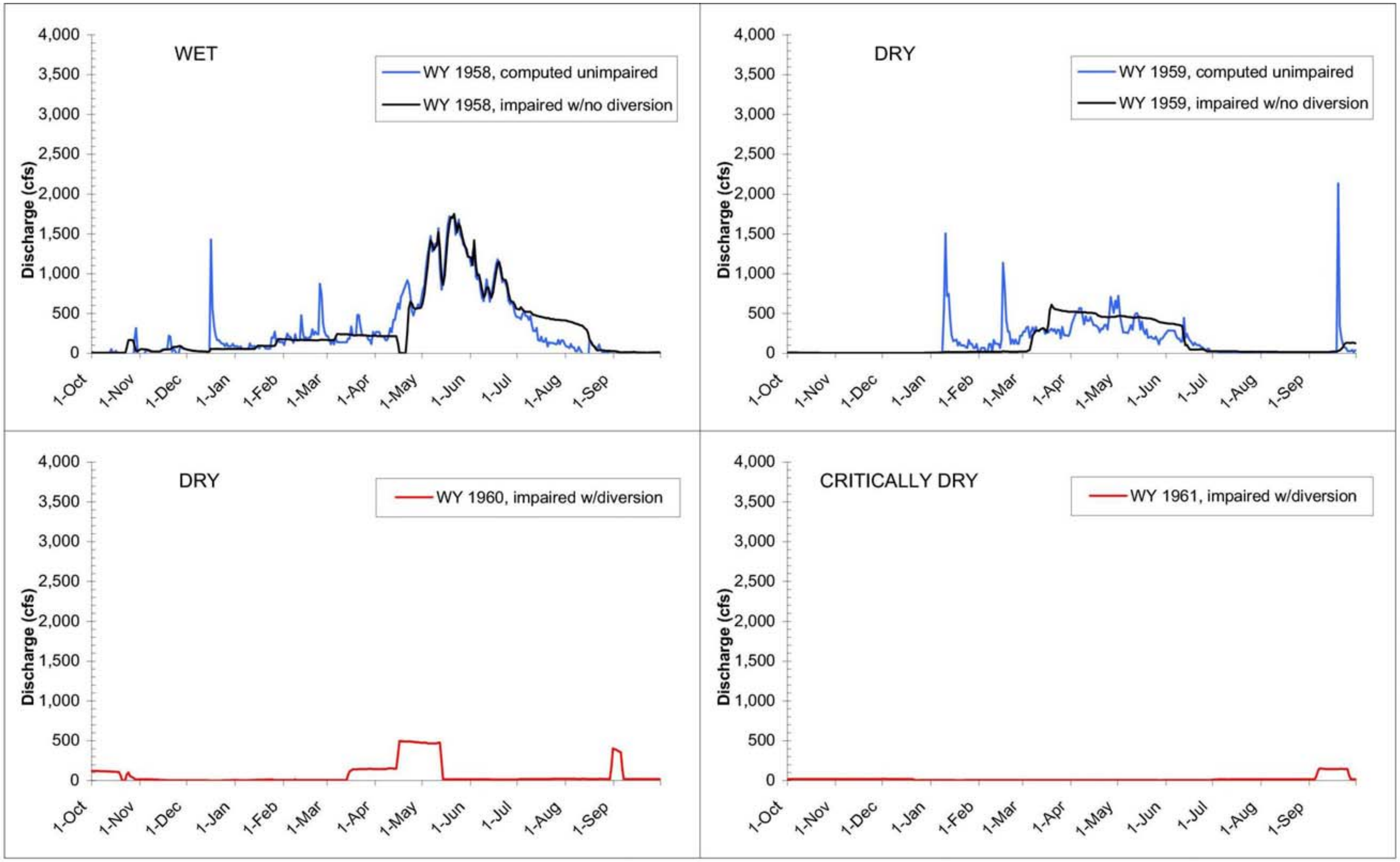
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



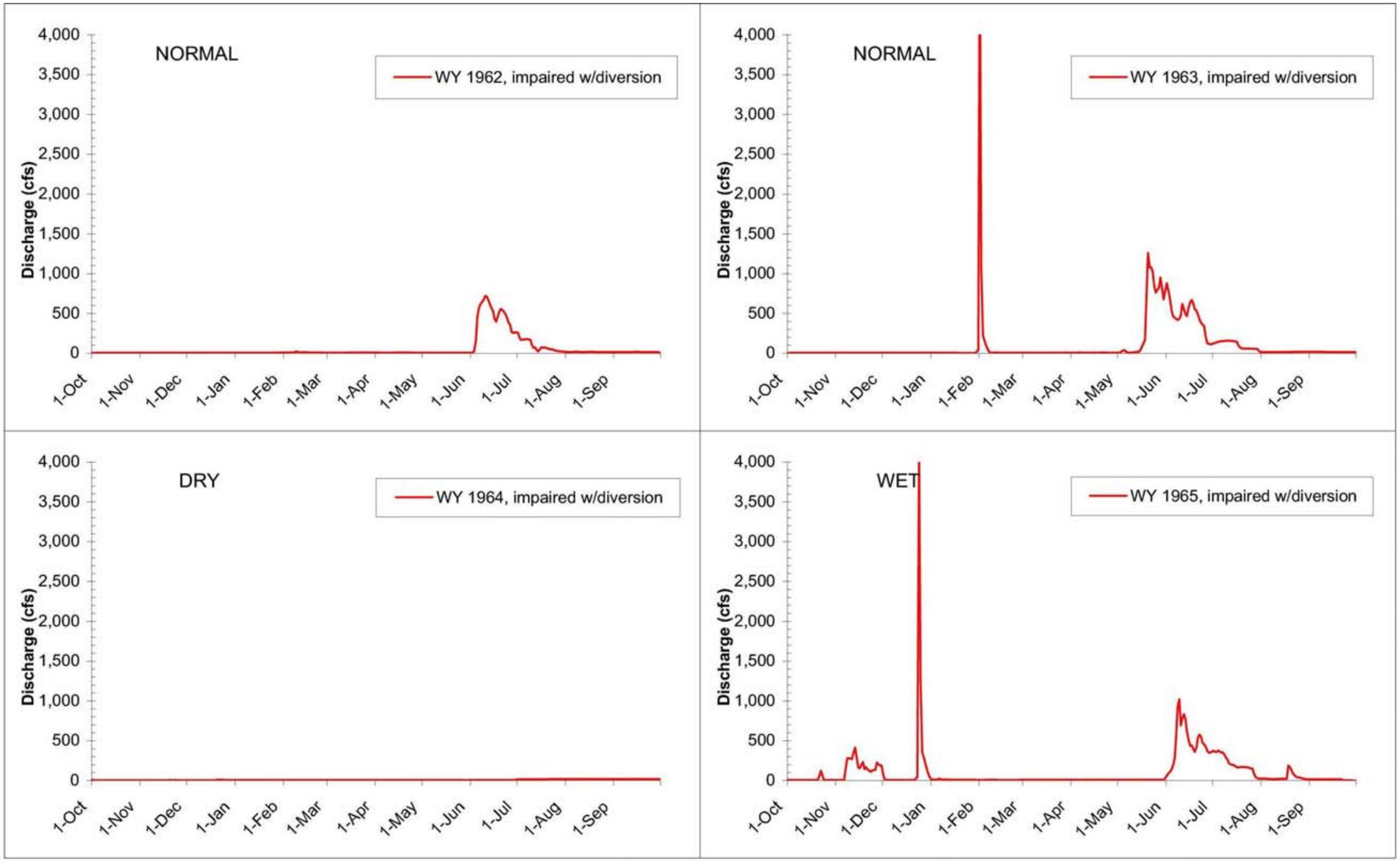
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



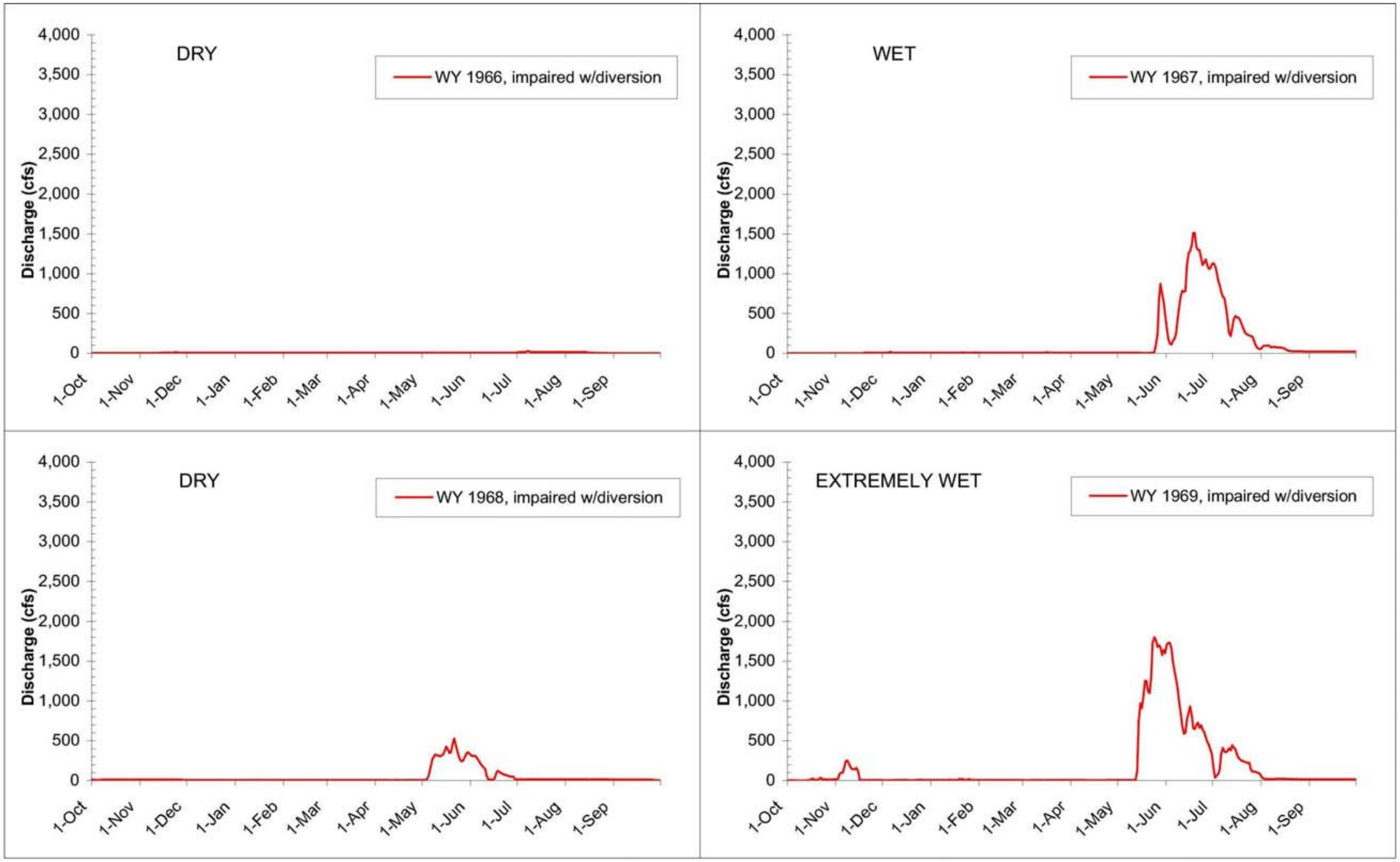
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



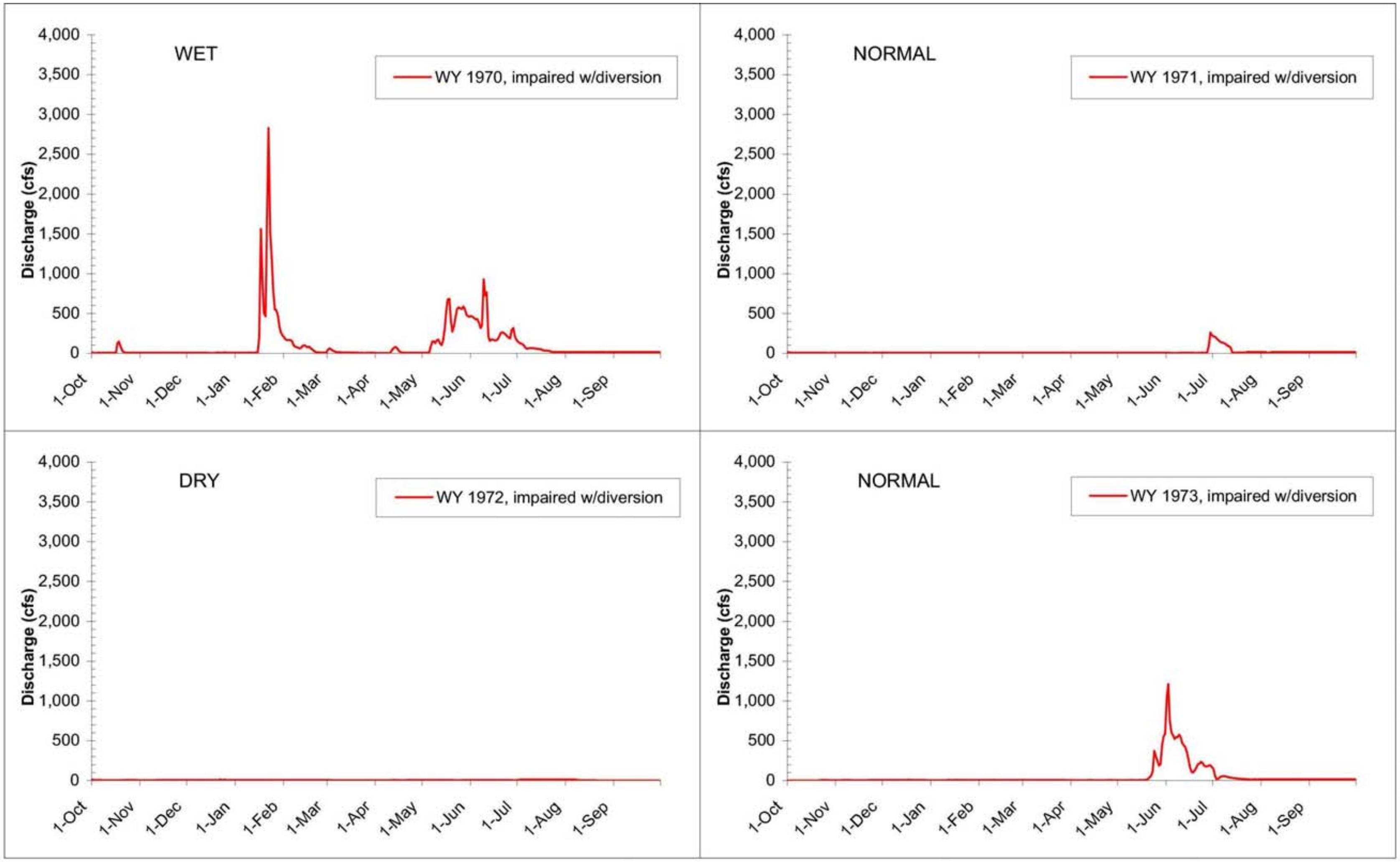
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



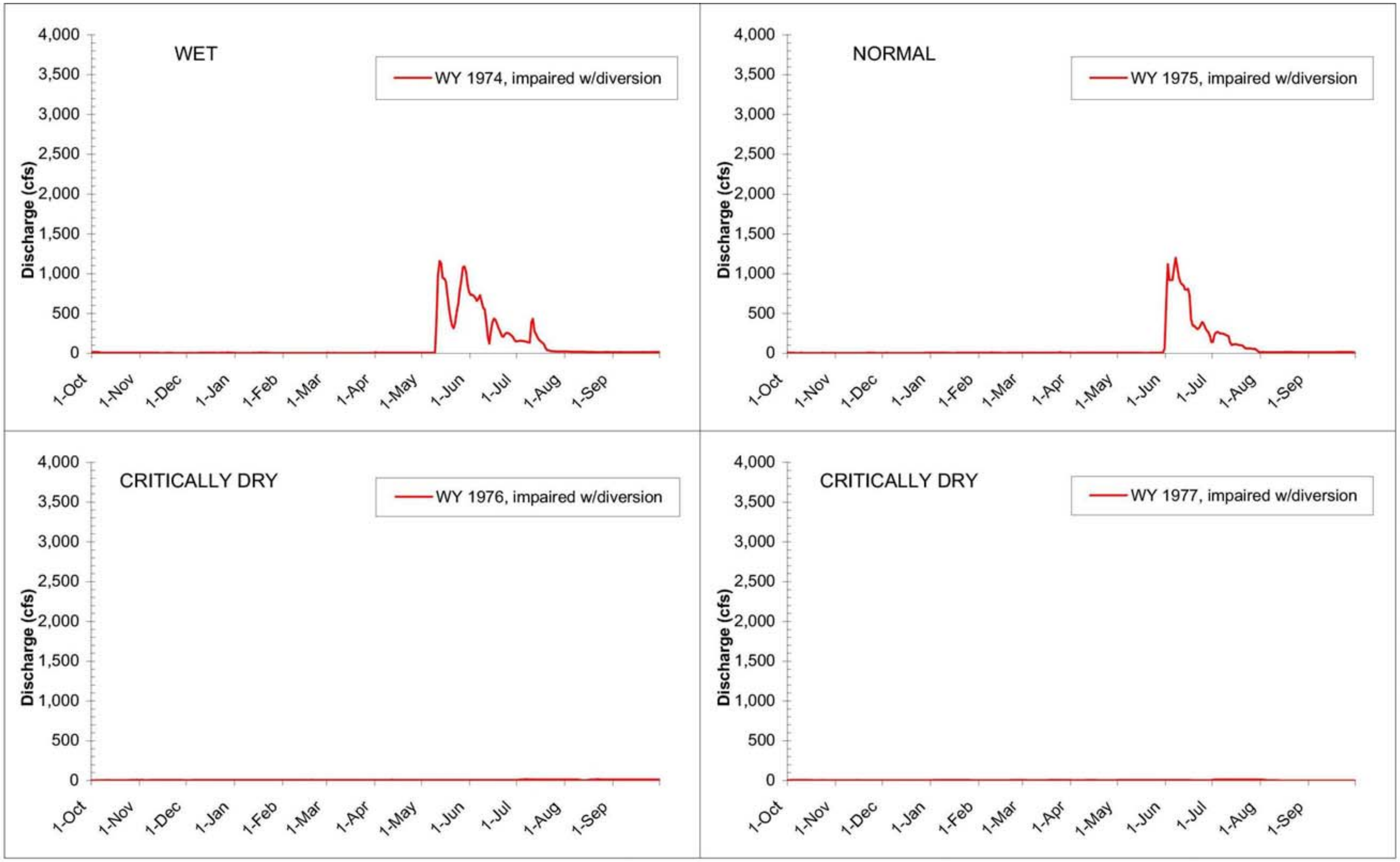
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



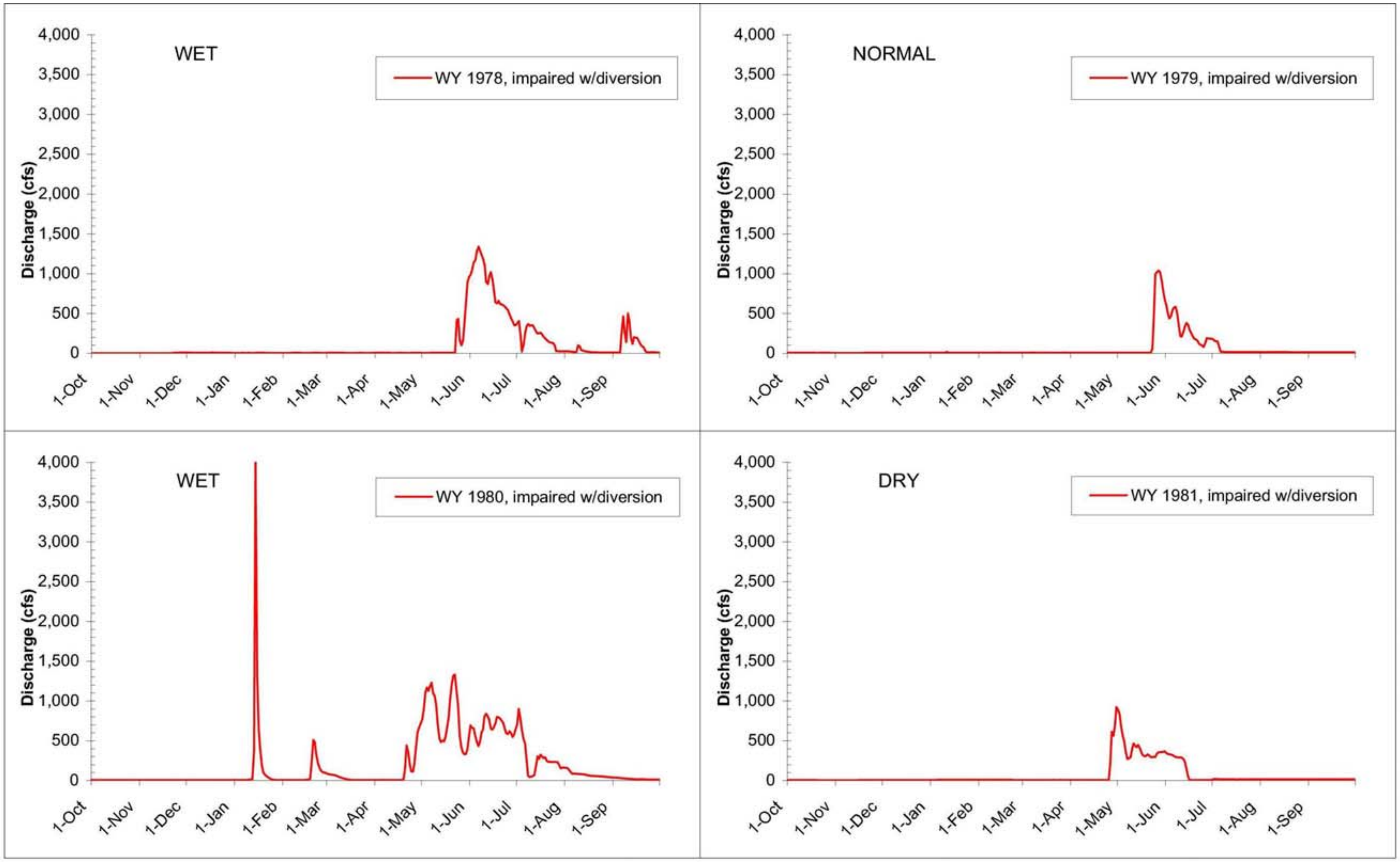
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



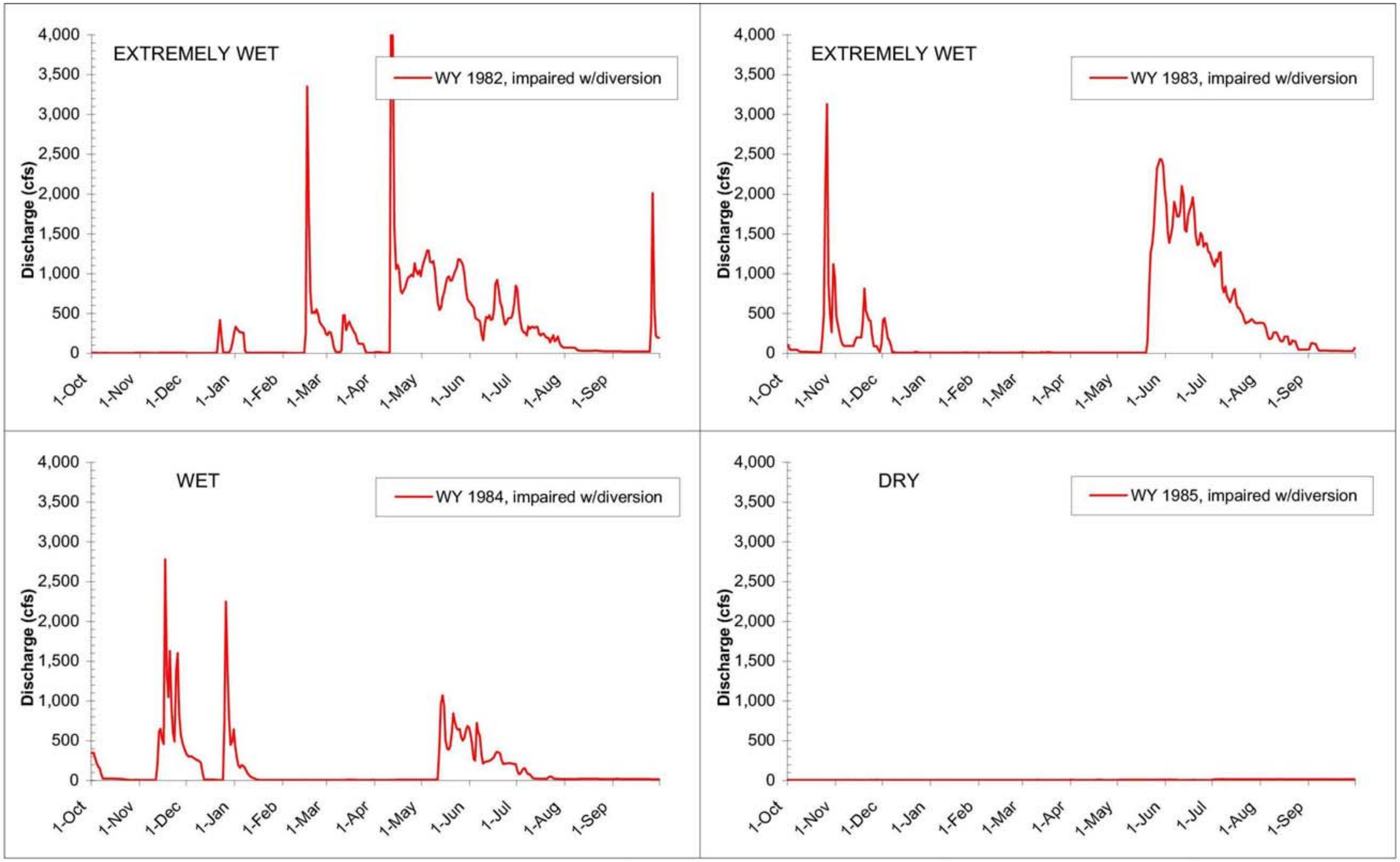
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



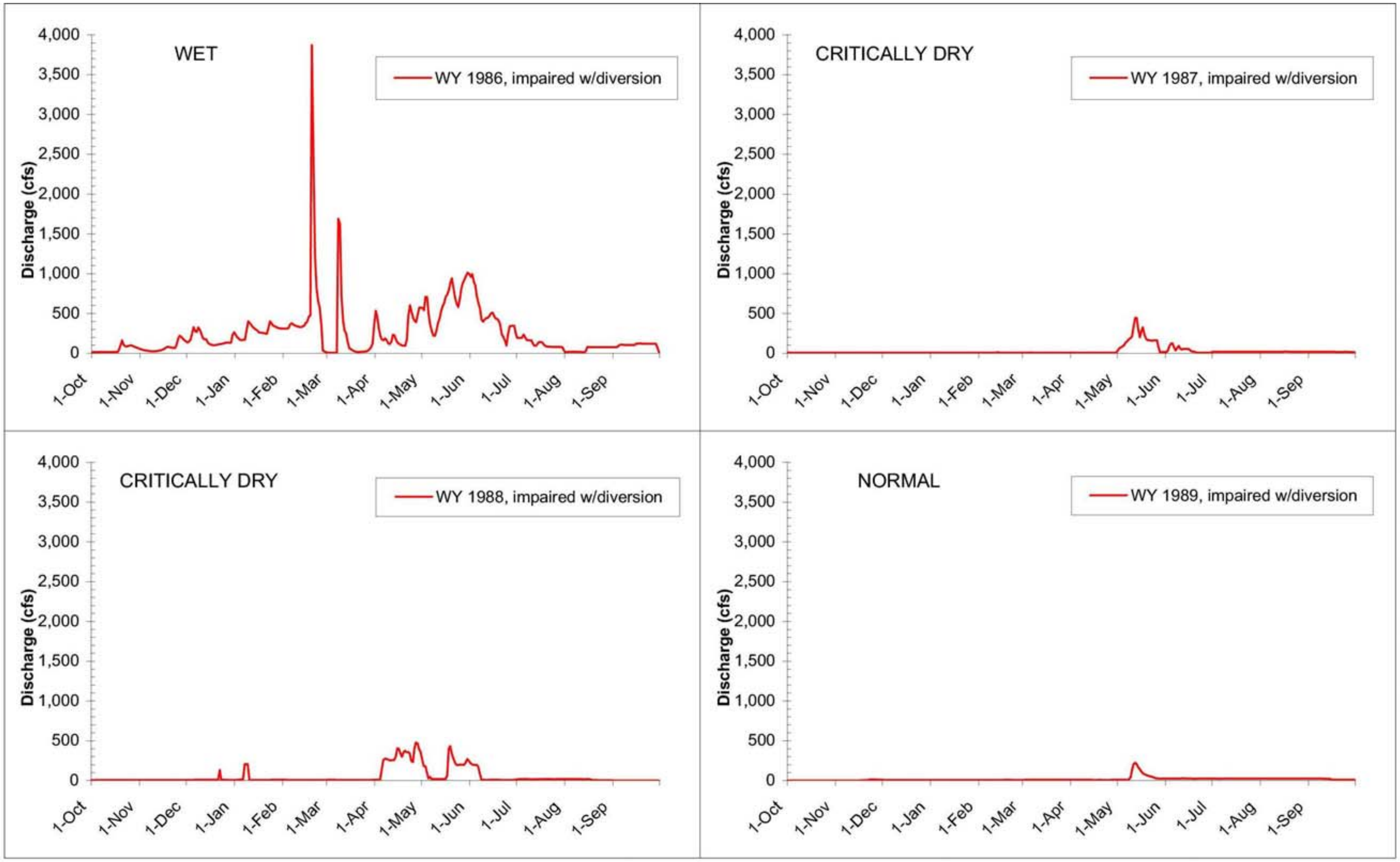
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



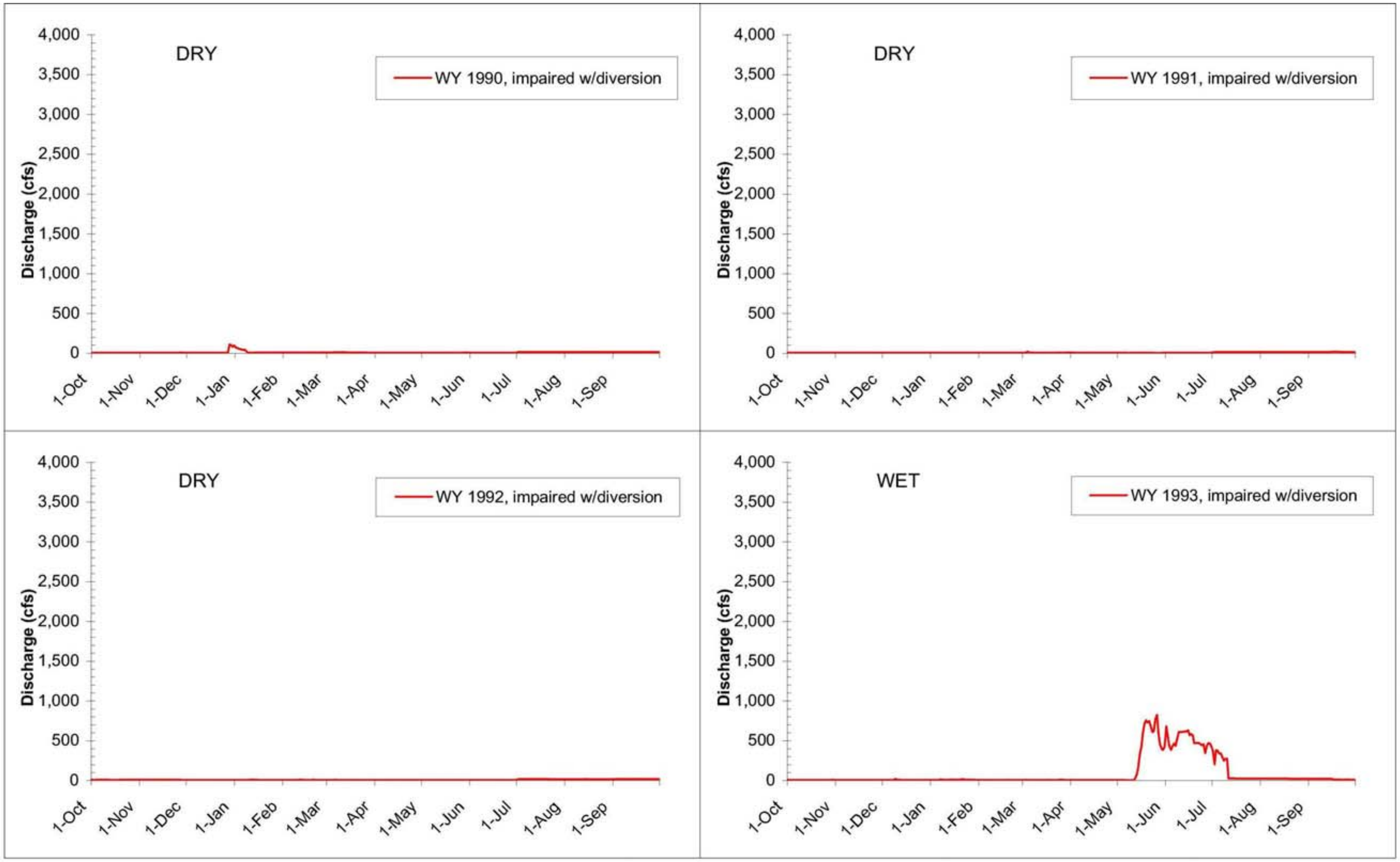
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



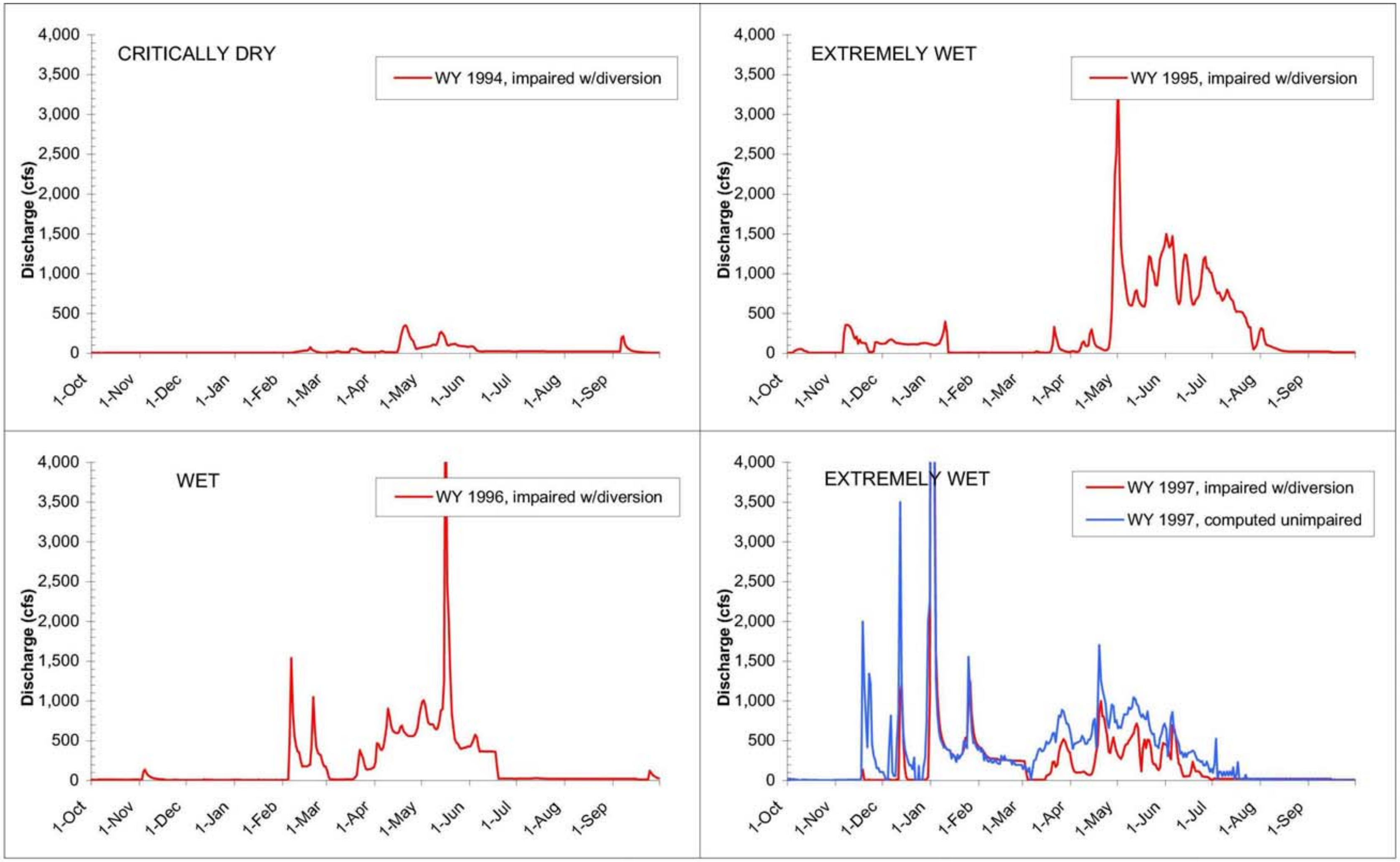
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



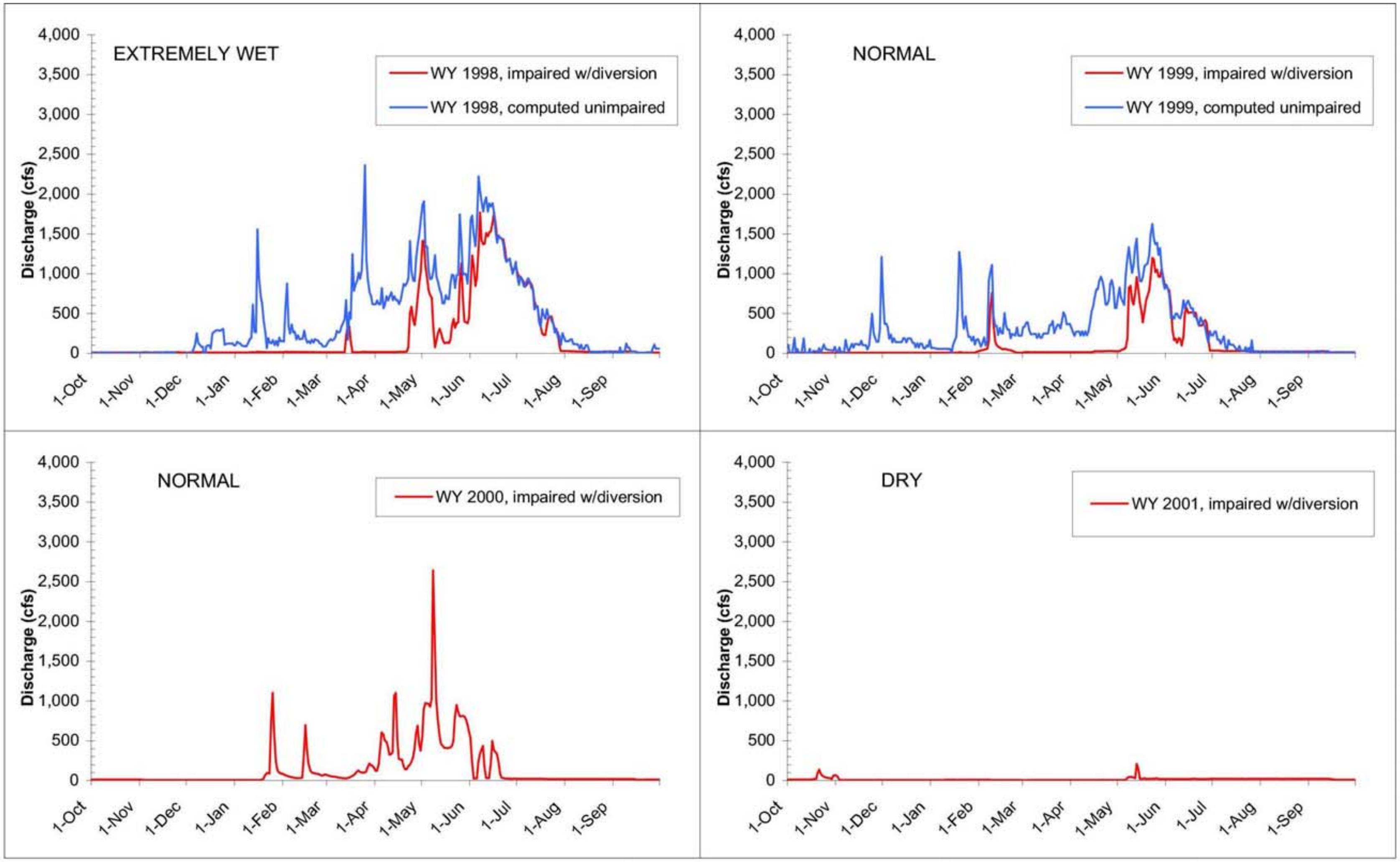
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



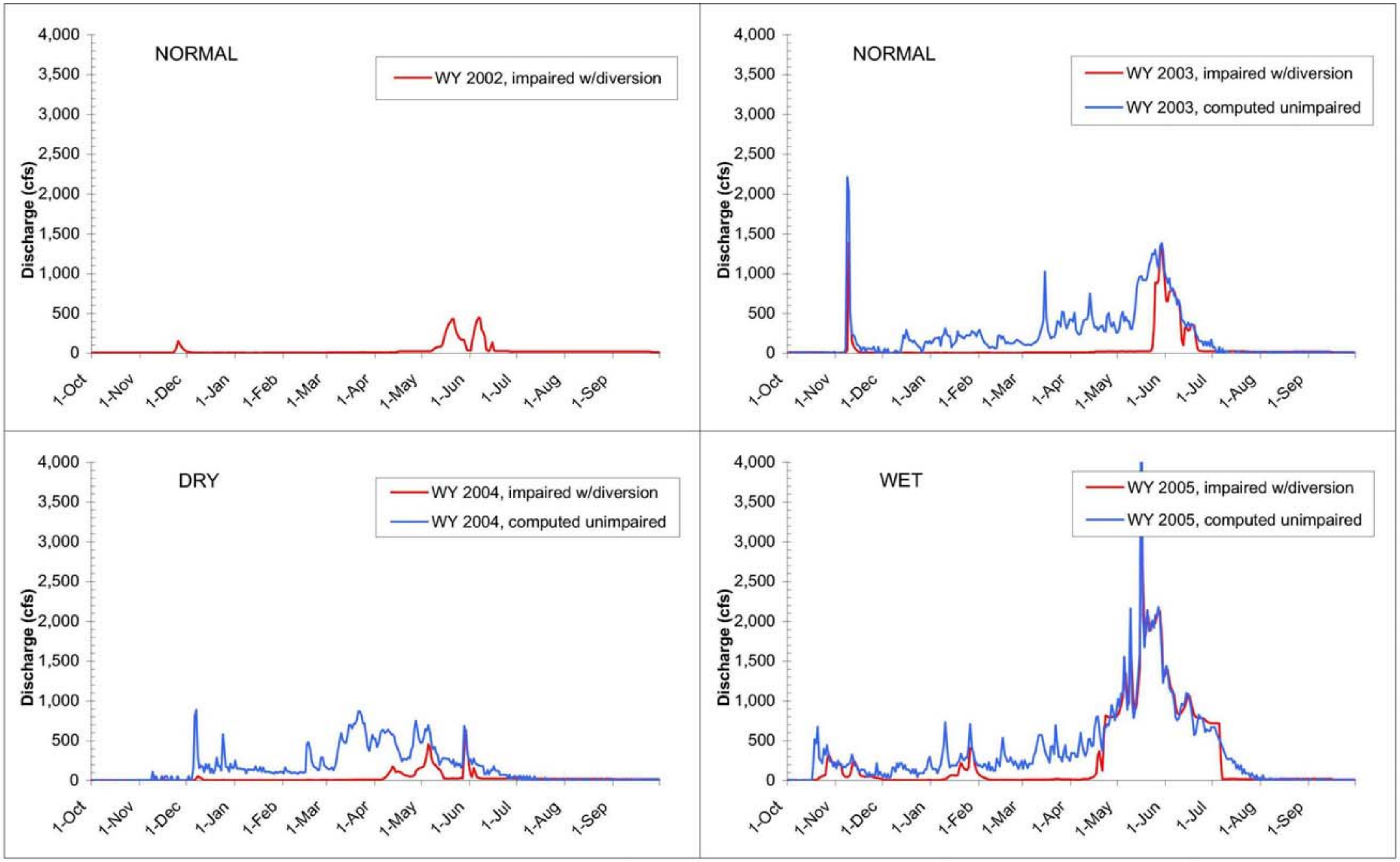
Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)



Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)

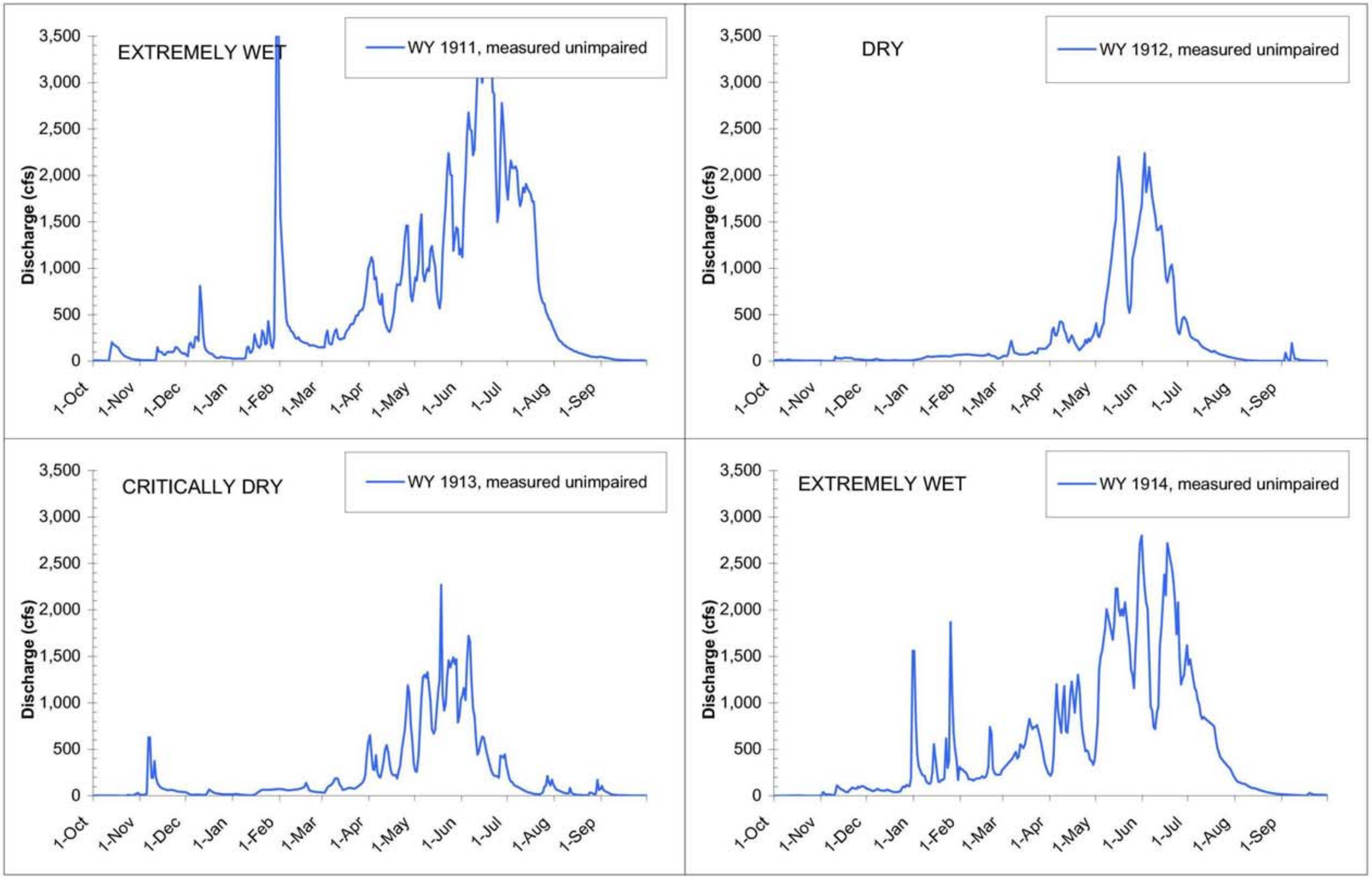


Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)

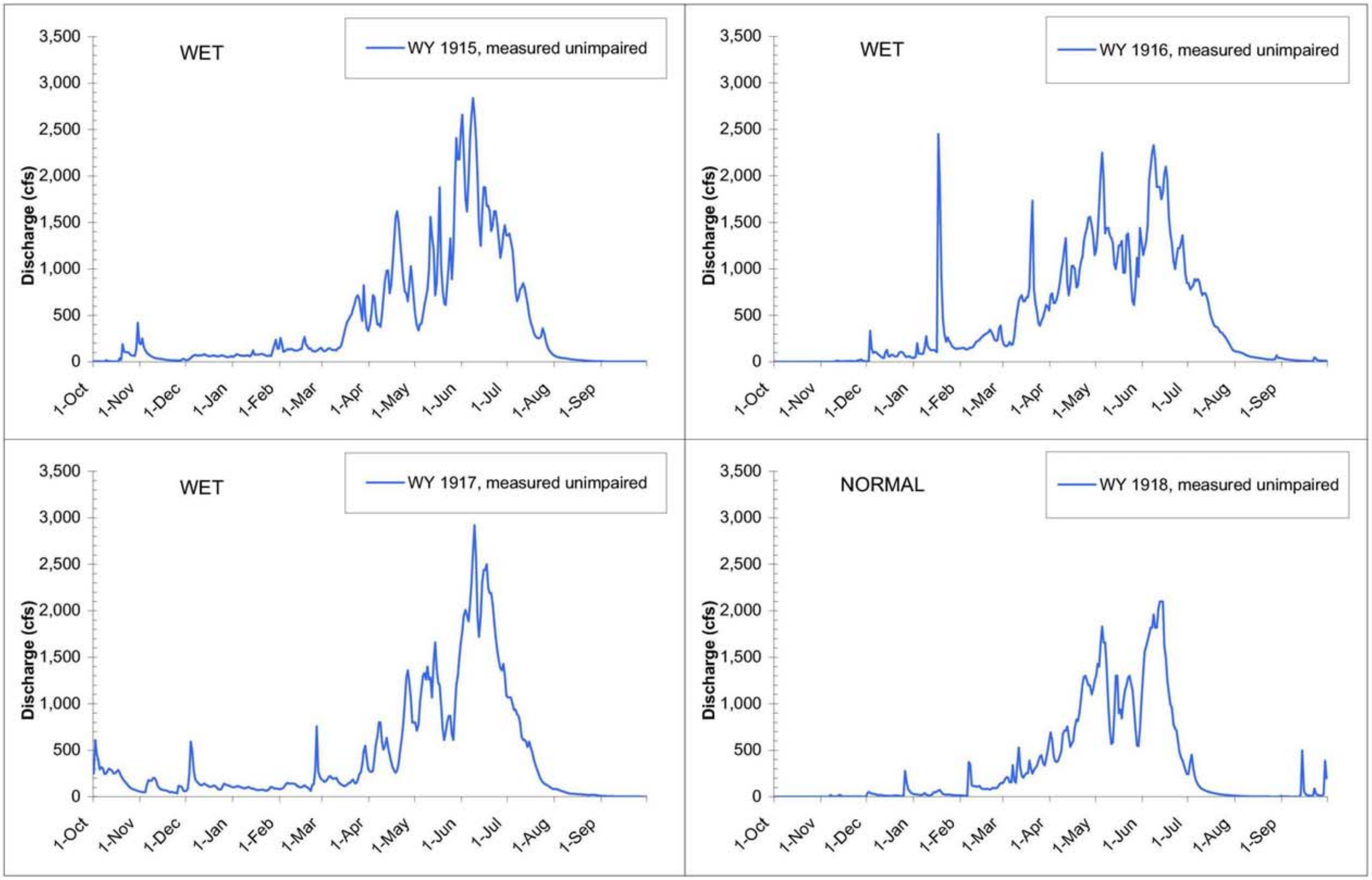


Eleanor C nr Hetch Hetchy, CA (USGS Stn 11-278000)

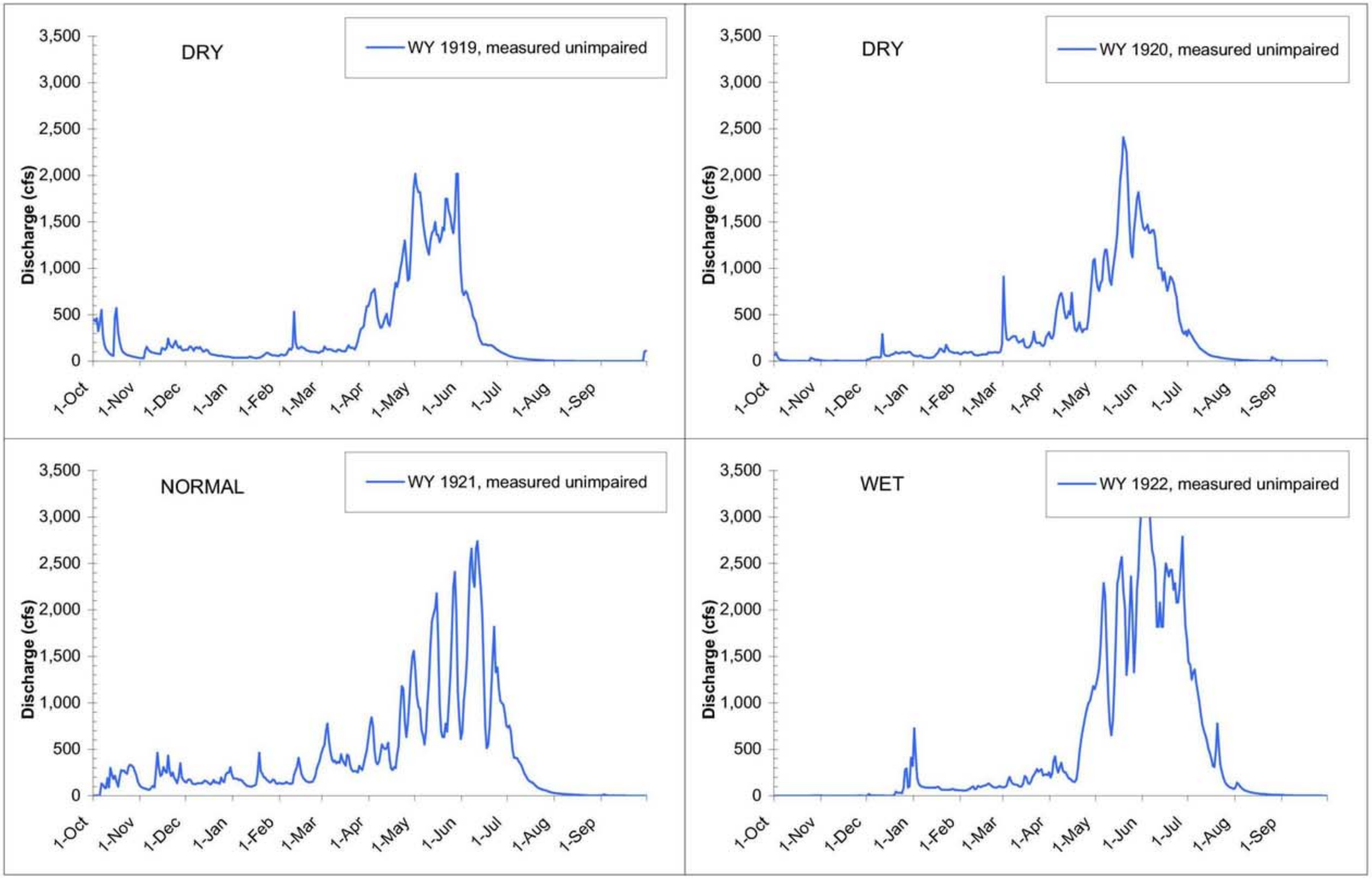
Appendix C: Daily average hydrographs for Cherry Creek near Hetch Hetchy below Cherry Valley Dam (USGS 11-277000) for Water Years 1910-2005.



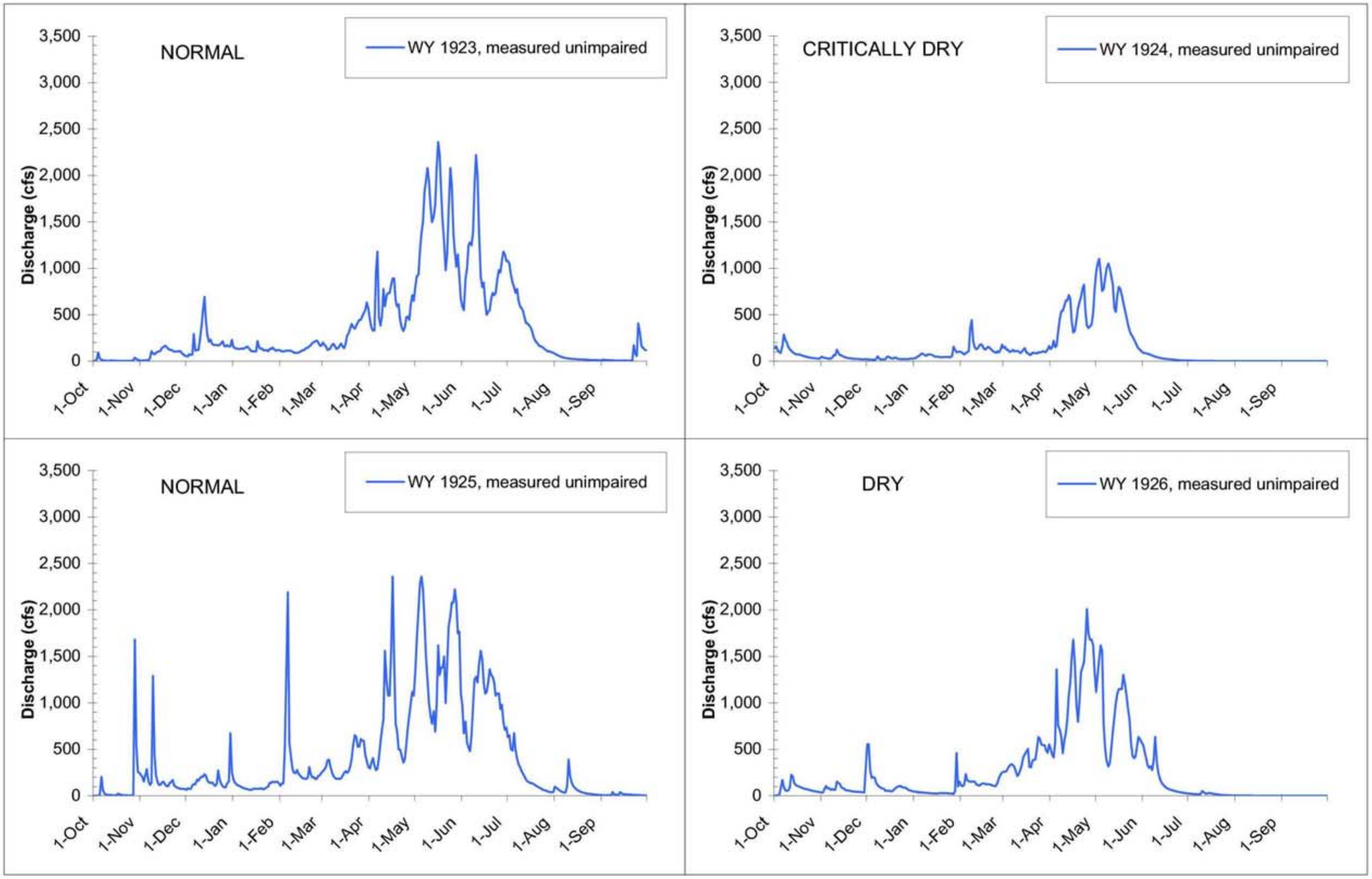
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



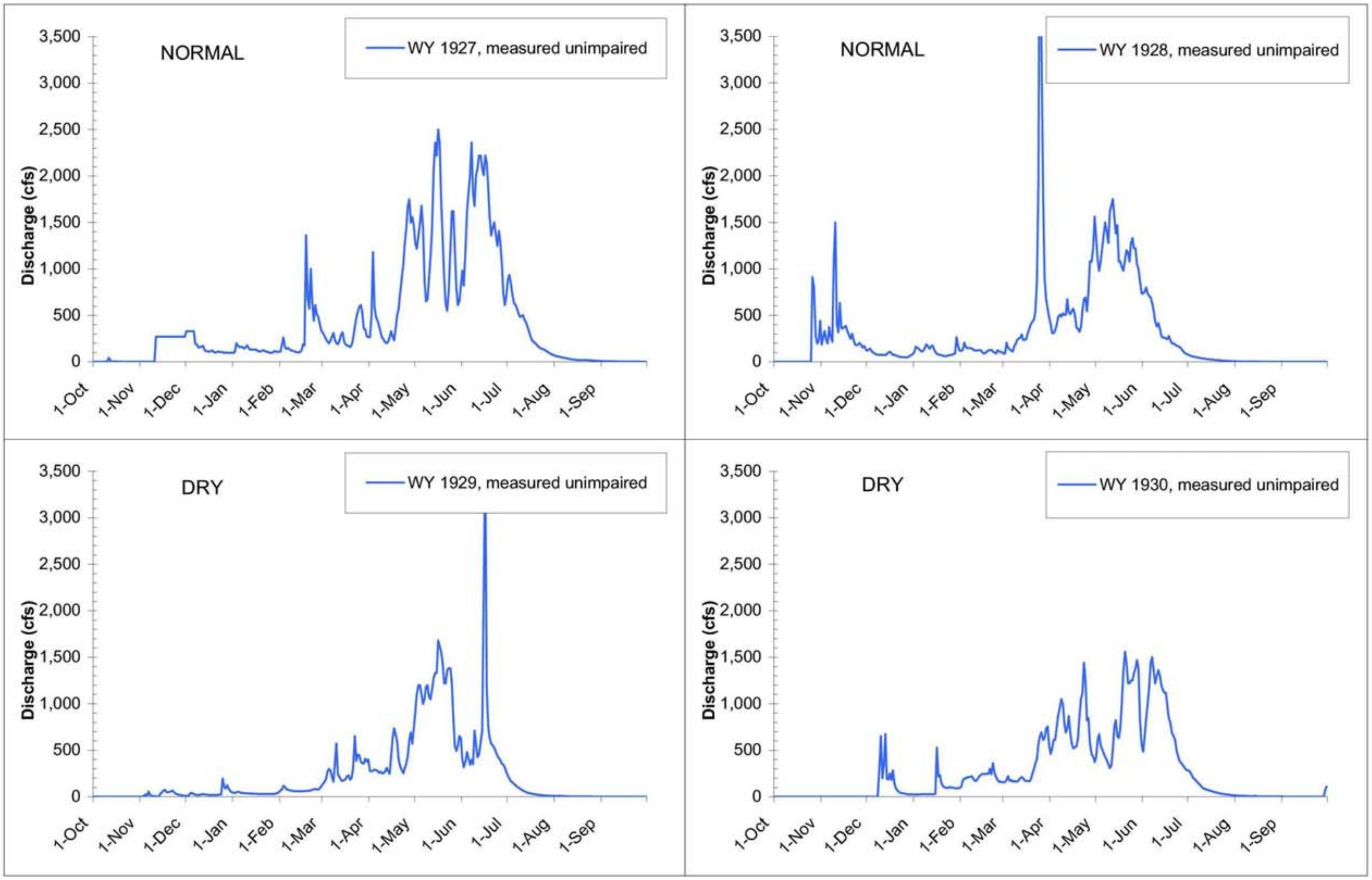
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



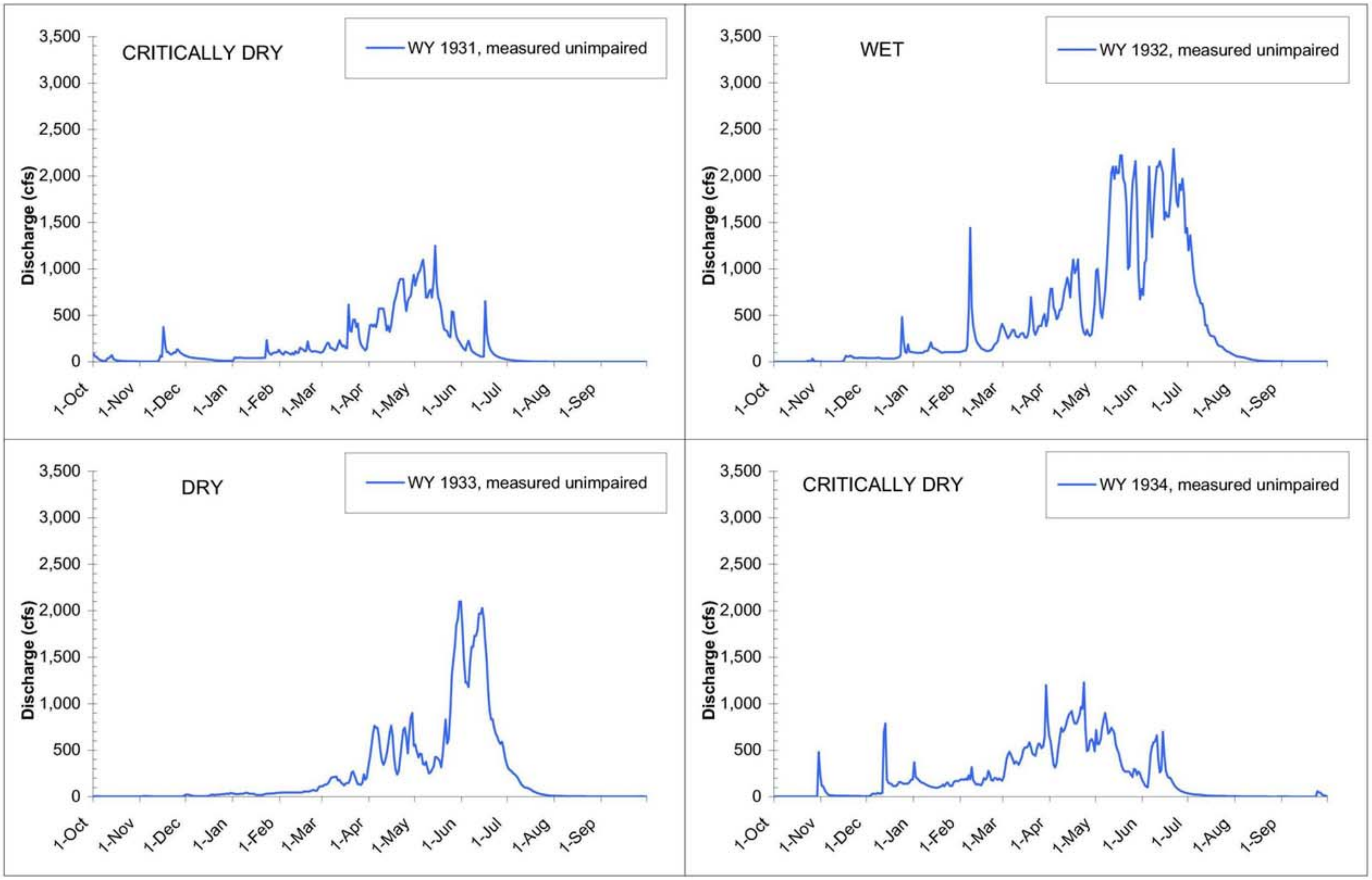
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



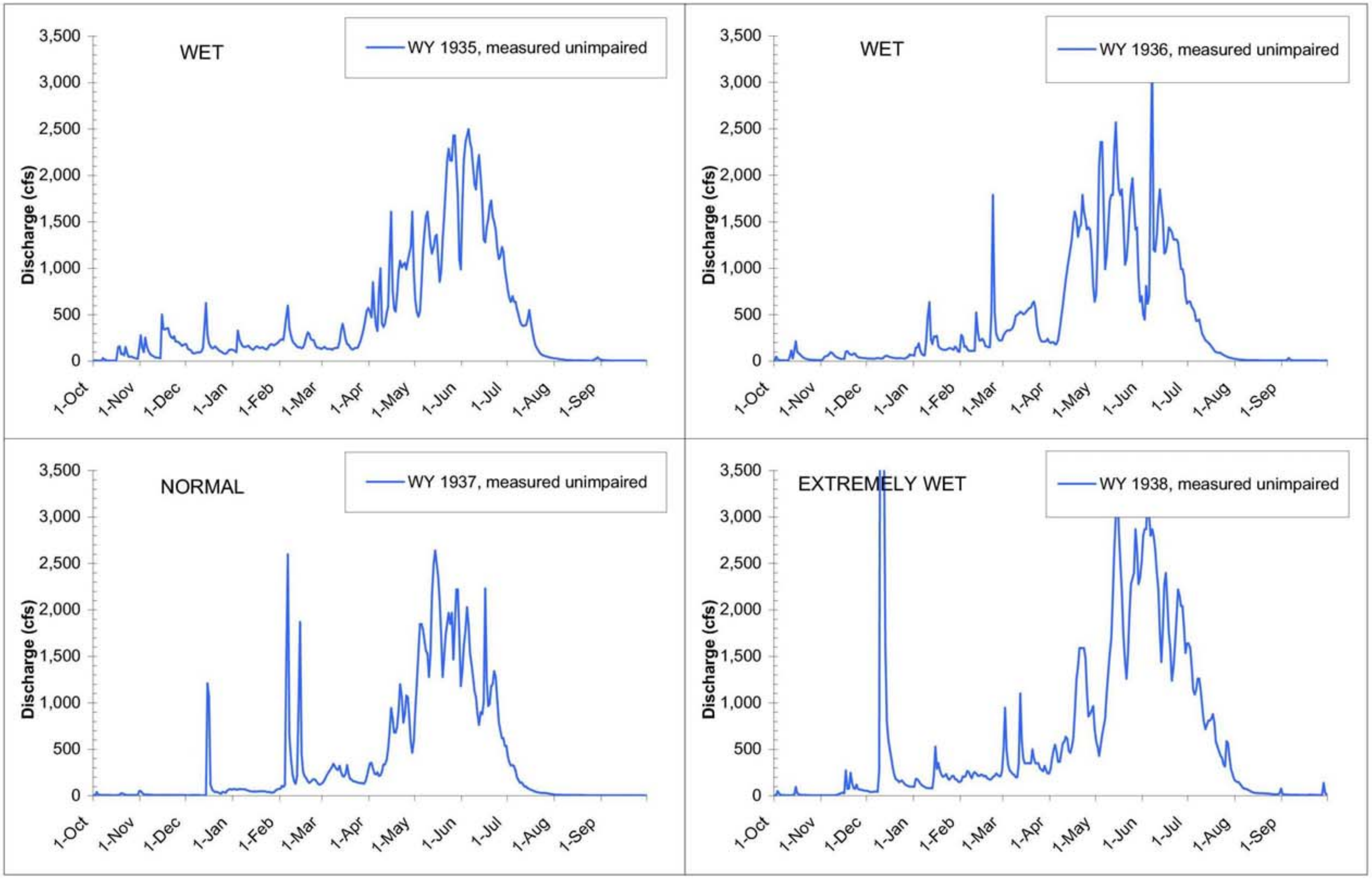
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



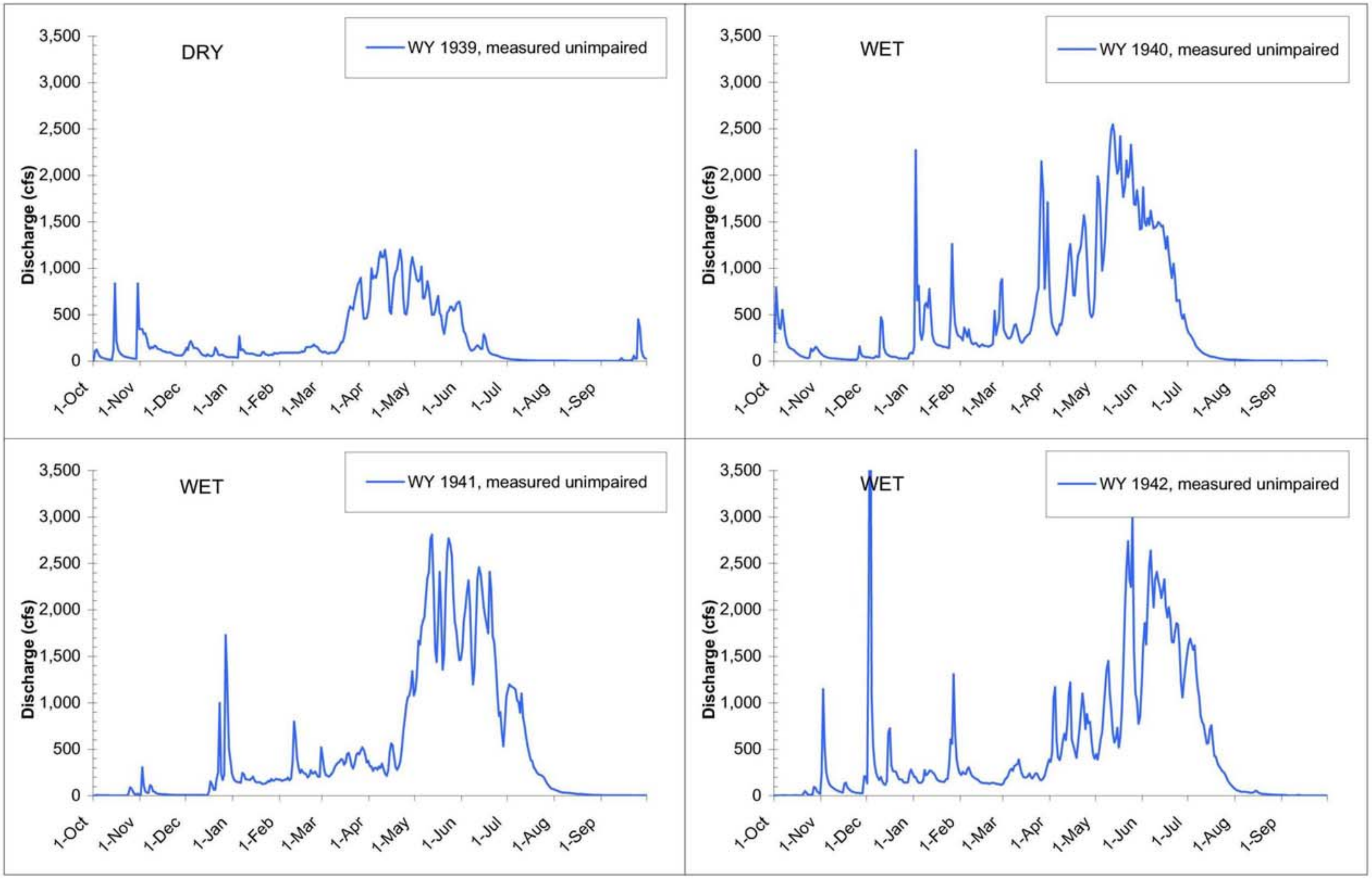
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



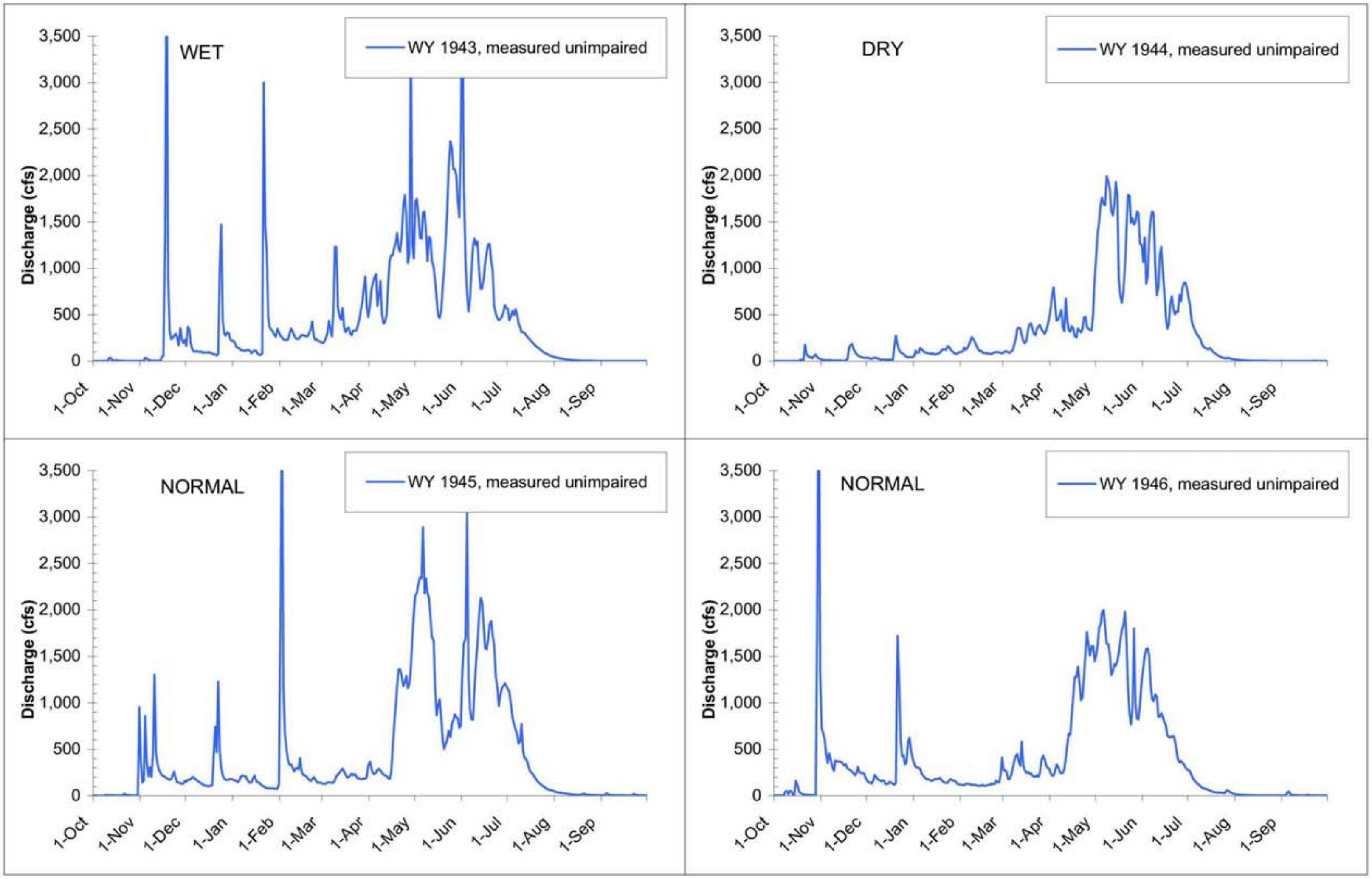
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



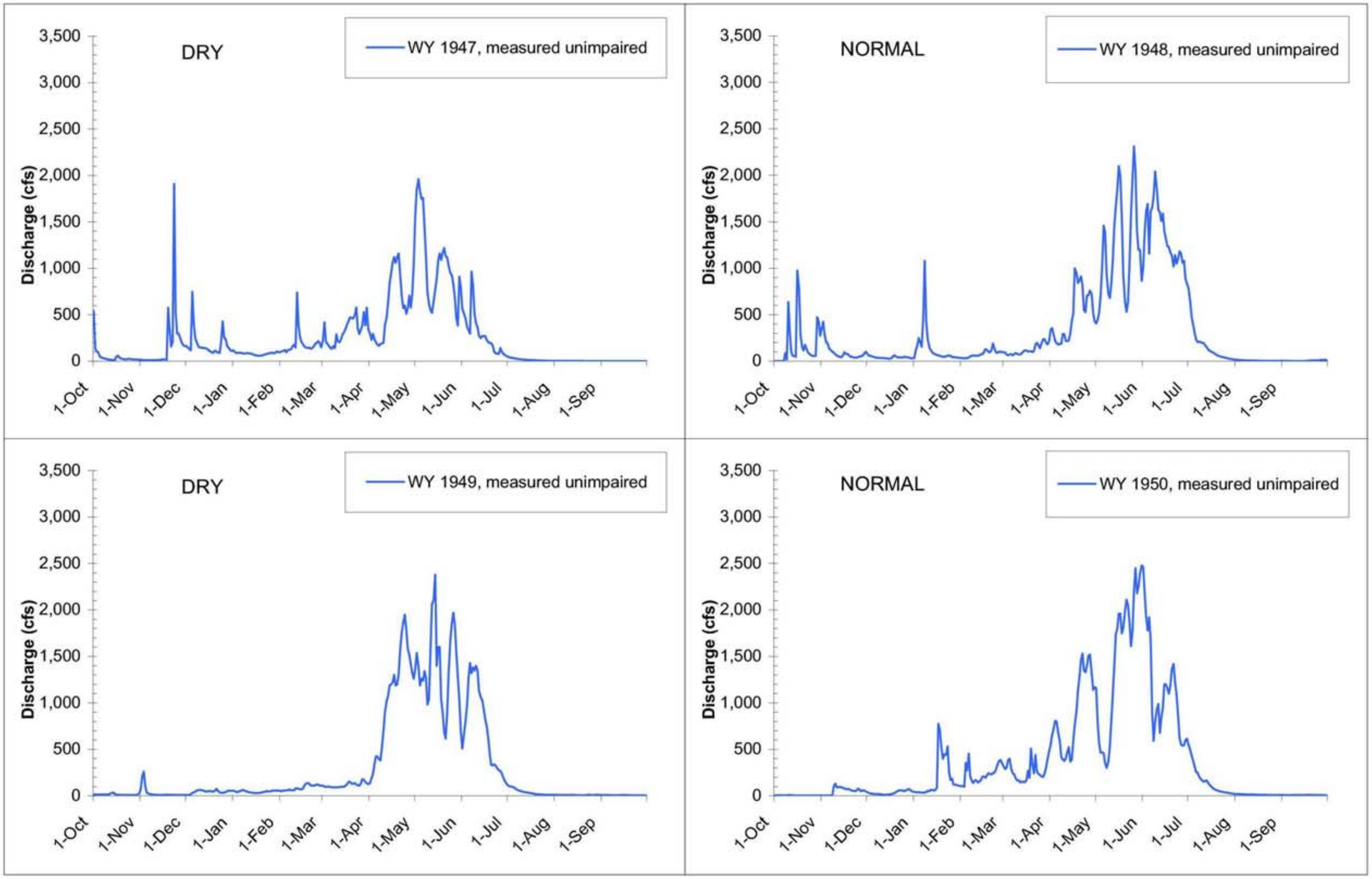
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



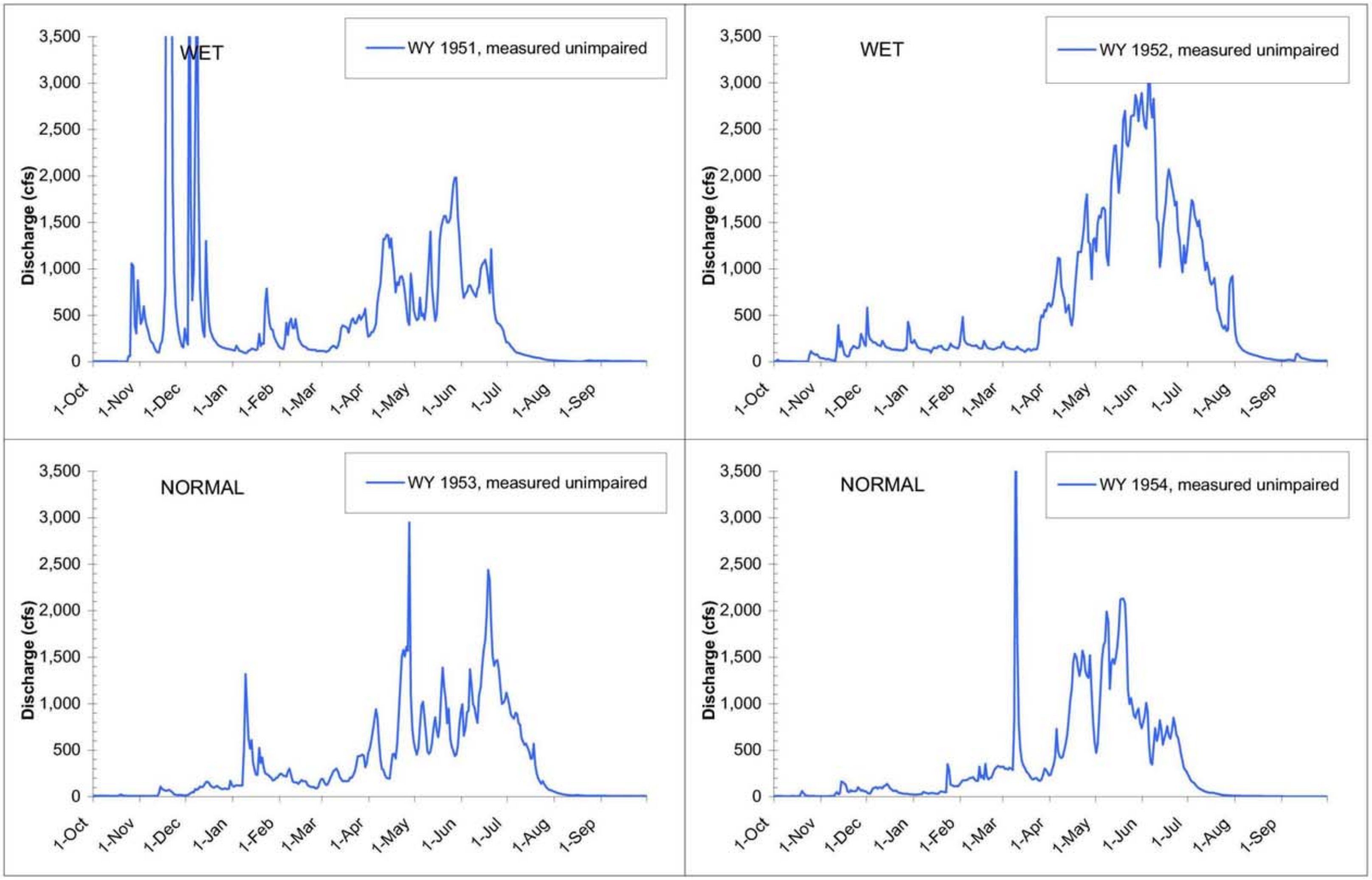
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



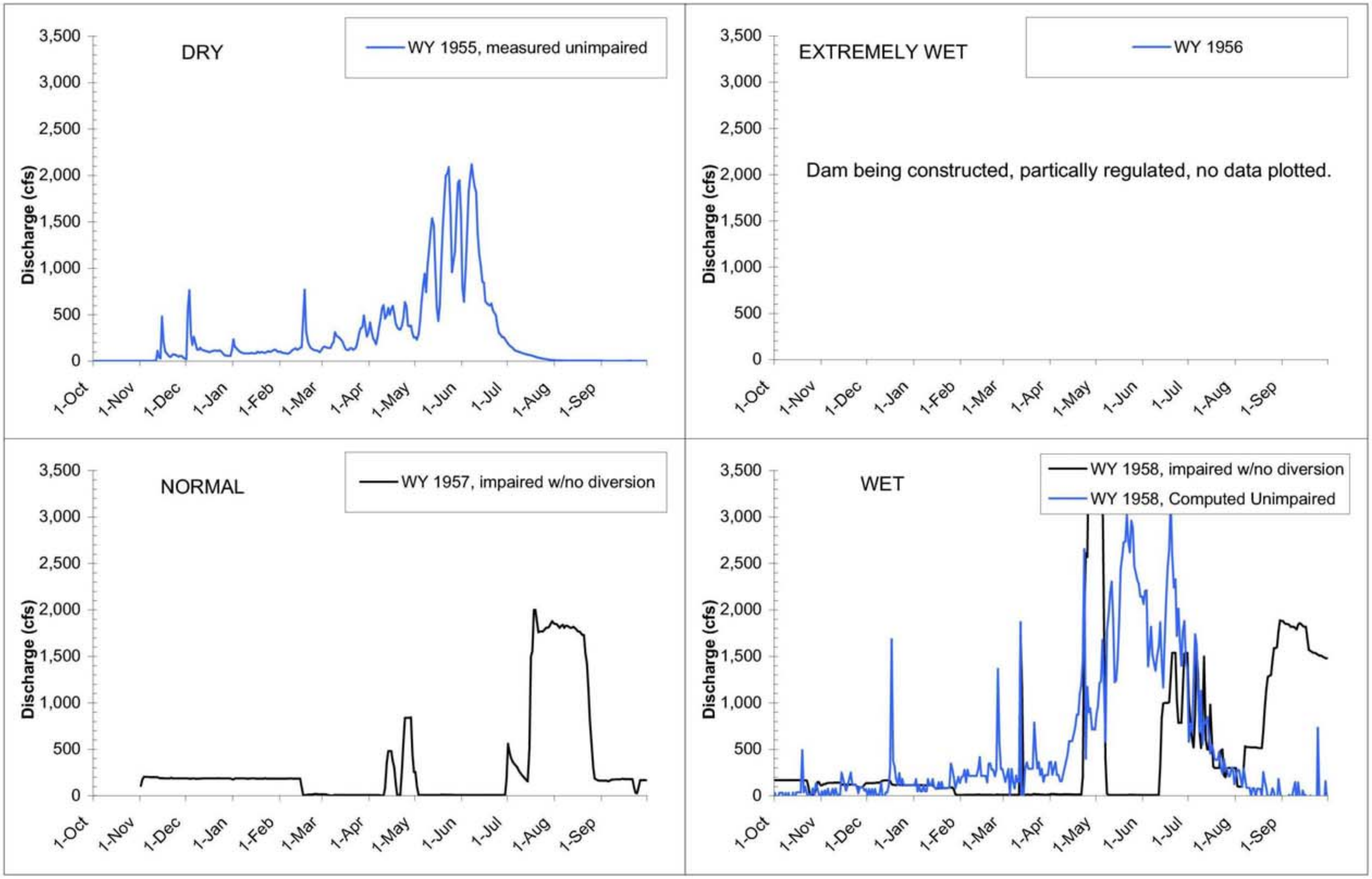
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



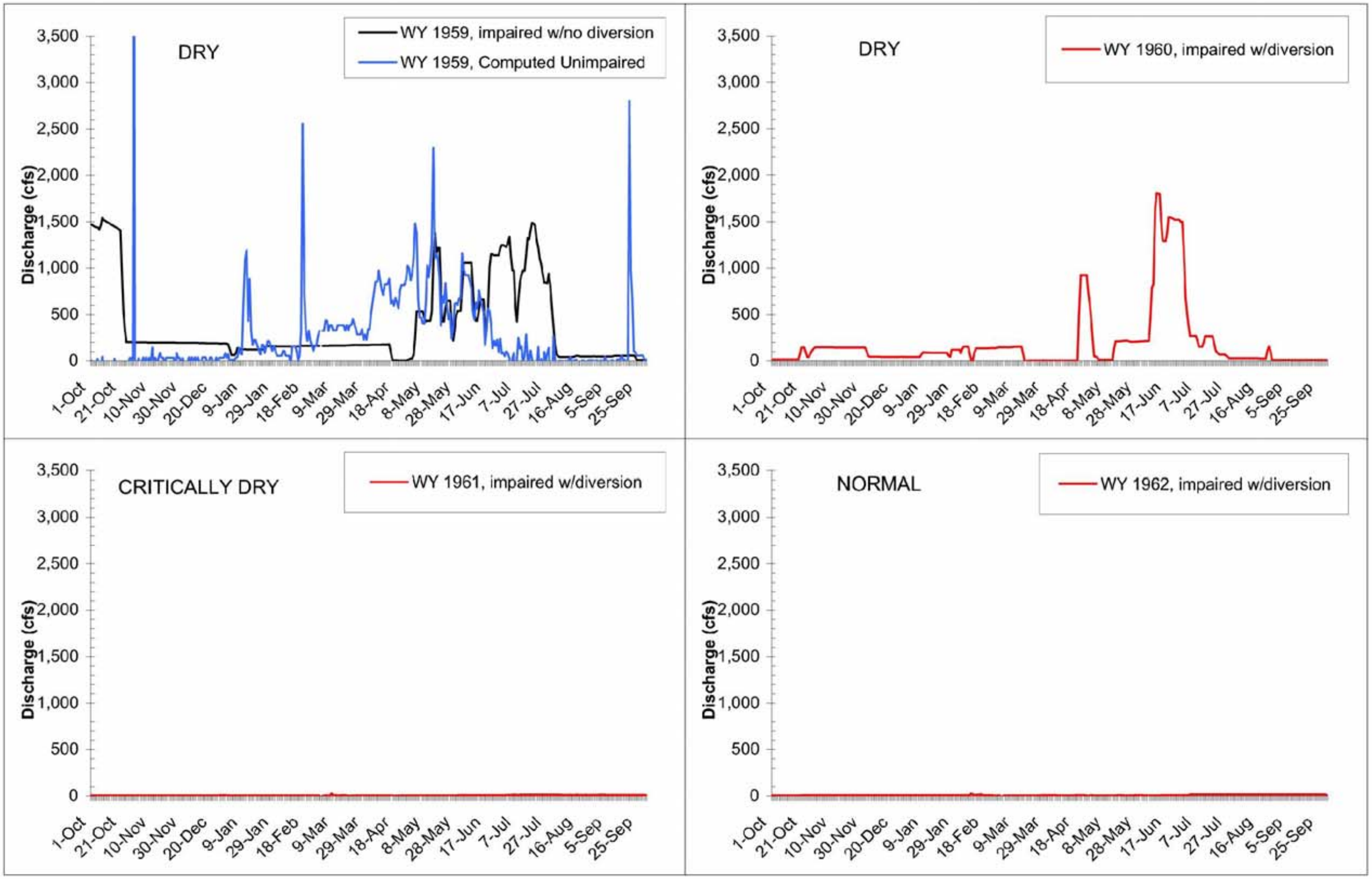
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



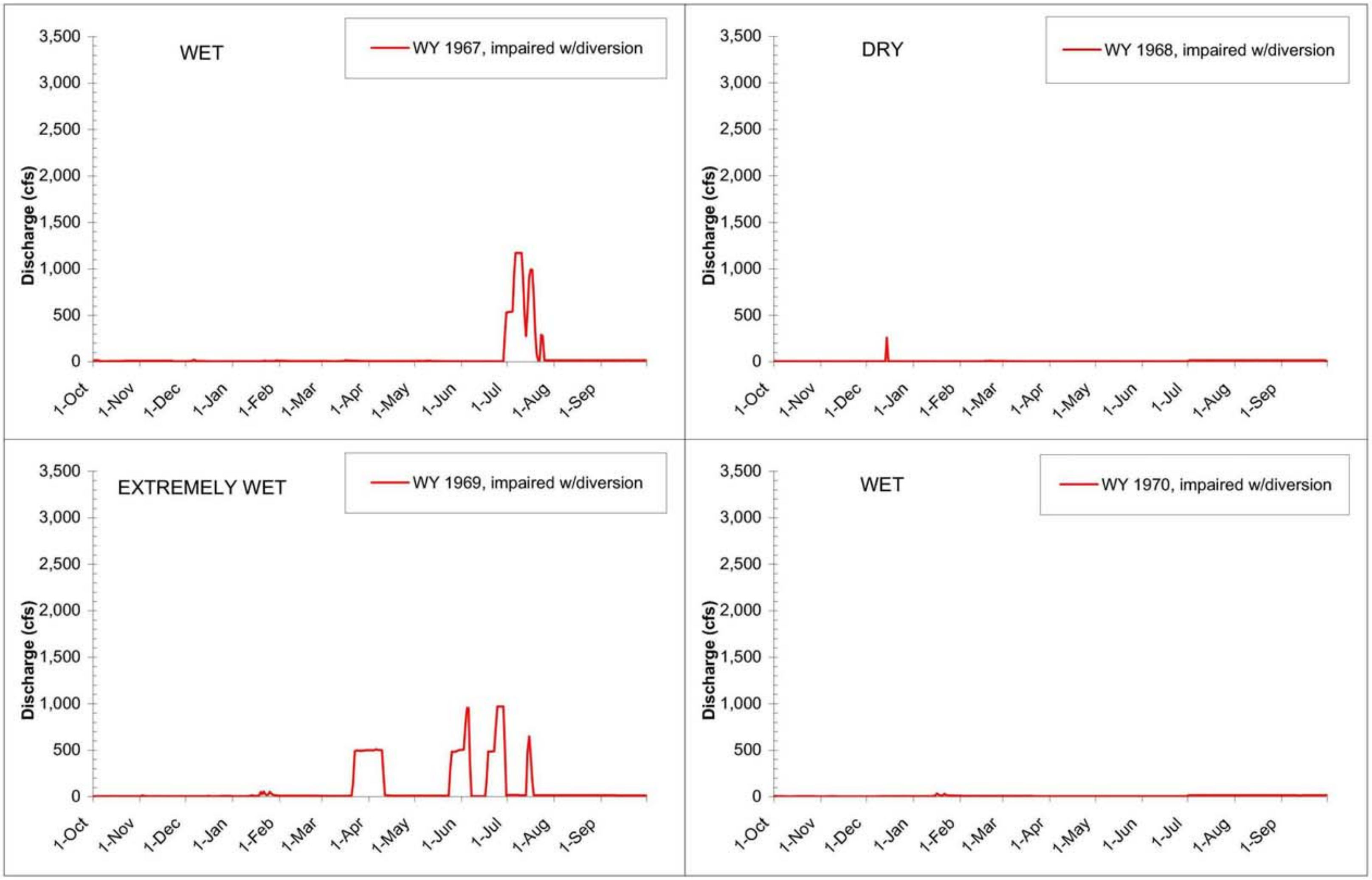
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



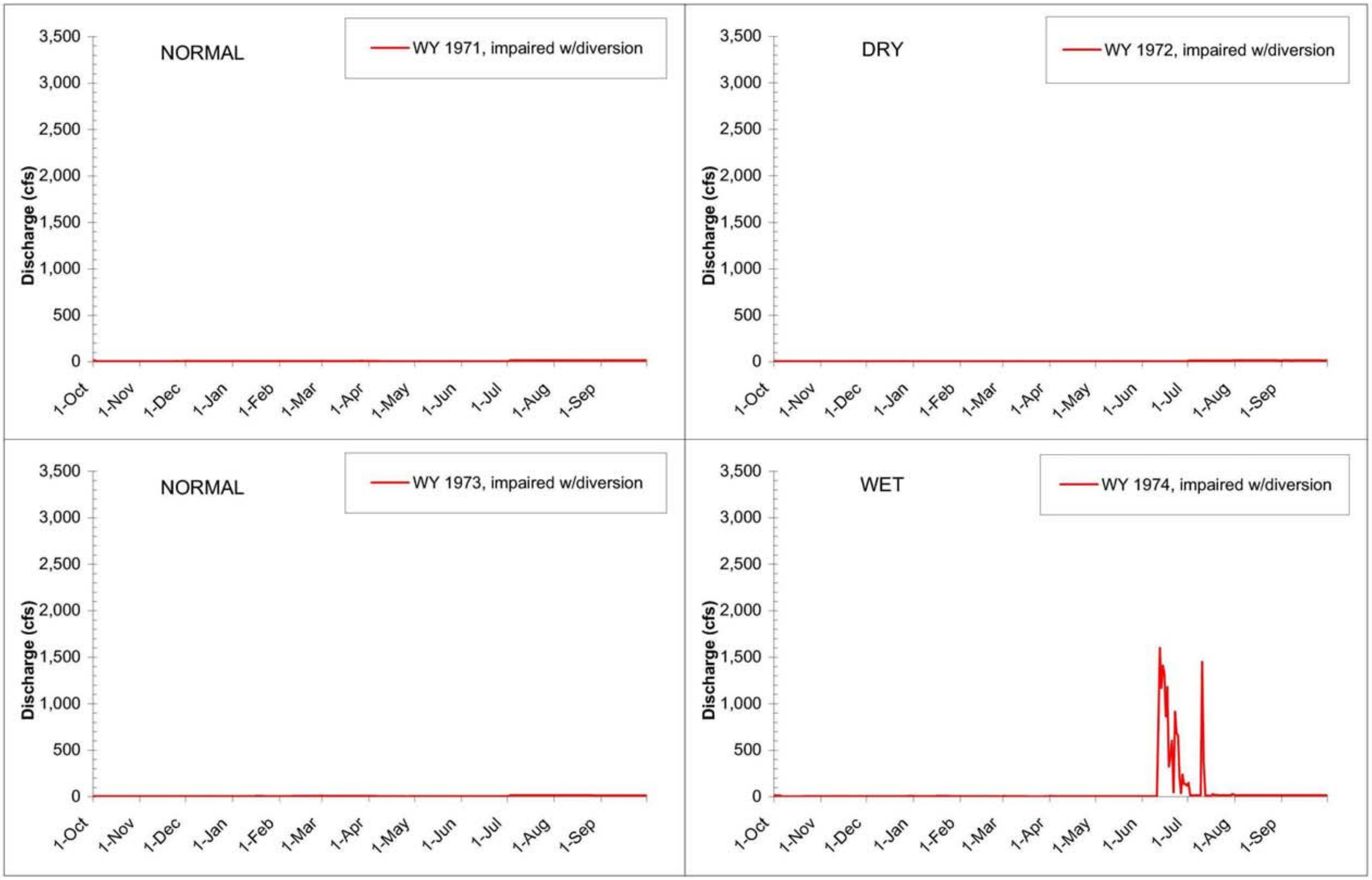
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



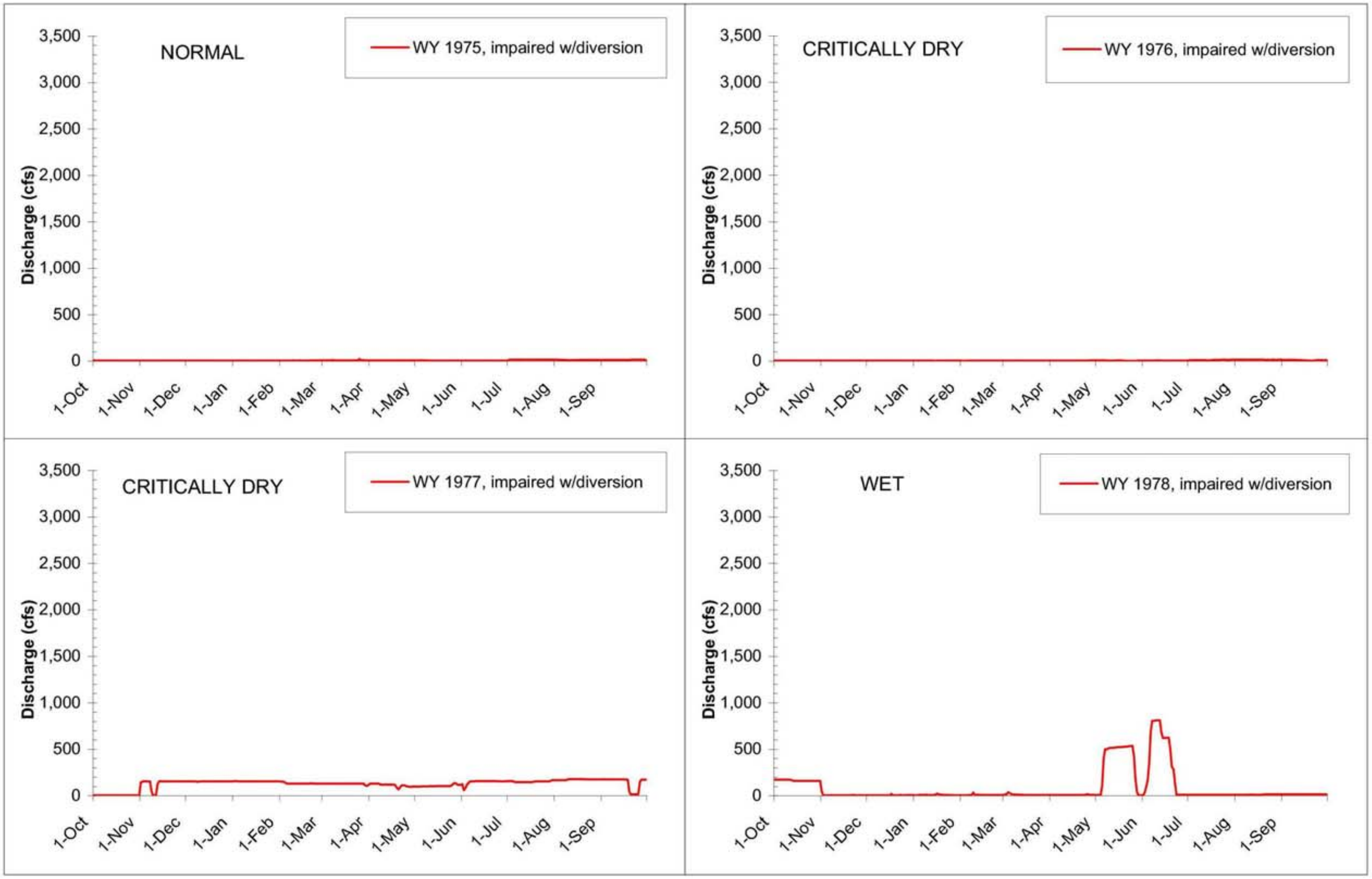
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



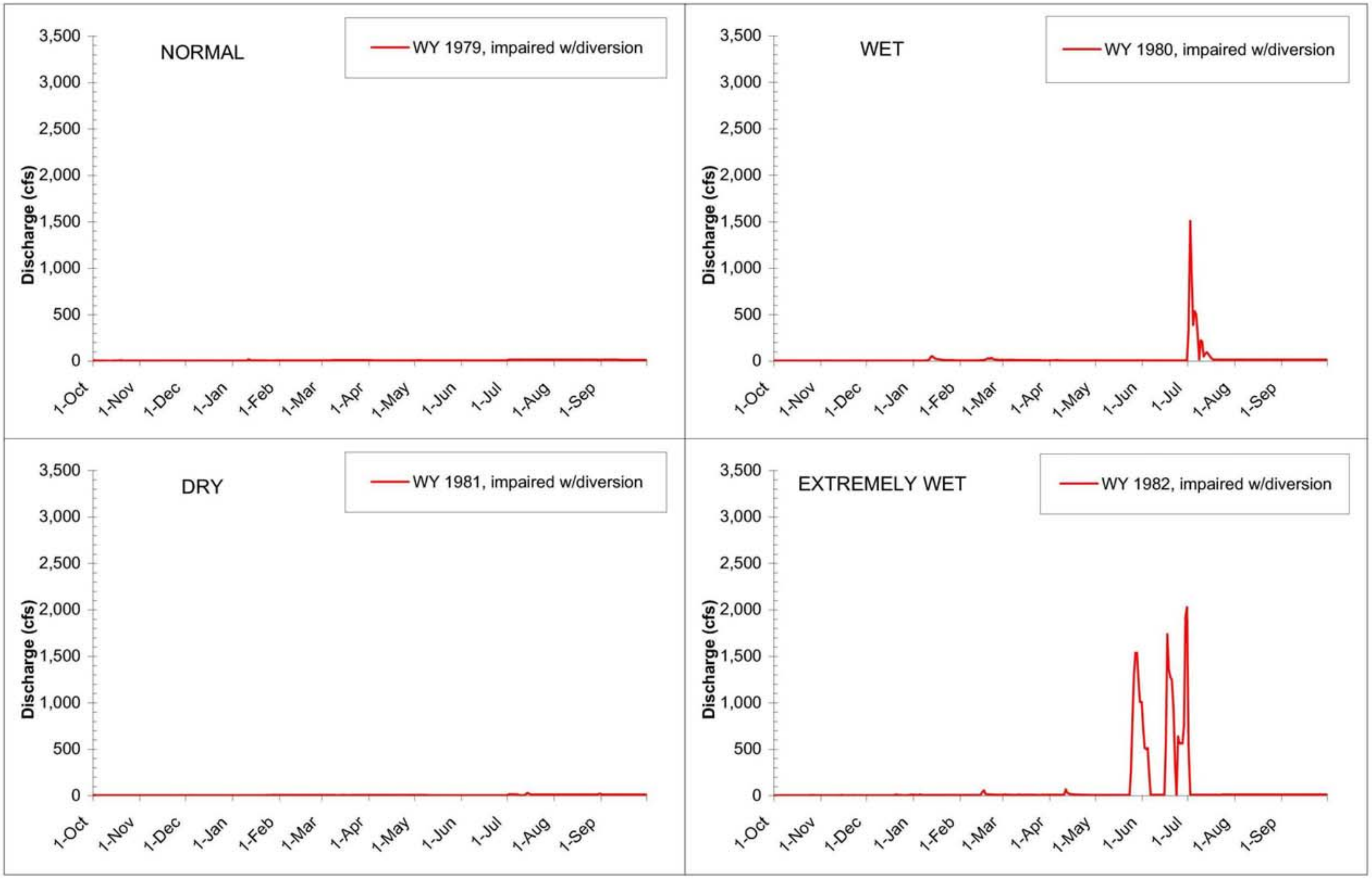
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



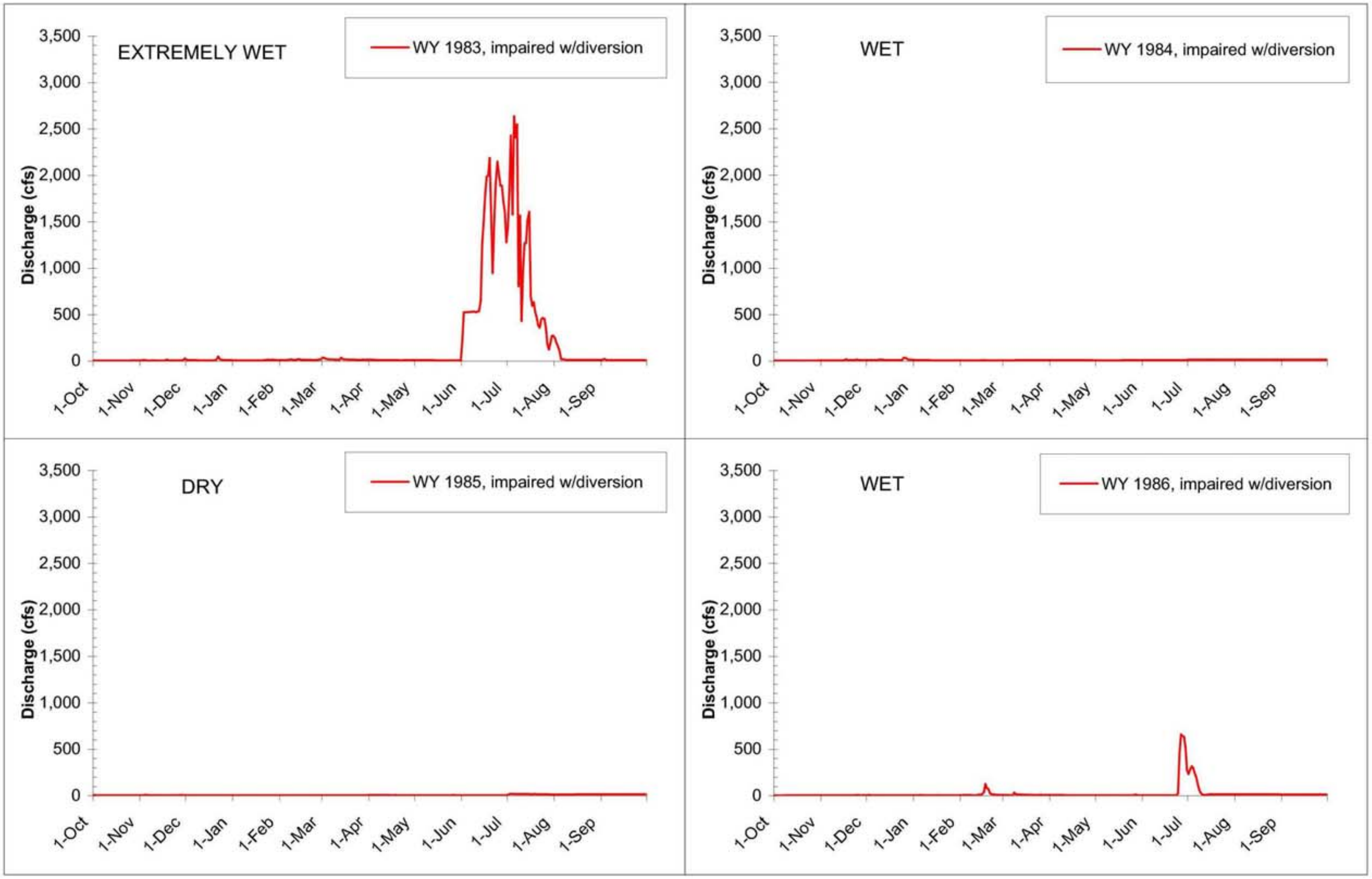
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



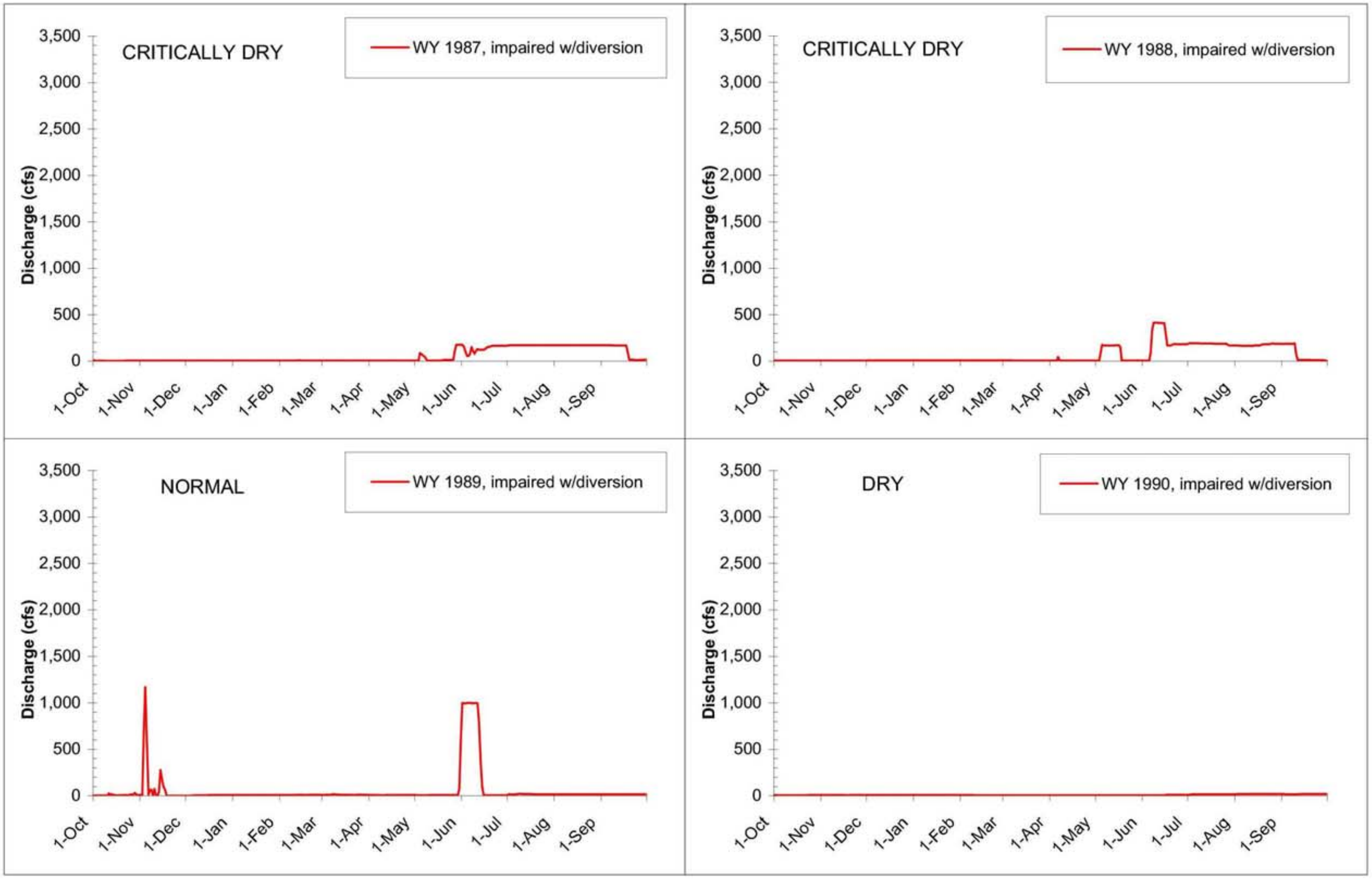
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



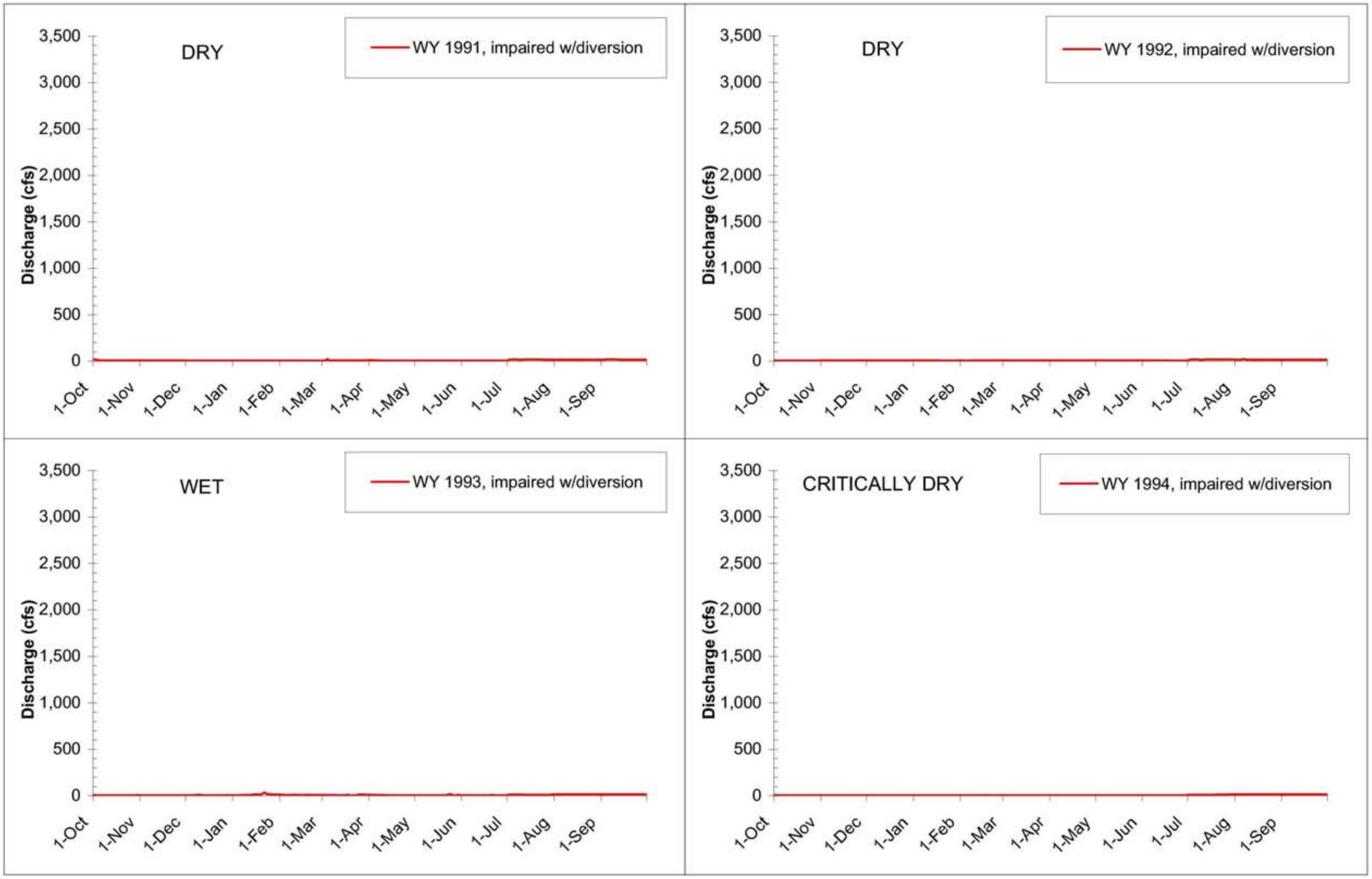
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



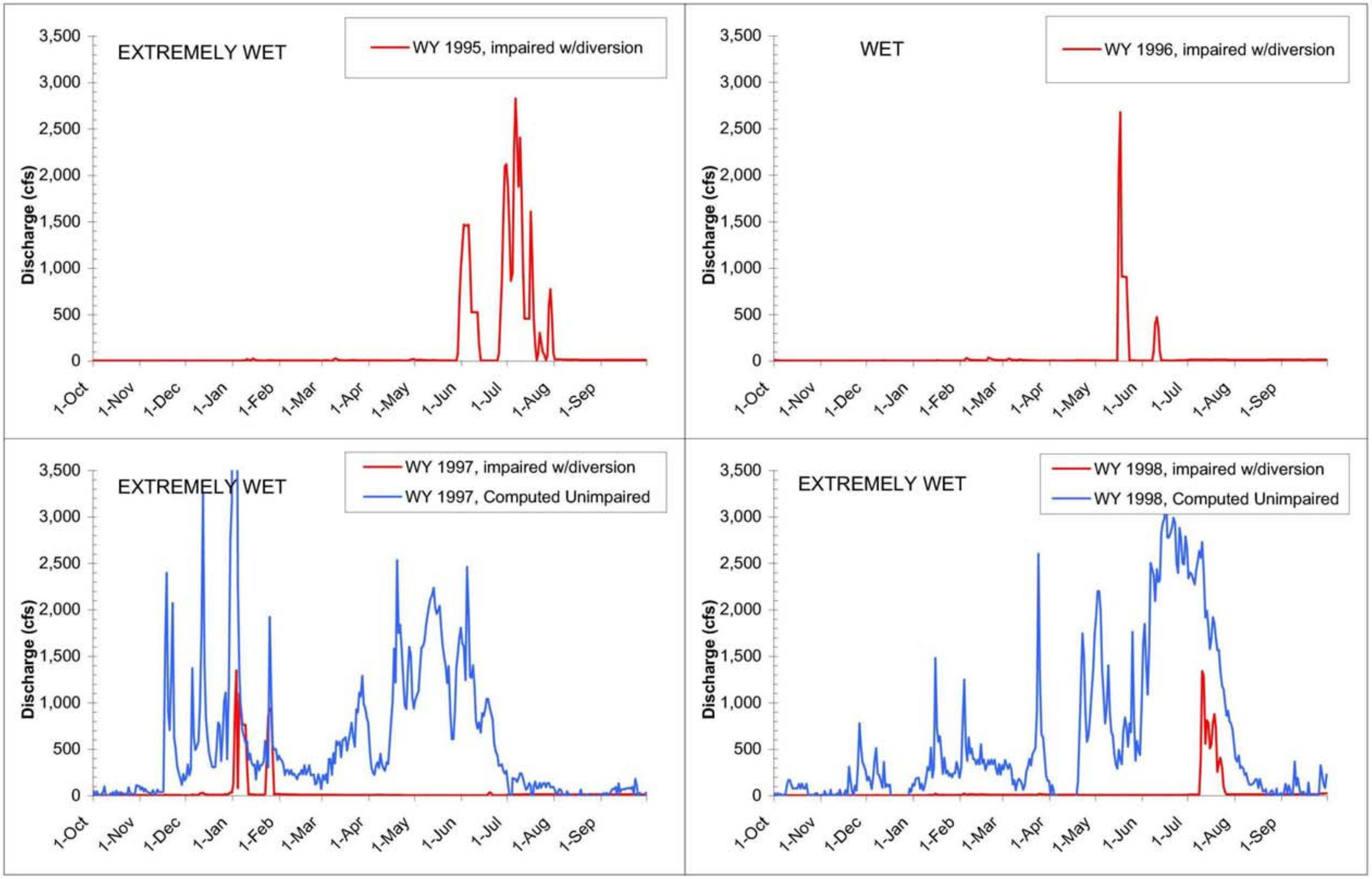
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



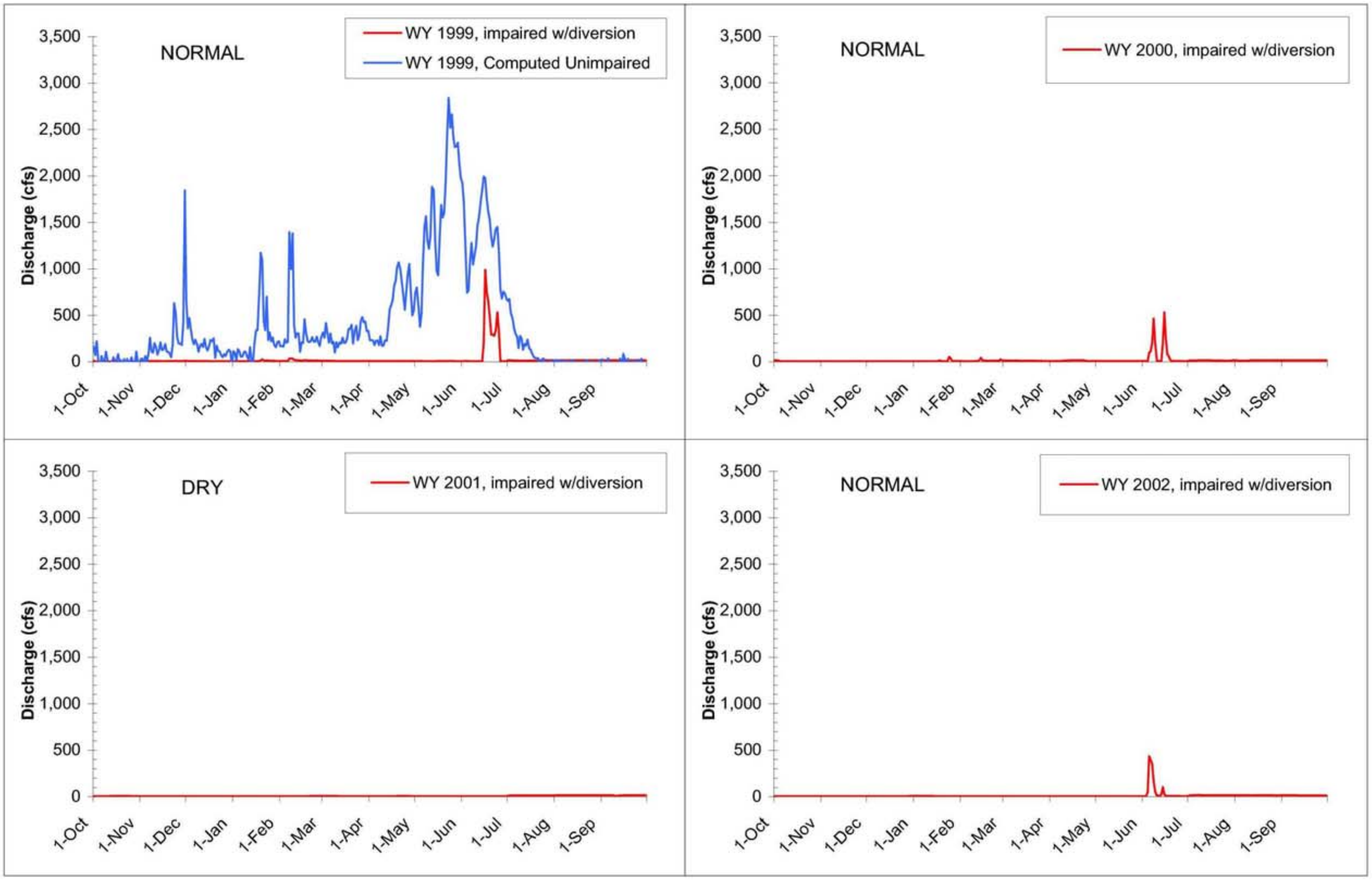
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



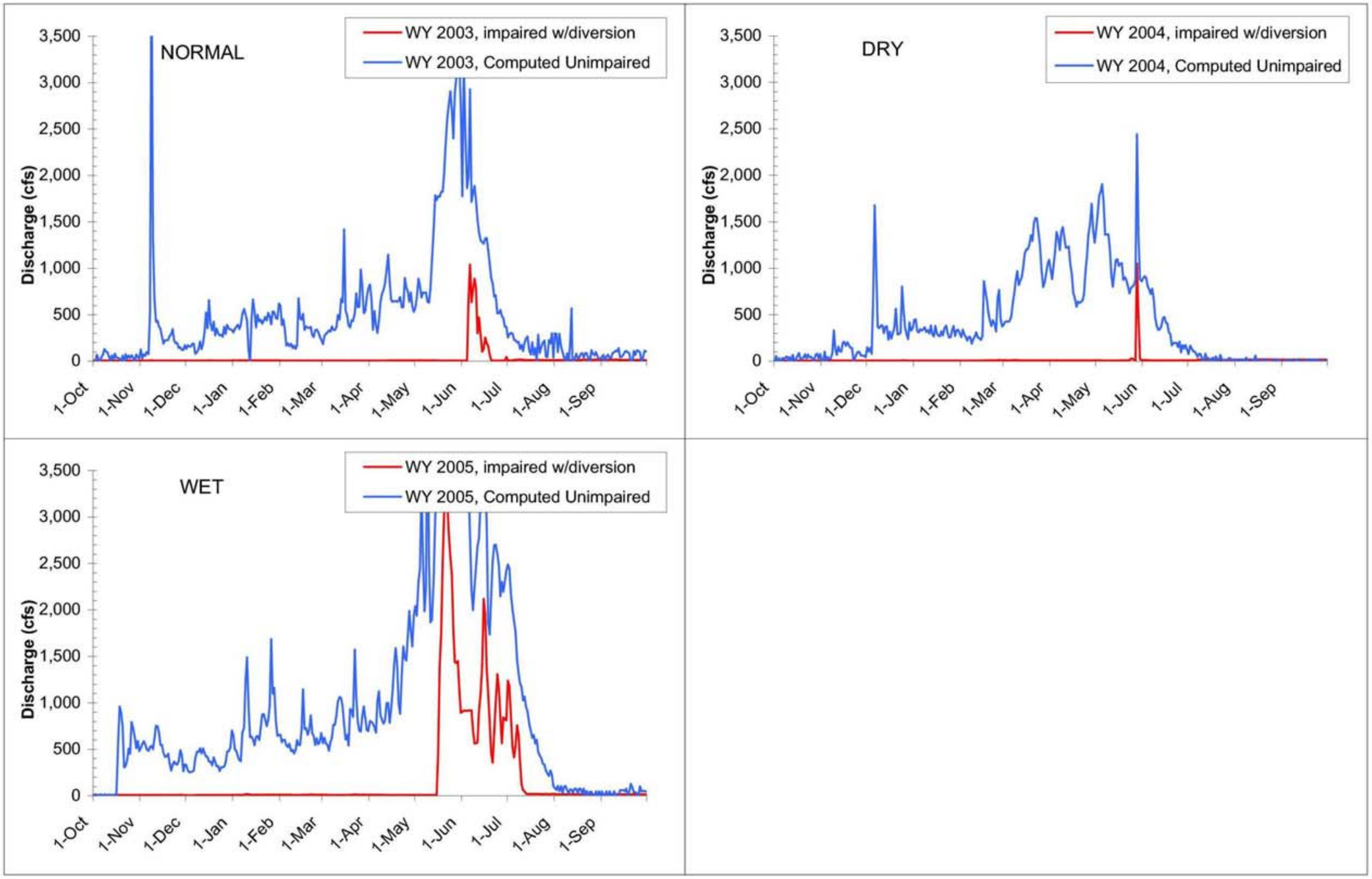
Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)



Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)

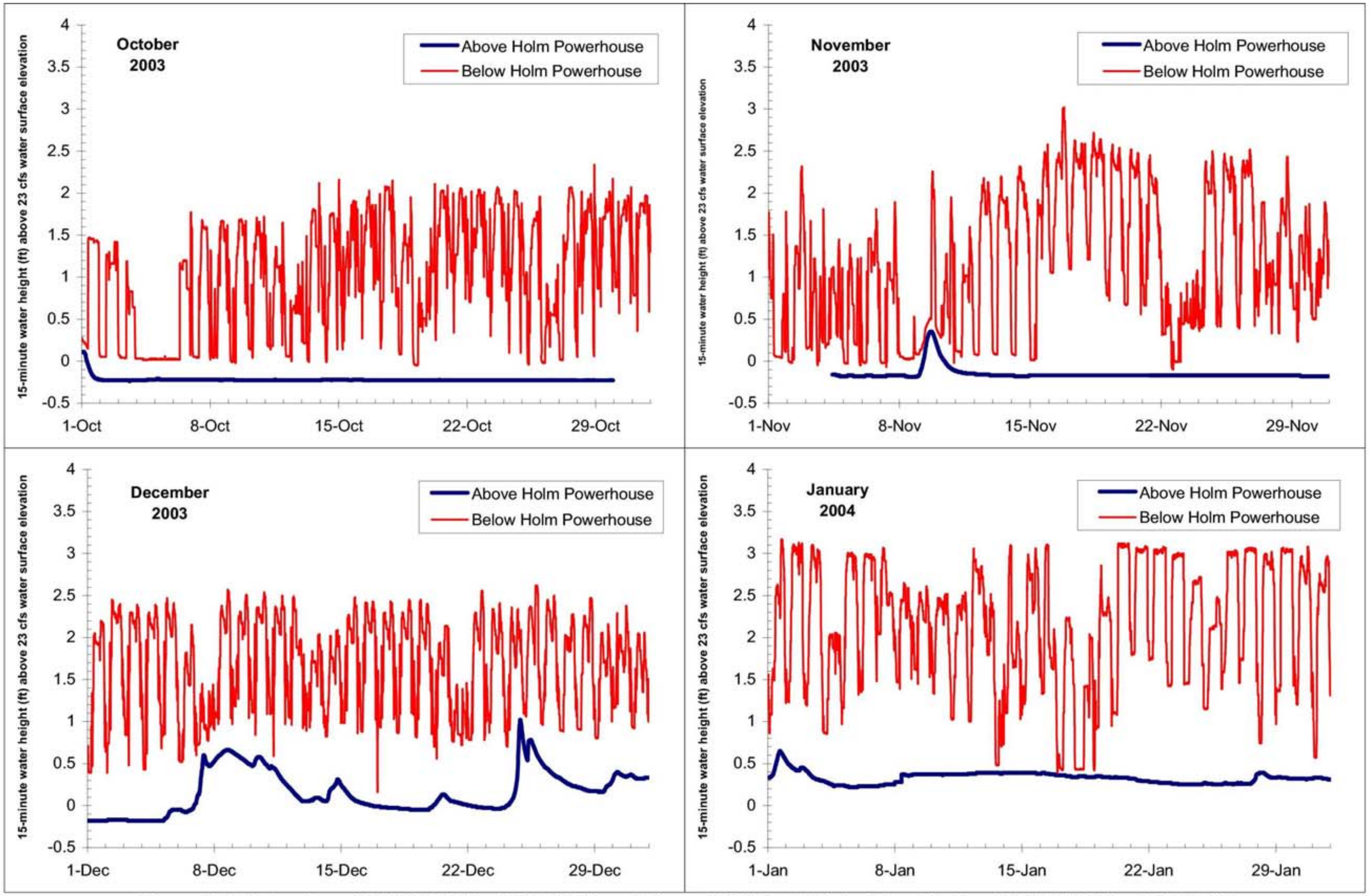


Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)

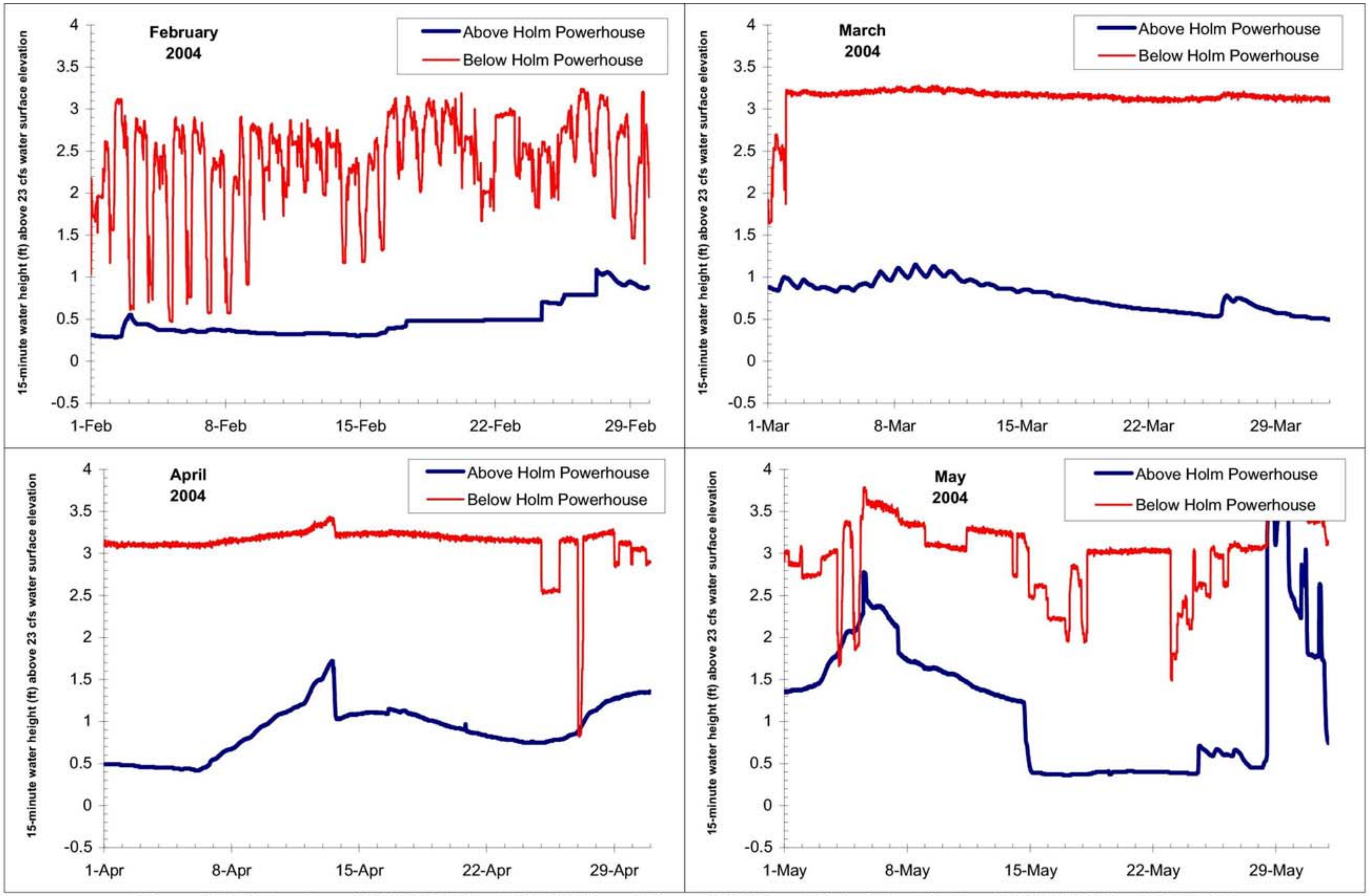


Cherry Creek bl Valley Dam, CA (USGS Stn 11-277300)

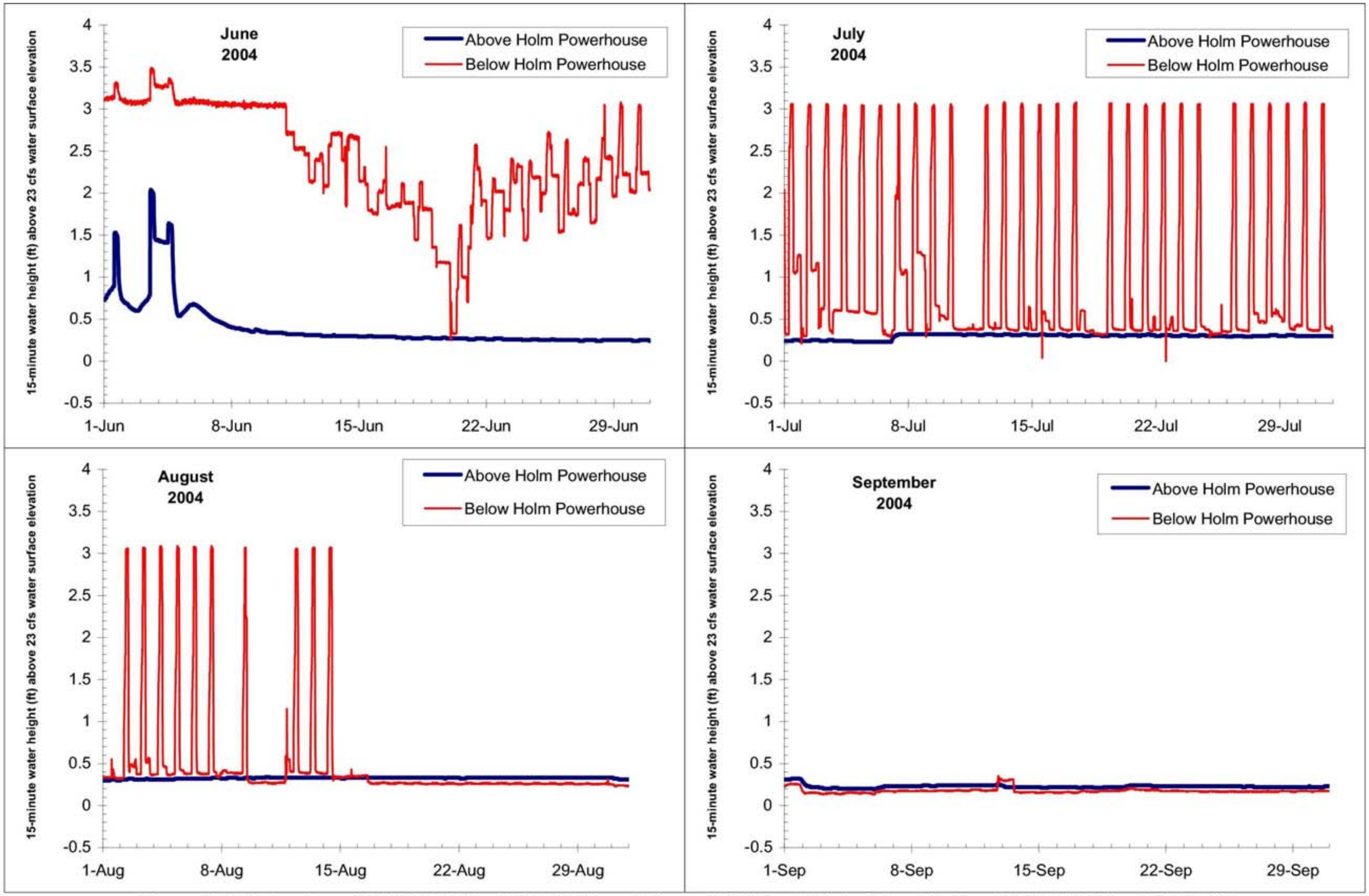
Appendix D: 15-minute stage and discharge plots for each month in Water Year 2004 (DRY) and 2005 (WET) for Cherry Creek near Early Intake above Holm Powerhouse (USGS 11-278300) and Cherry Creek below Holm Powerhouse (USGS 11-278400). Simulated 15-minute discharge plots for each month in Water Year 2004 and 2005 for Tuolumne River below Cherry Creek confluence.



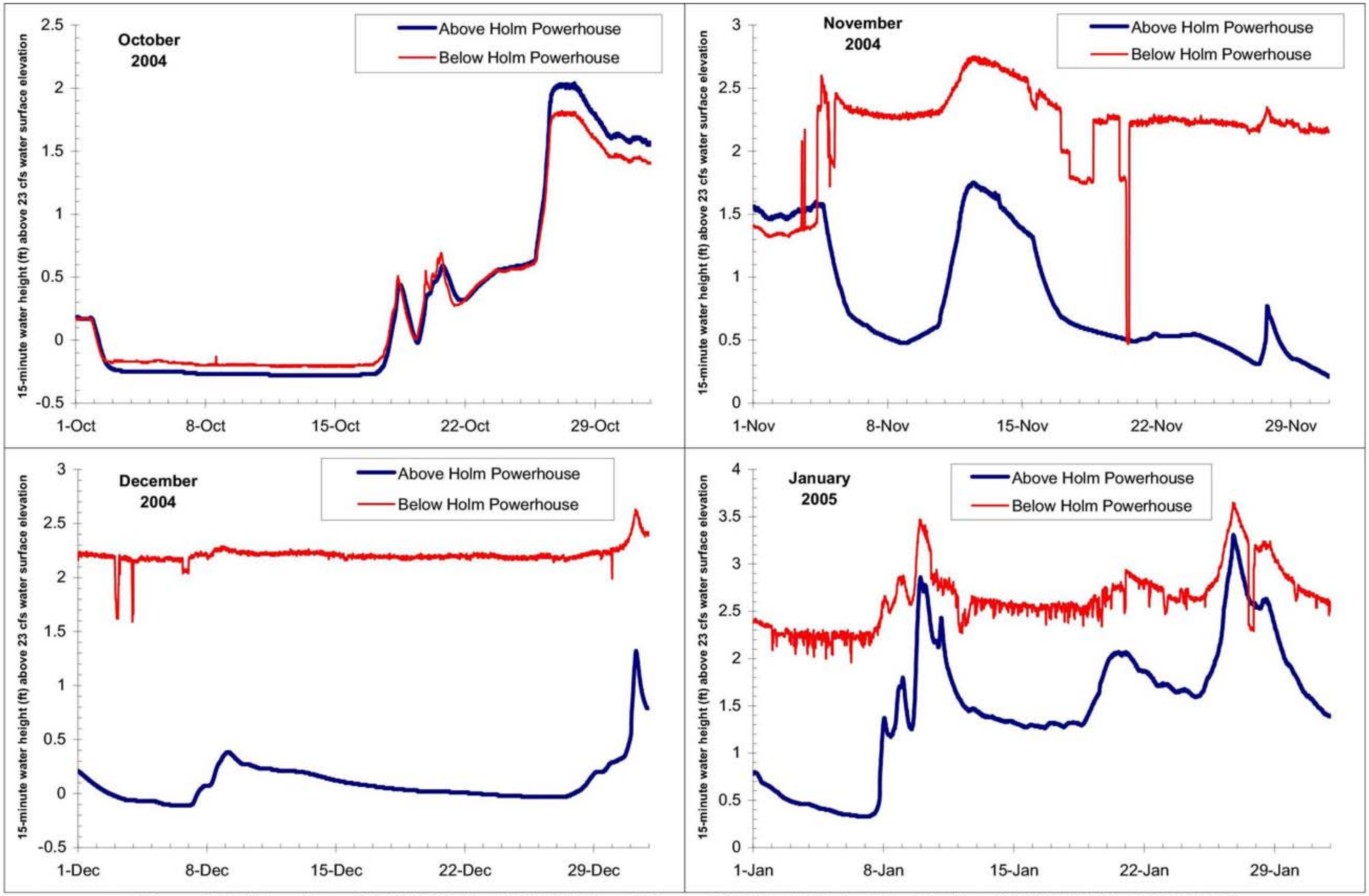
Cherry C bl Valley Dam, CA (USGS Stn 11-278300) and Cherry C Bl Dion R Holm Ph nr Mather, CA (USGS Stn 11-278400)



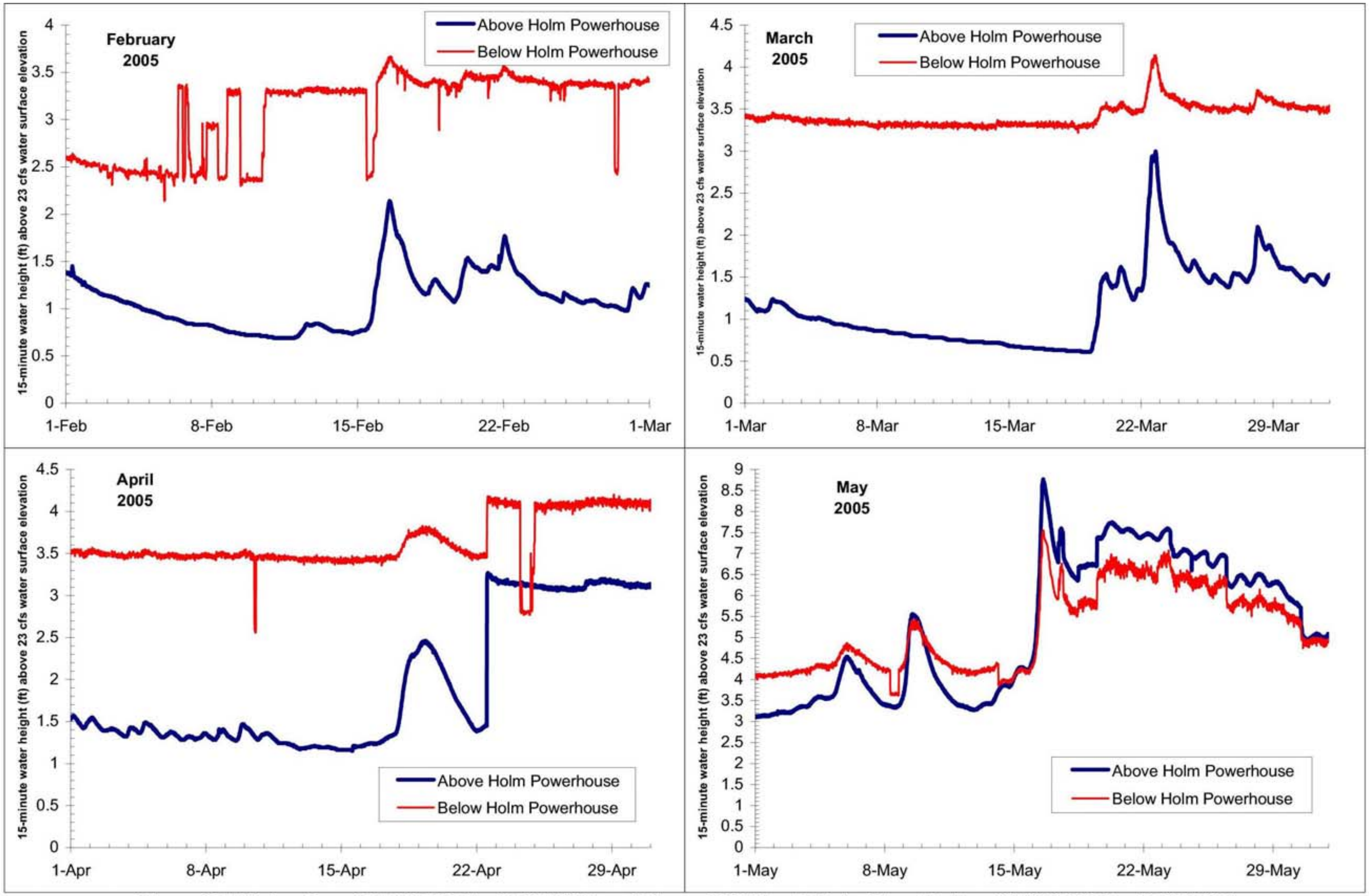
Cherry C bl Valley Dam, CA (USGS Stn 11-278300) and Cherry C Bl Dion R Holm Ph nr Mather, CA (USGS Stn 11-278400)



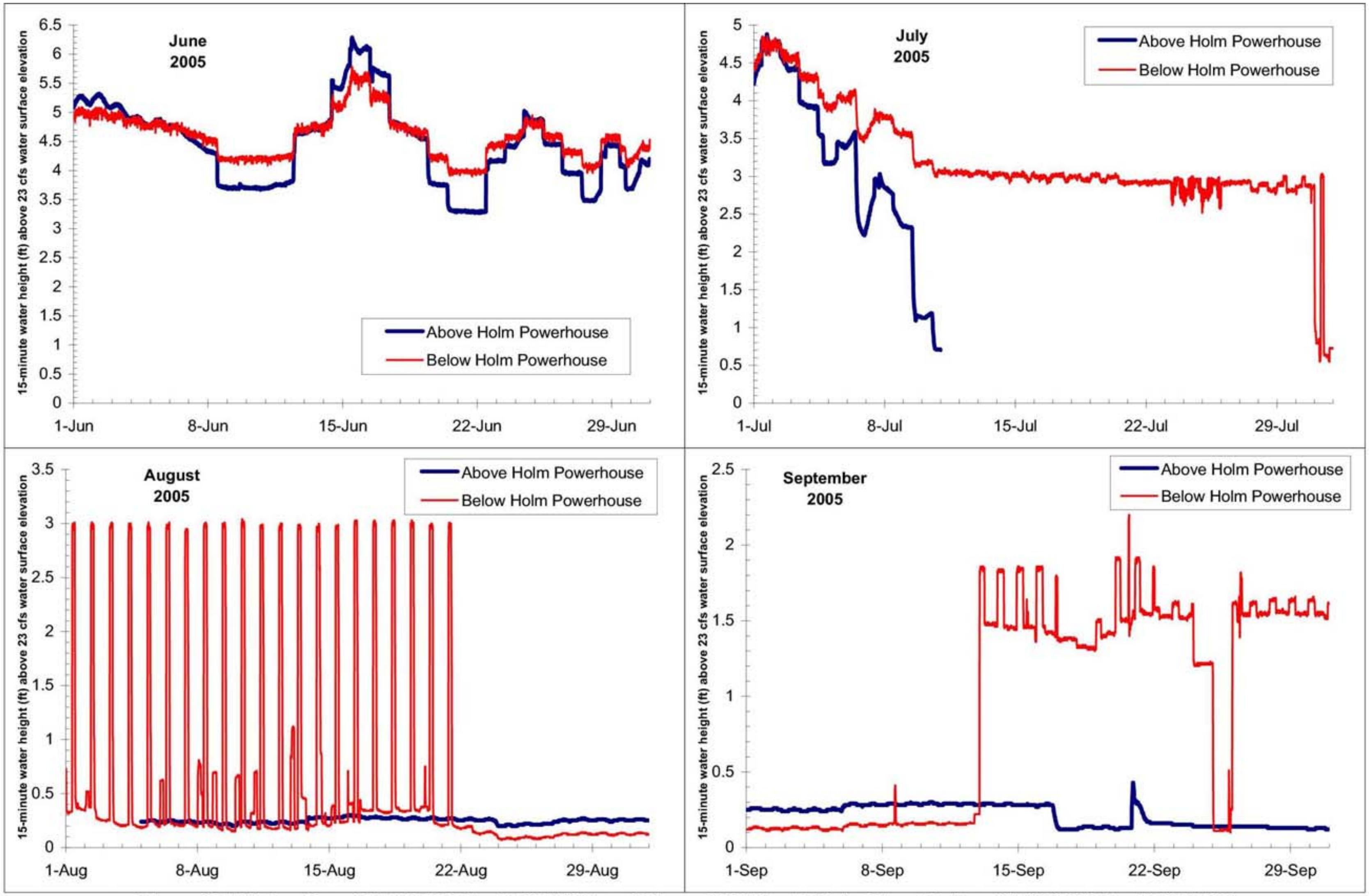
Cherry C bl Valley Dam, CA (USGS Stn 11-278300) and Cherry C Bl Dion R Holm Ph nr Mather, CA (USGS Stn 11-278400)



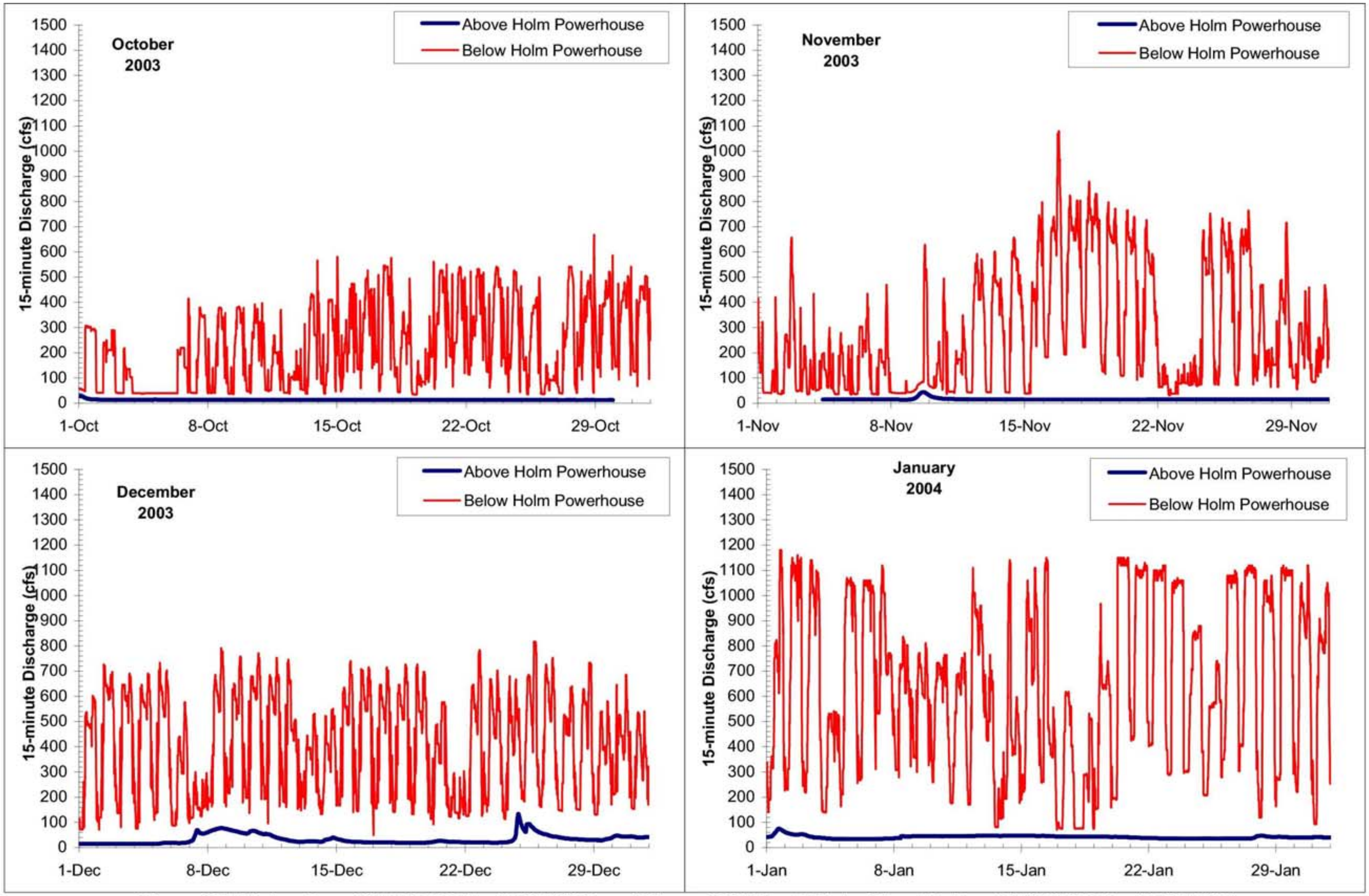
Cherry C bl Valley Dam, CA (USGS Stn 11-278300) and Cherry C Bl Dion R Holm Ph nr Mather, CA (USGS Stn 11-278400)



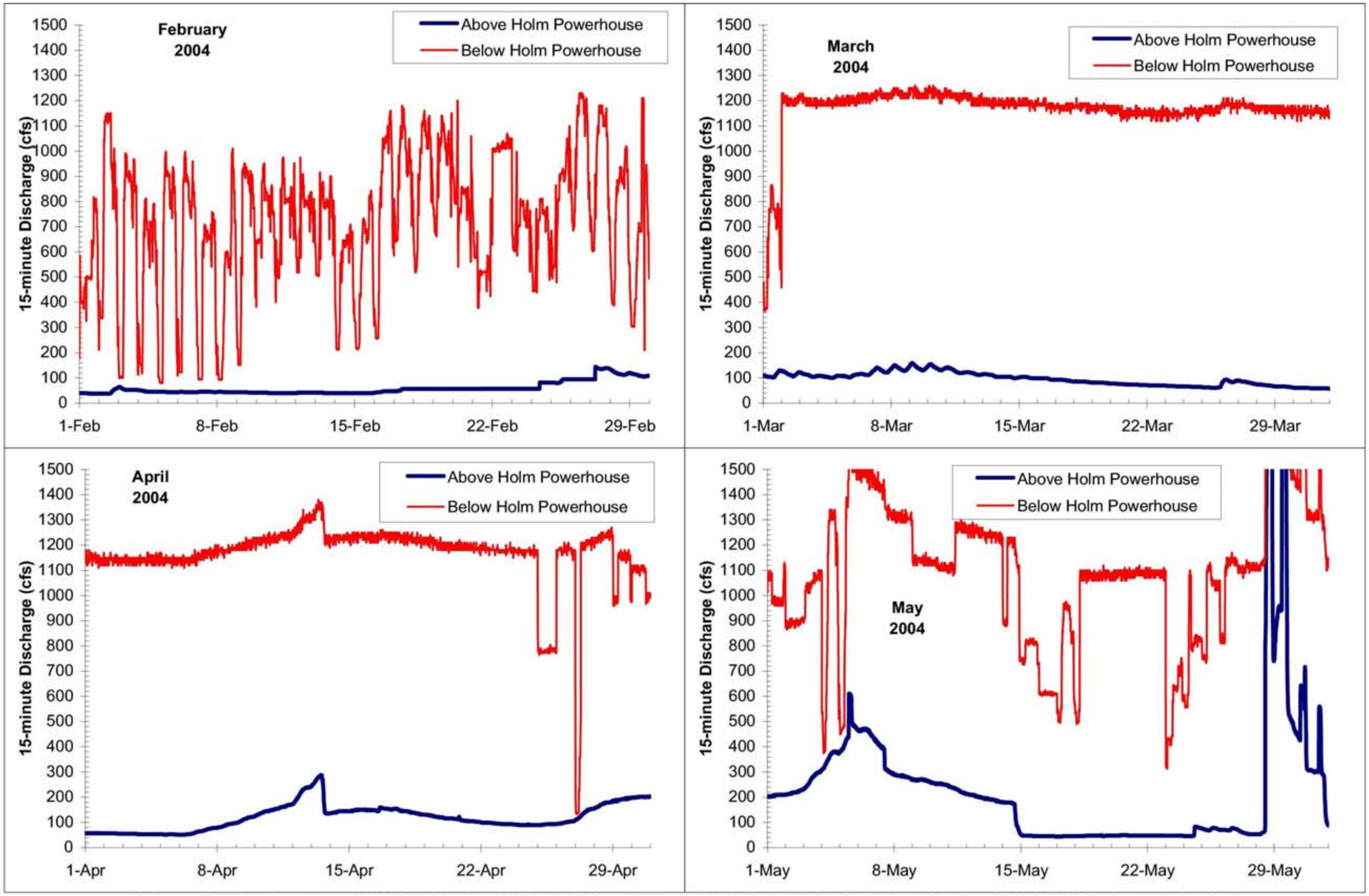
Cherry C bl Valley Dam, CA (USGS Stn 11-278300) and Cherry C Bl Dion R Holm Ph nr Mather, CA (USGS Stn 11-278400)



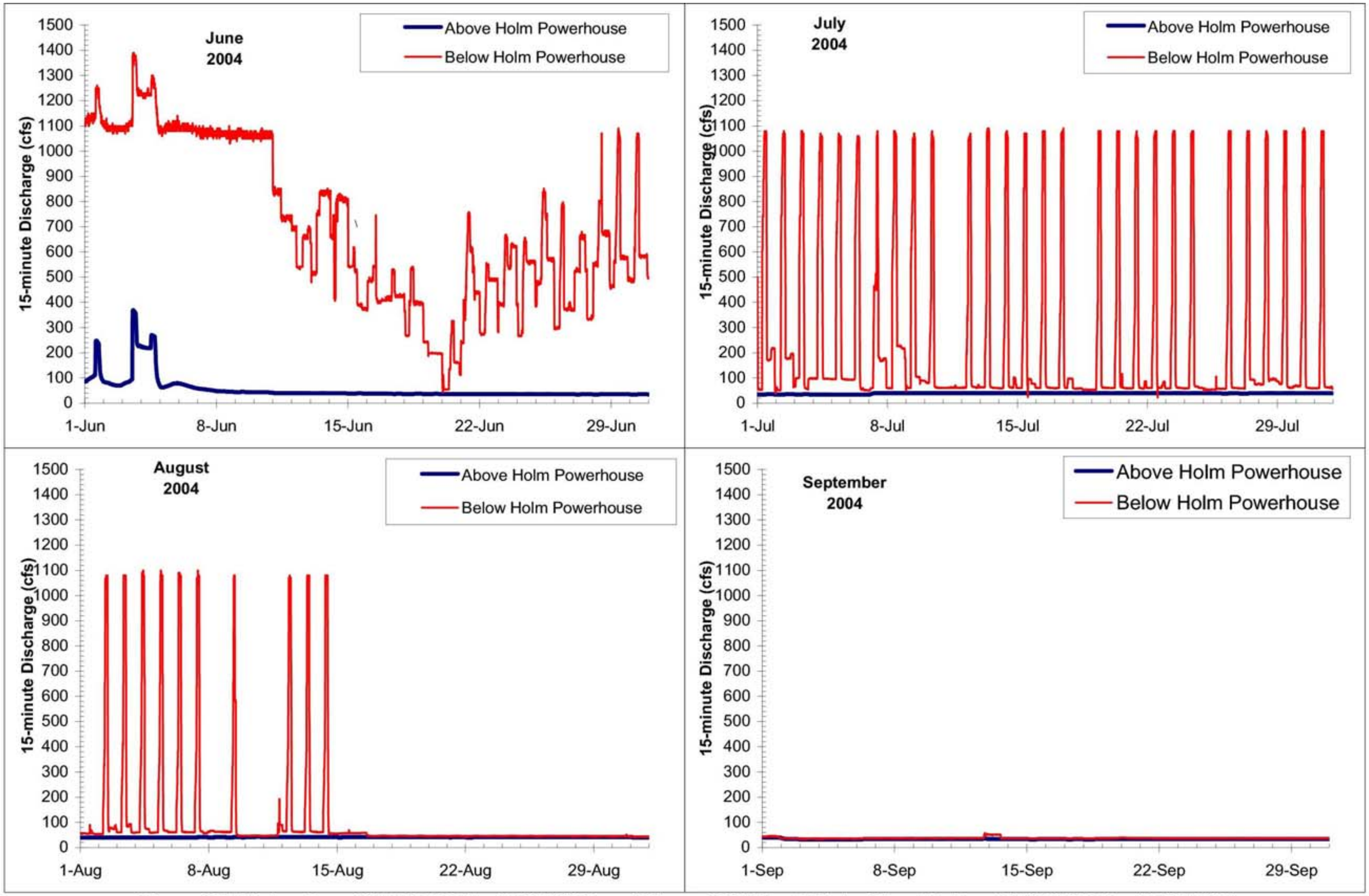
Cherry C bl Valley Dam, CA (USGS Stn 11-278300) and Cherry C Bl Dion R Holm Ph nr Mather, CA (USGS Stn 11-278400)



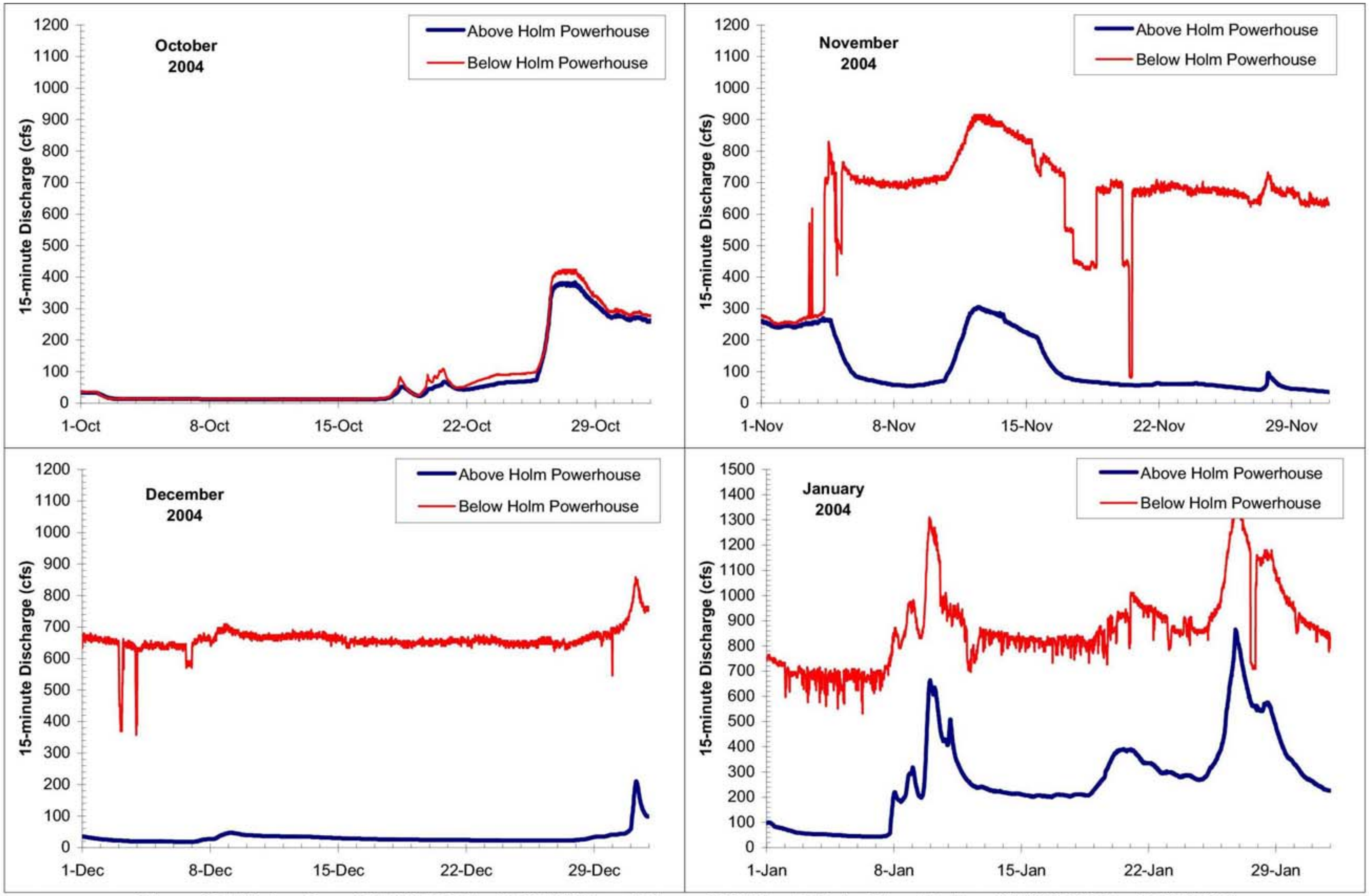
Cherry C bl Valley Dam, CA (USGS Stn 11-278300) and Cherry C Bl Dion R Holm Ph nr Mather, CA (USGS Stn 11-278400)



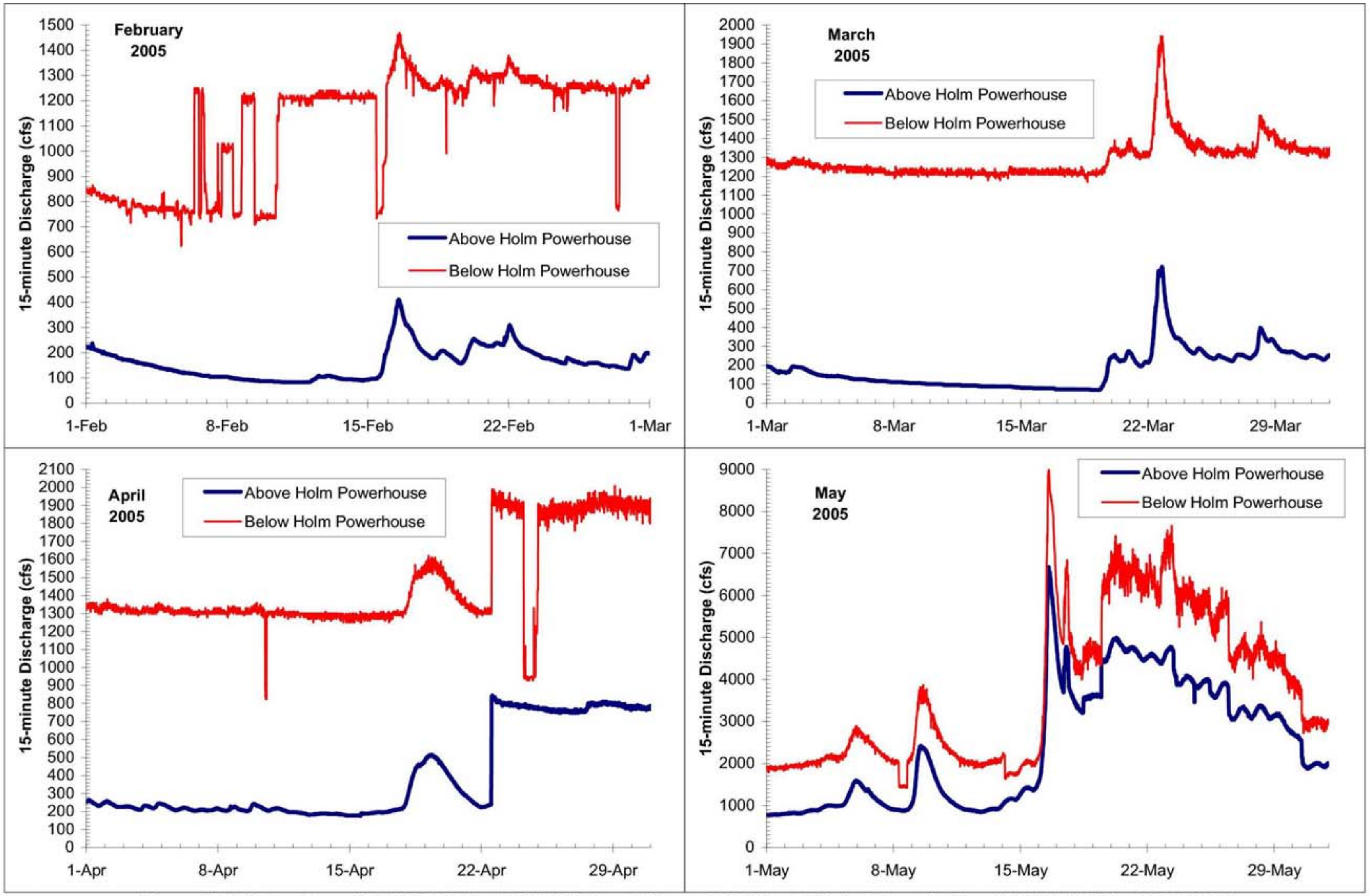
Cherry C bl Valley Dam, CA (USGS Stn 11-278300) and Cherry C Bl Dion R Holm Ph nr Mather, CA (USGS Stn 11-278400)



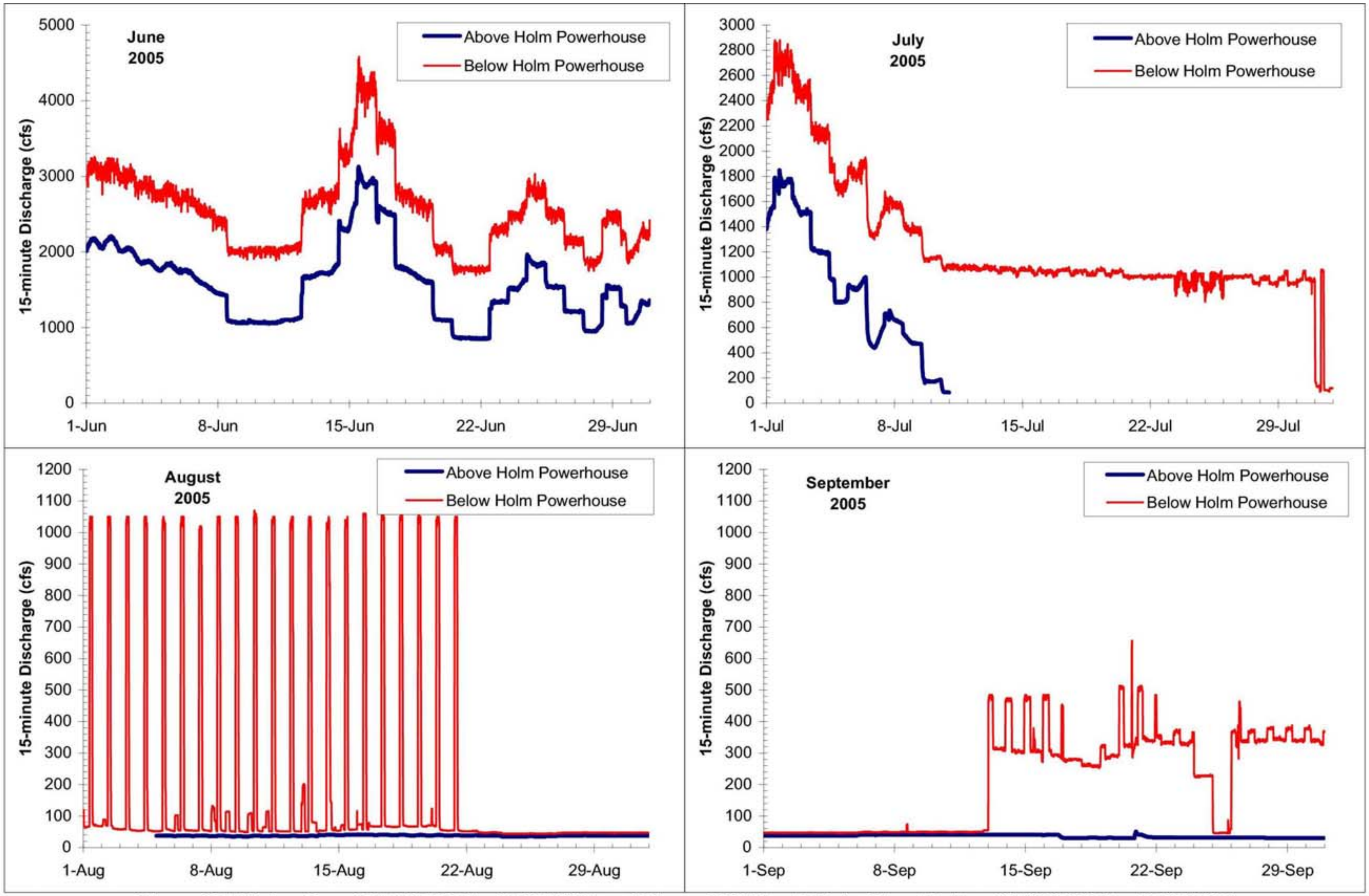
Cherry C bl Valley Dam, CA (USGS Stn 11-278300) and Cherry C Bl Dion R Holm Ph nr Mather, CA (USGS Stn 11-278400)



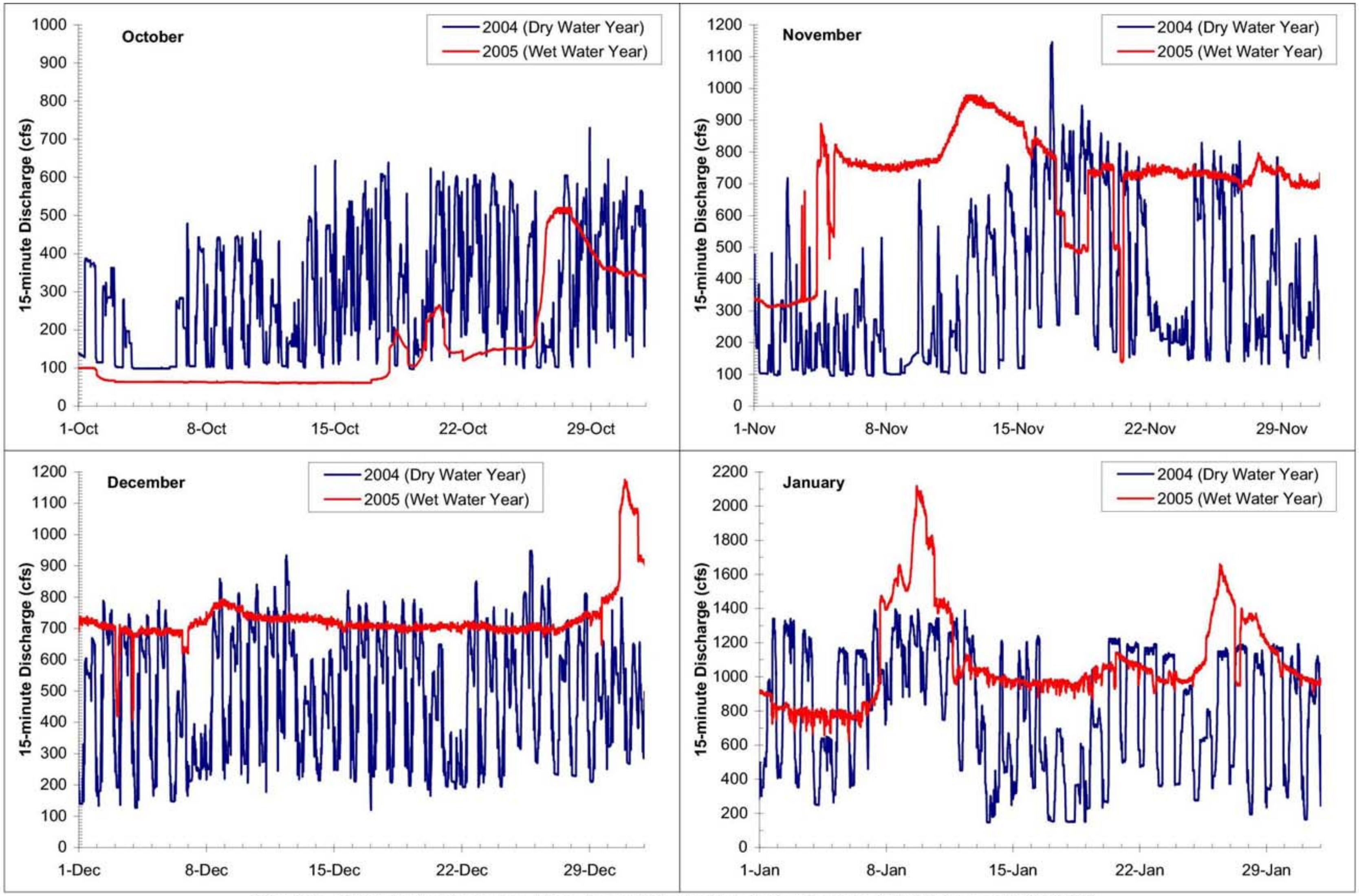
Cherry C bl Valley Dam, CA (USGS Stn 11-278300) and Cherry C Bl Dion R Holm Ph nr Mather, CA (USGS Stn 11-278400)



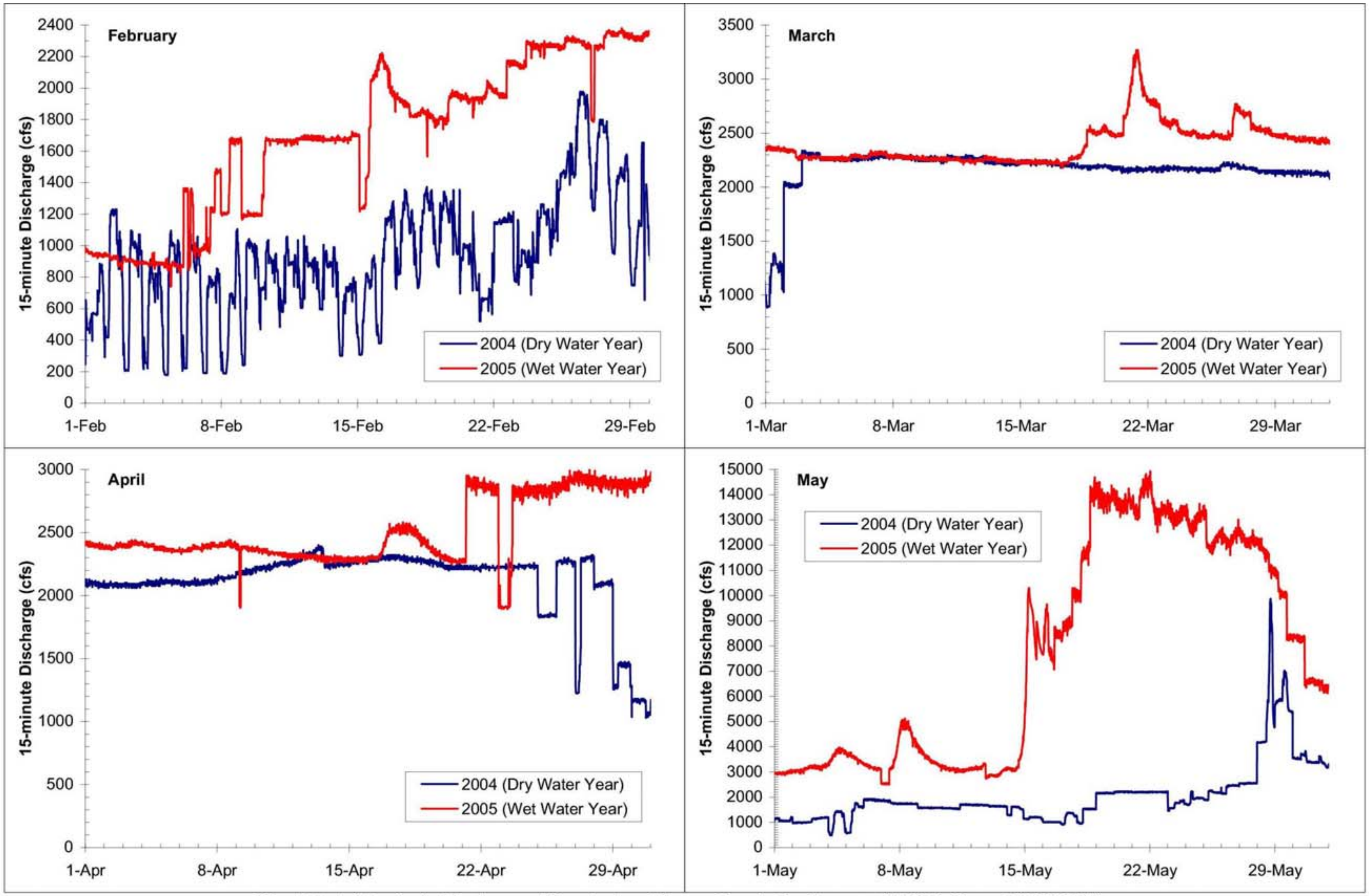
Cherry C bl Valley Dam, CA (USGS Stn 11-278300) and Cherry C Bl Dion R Holm Ph nr Mather, CA (USGS Stn 11-278400)



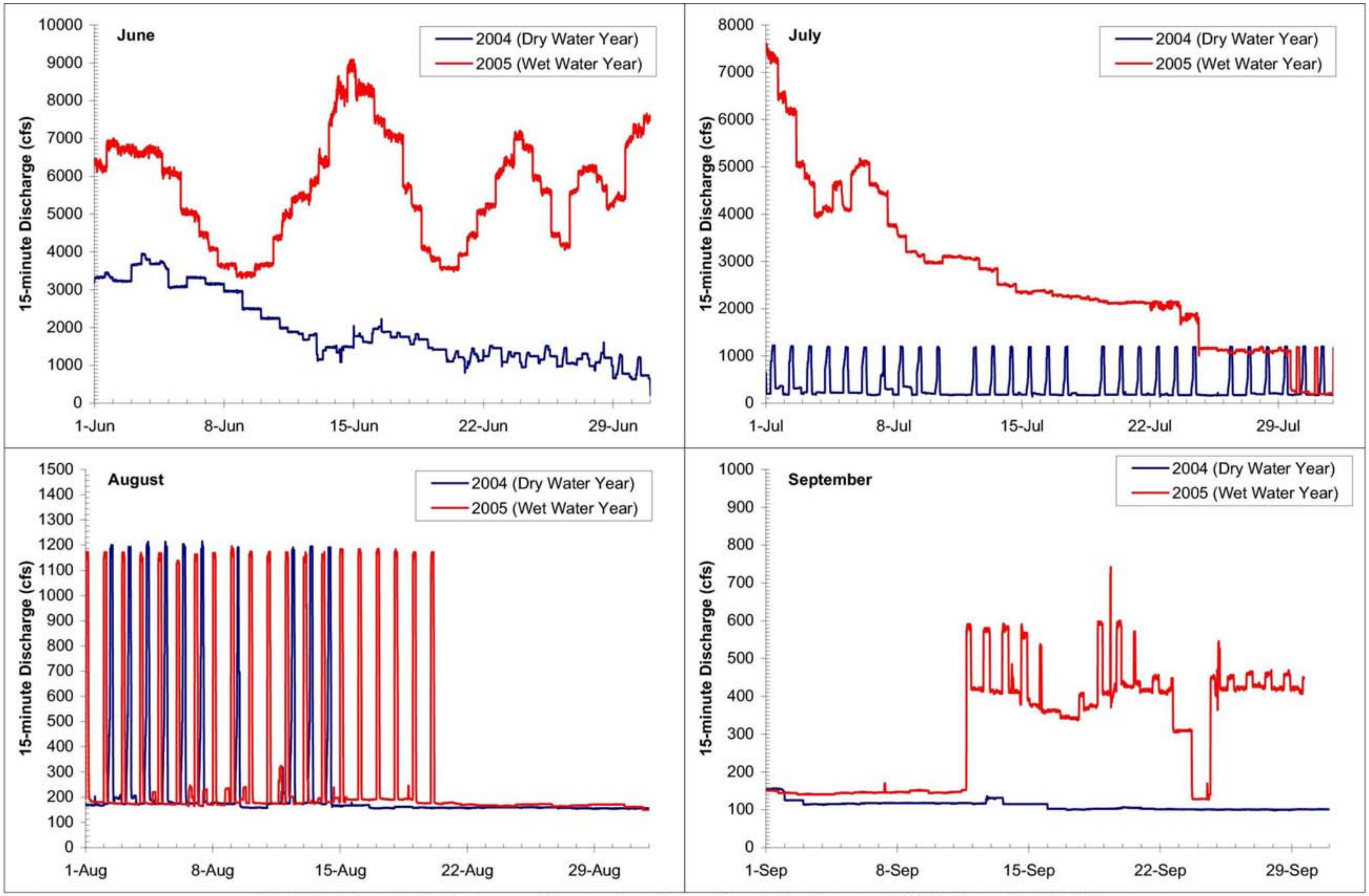
Cherry C bl Valley Dam, CA (USGS Stn 11-278300) and Cherry C Bl Dion R Holm Ph nr Mather, CA (USGS Stn 11-278400)



Simulated 15-minute Tuolumne River below Cherry Creek Confluence (USGS Gage 11-276900).

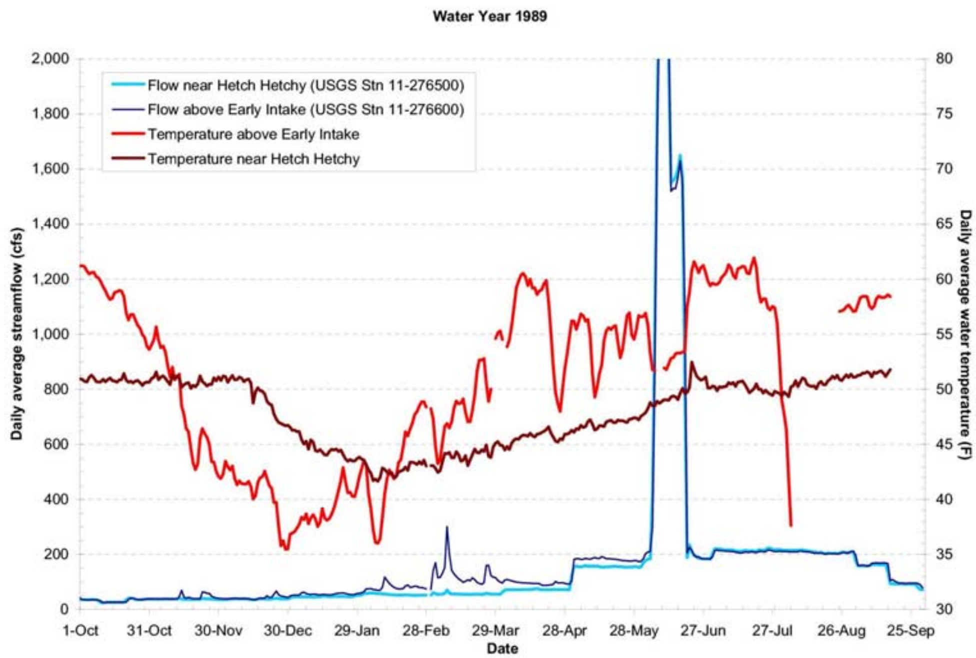


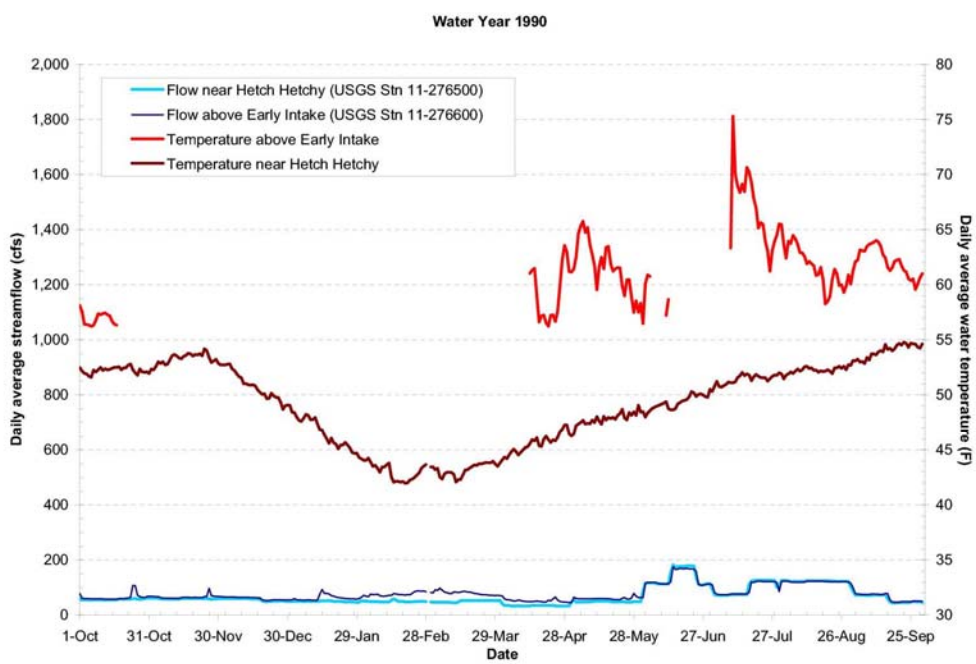
Simulated 15-minute Tuolumne River below Cherry Creek Confluence (USGS Gage 11-276900).

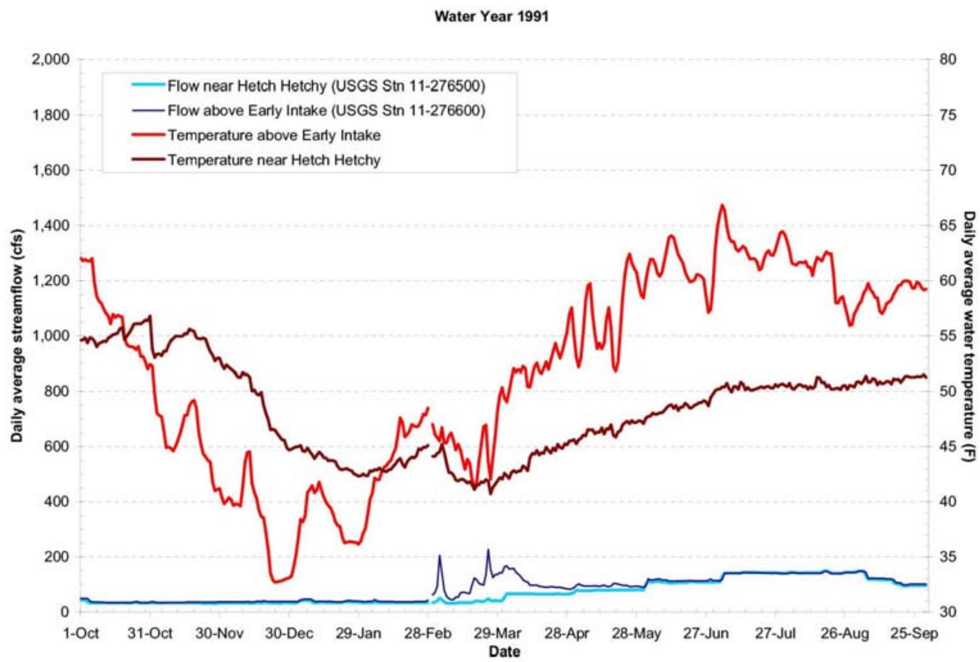


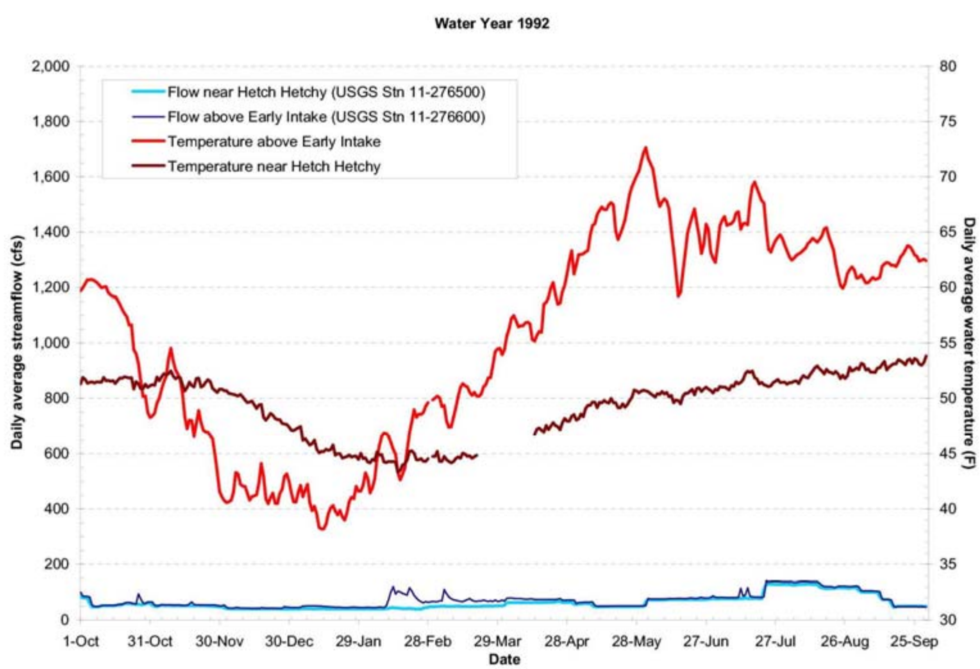
Simulated 15-minute Tuolumne River below Cherry Creek Confluence (USGS Gage 11-276900).

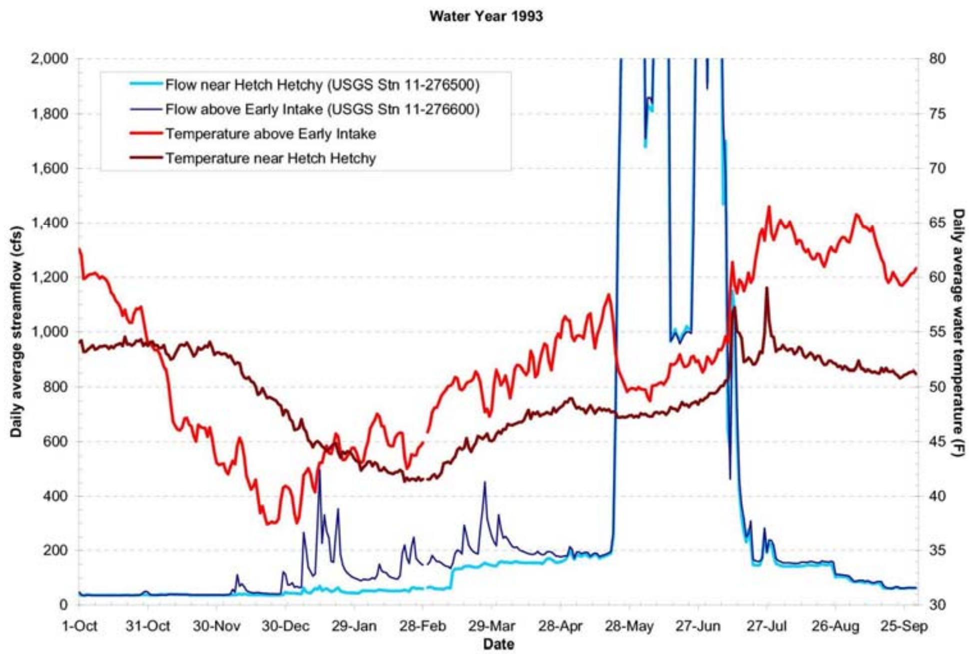
Appendix E: Daily average streamflows and water temperatures for Tuolumne River near Hetch Hetchy (USGS 11-276500) and above Early Intake (USGS 11-276600).

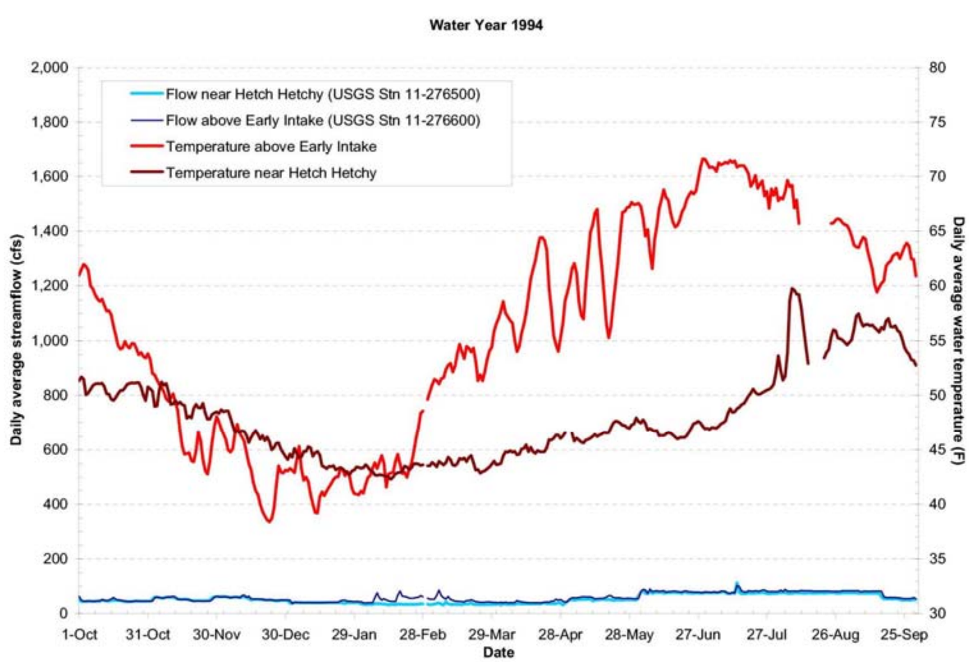

Water Year 1989
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Temperature above Early Intake
Temperature near Hetch Hetchy
Daily average streamflow (cfs)
Daily average water temperature (F)
Date
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep

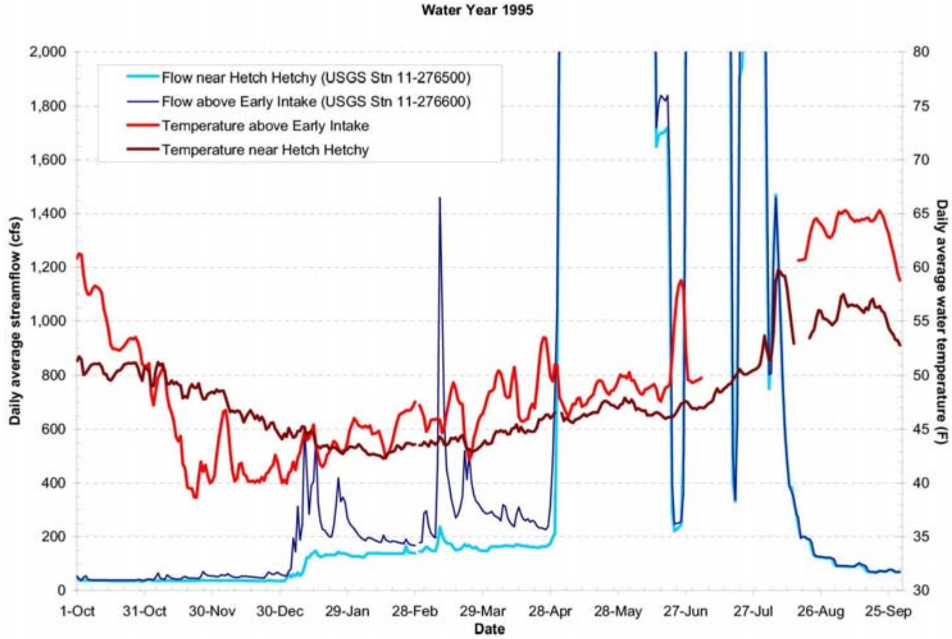

Water Year 1990
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Temperature above Early Intake
Temperature near Hetch Hetchy
Daily average streamflow (cfs)
Daily average water temperature (F)
Date
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep

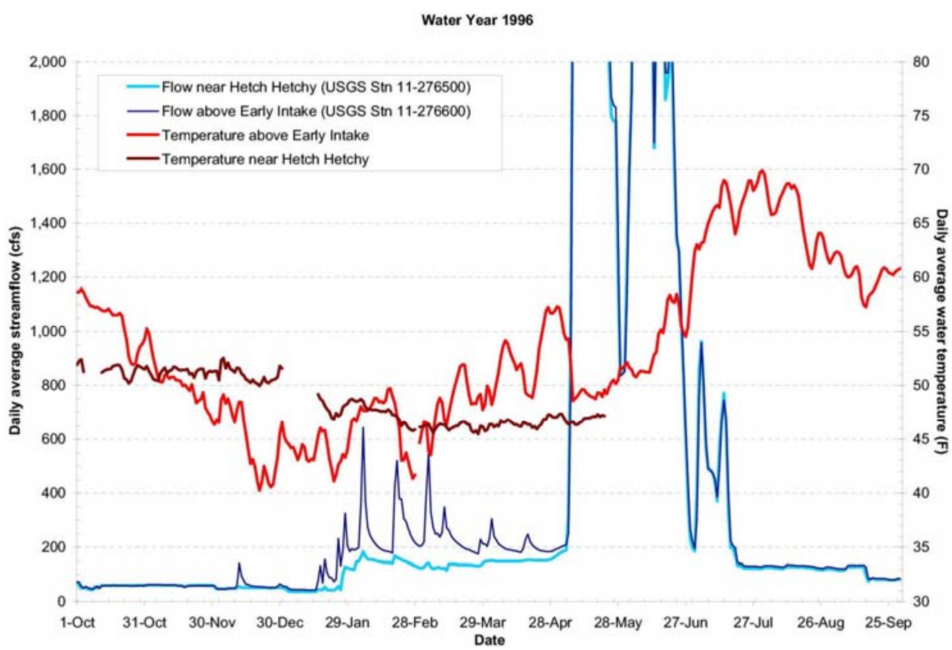

Water Year 1991
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Temperature above Early Intake
Temperature near Hetch Hetchy
Daily average streamflow (cfs)
Daily average water temperature (F)
Date
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
80
75
70
65
60
55
50
45
40
35
30
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep

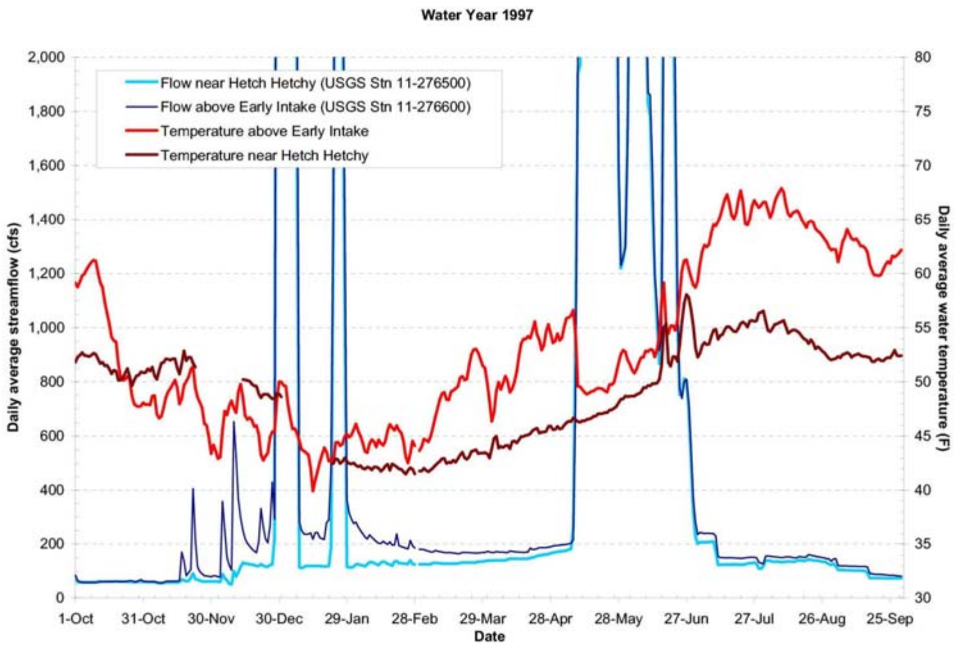

Water Year 1992
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Temperature above Early Intake
Temperature near Hetch Hetchy
Daily average streamflow (cfs)
Daily average water temperature (F)
Date
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
80
75
70
65
60
55
50
45
40
35
30
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep

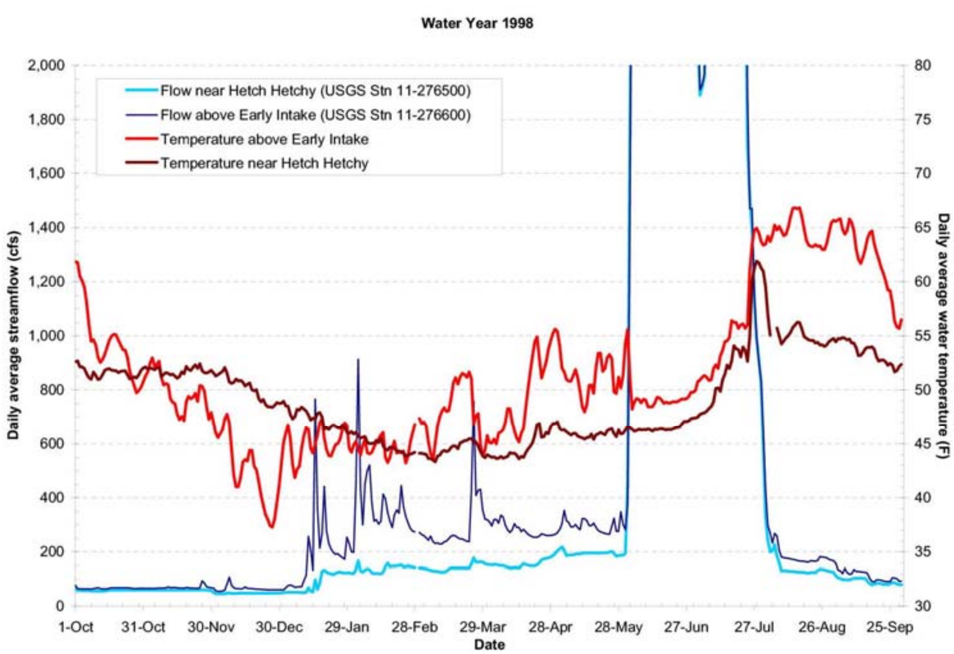

Water Year 1993
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Temperature above Early Intake
Temperature near Hetch Hetchy
Daily average streamflow (cfs)
Daily average water temperature (F)
Date
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
80
75
70
65
60
55
50
45
40
35
30
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep

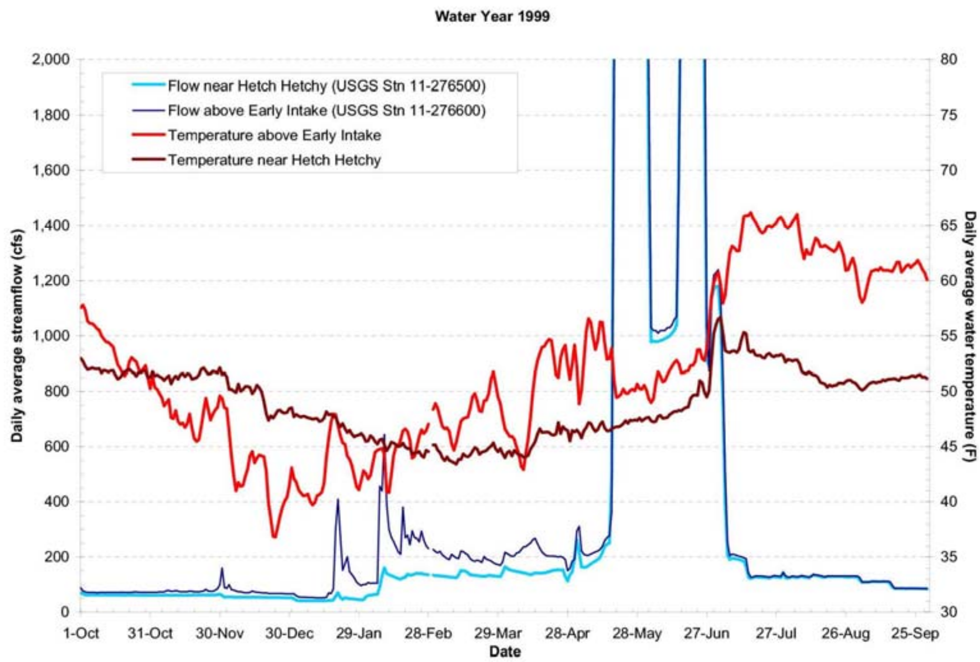

Water Year 1994
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Temperature above Early Intake
Temperature near Hetch Hetchy
Daily average streamflow (cfs)
Daily average water temperature (F)
Date
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
80
75
70
65
60
55
50
45
40
35
30
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep

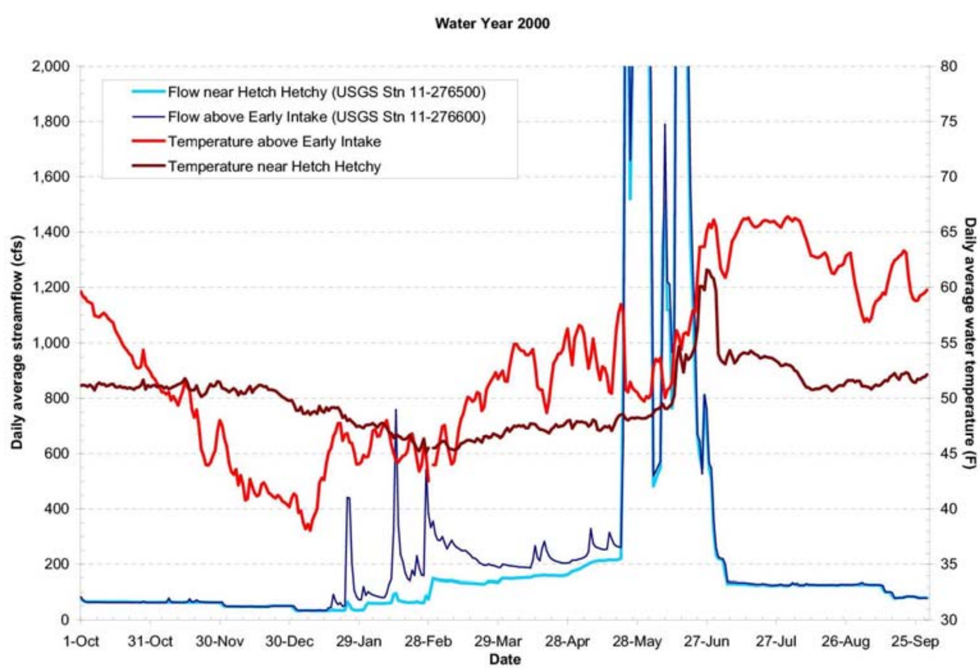

Water Year 1995
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Temperature above Early Intake
Temperature near Hetch Hetchy
Daily average streamflow (cfs)
Daily average water temperature (F)
Date
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep

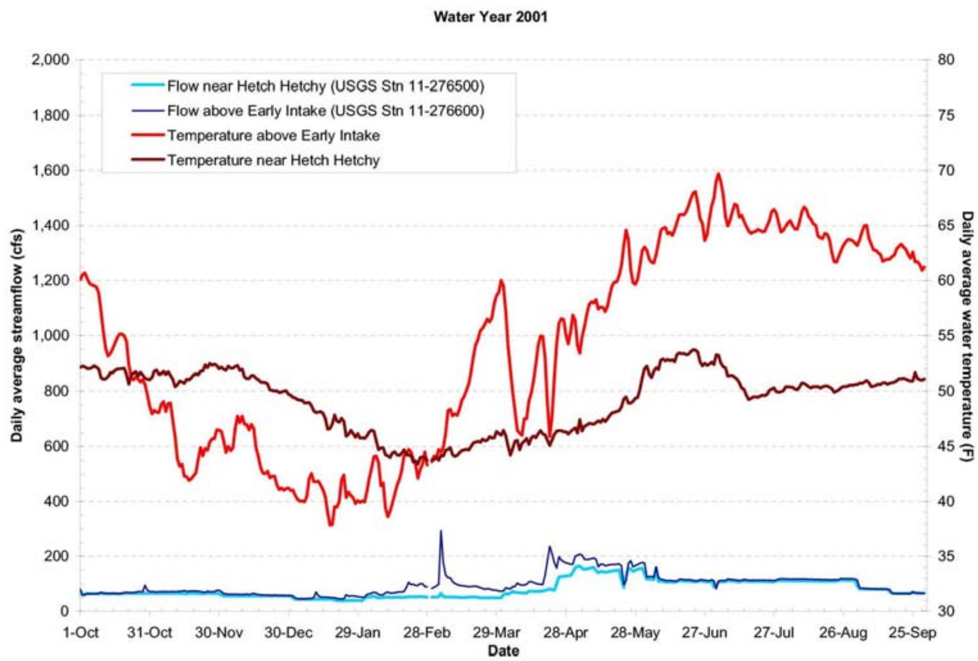

Water Year 1996
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Temperature above Early Intake
Temperature near Hetch Hetchy
Daily average streamflow (cfs)
Daily average water temperature (F)
Date
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep

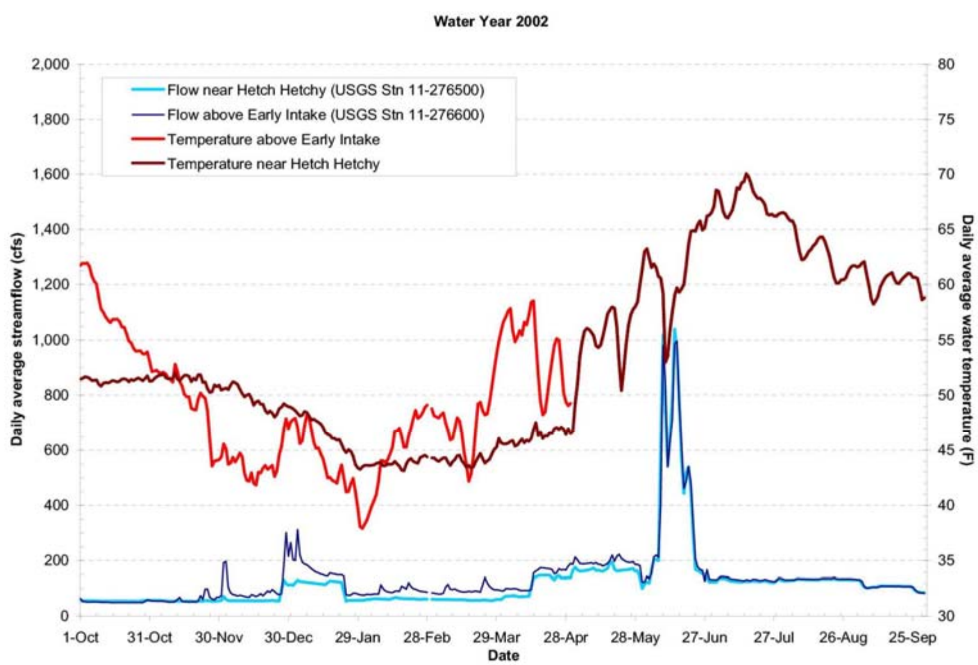

Water Year 1997
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Temperature above Early Intake
Temperature near Hetch Hetchy
Daily average streamflow (cfs)
Daily average water temperature (F)
Date
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep

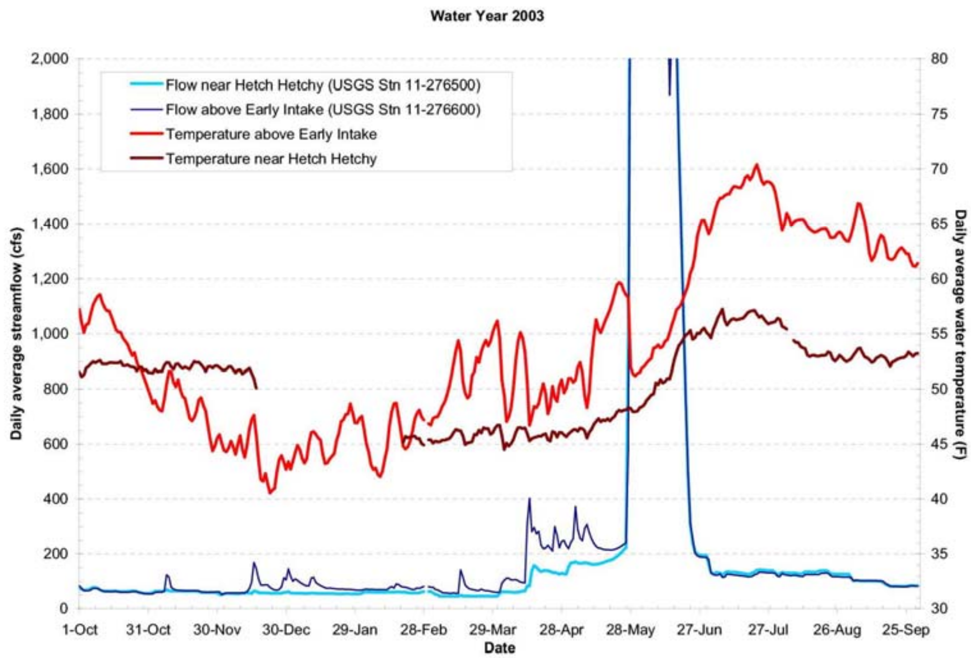

Water Year 1998
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Temperature above Early Intake
Temperature near Hetch Hetchy
Daily average streamflow (cfs)
Daily average water temperature (F)
Date
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep

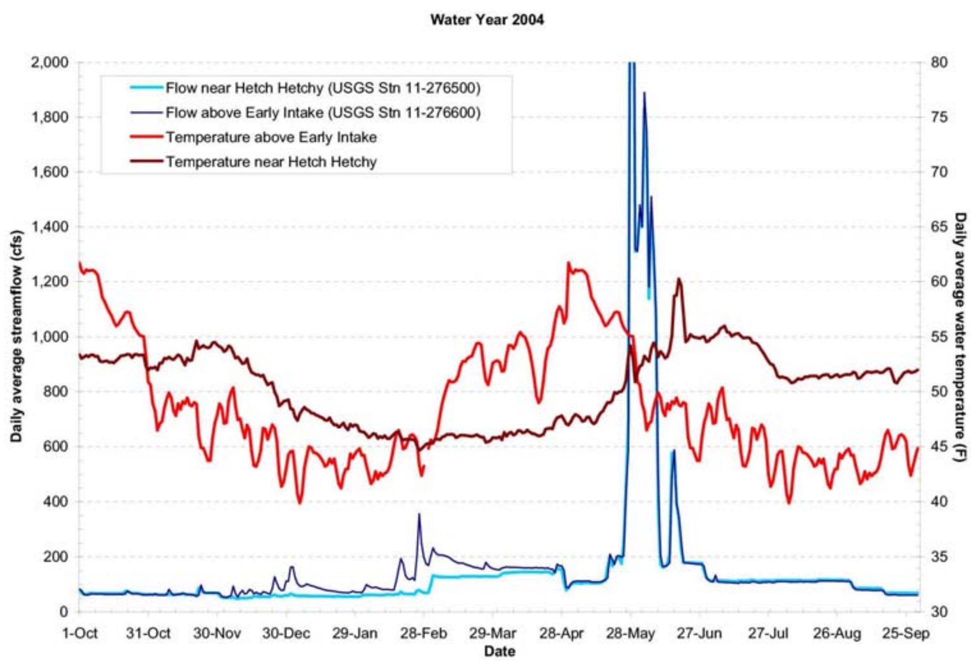

Water Year 1999
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Temperature above Early Intake
Temperature near Hetch Hetchy
Daily average streamflow (cfs)
Daily average water temperature (F)
Date
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep

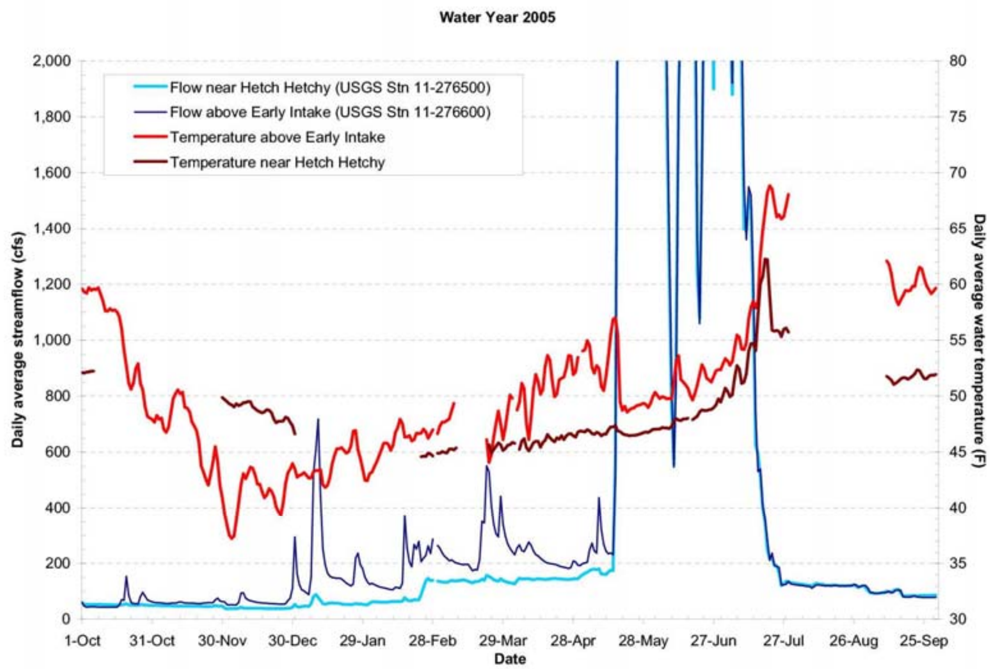

Water Year 2000
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Temperature above Early Intake
Temperature near Hetch Hetchy
Daily average streamflow (cfs)
Daily average water temperature (F)
Date
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep

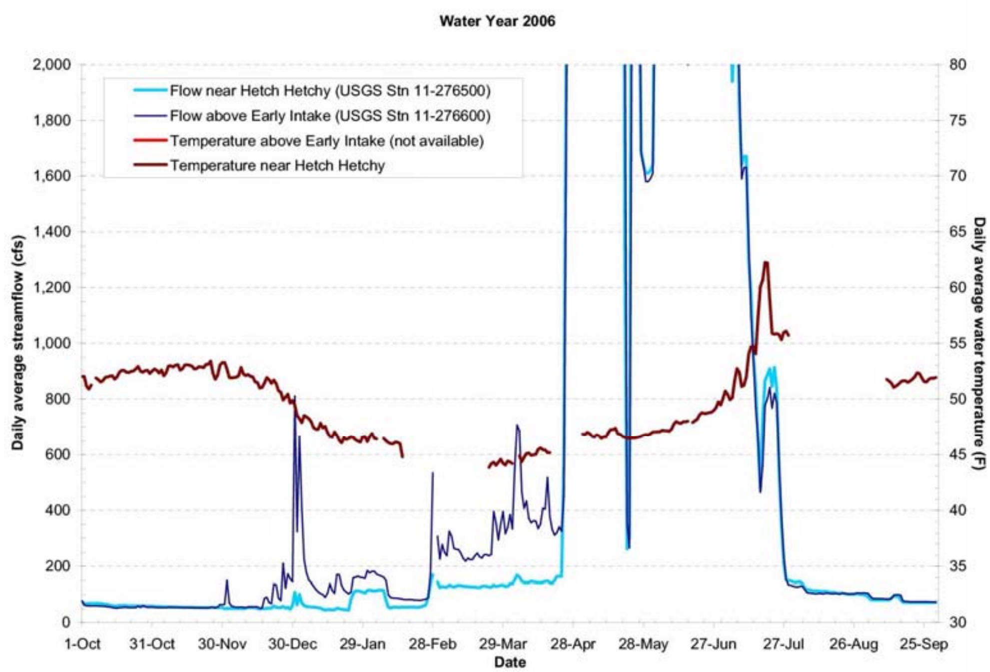

Water Year 2001
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Temperature above Early Intake
Temperature near Hetch Hetchy
Daily average streamflow (cfs)
Daily average water temperature (F)
Date
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
80
75
70
65
60
55
50
45
40
35
30
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep

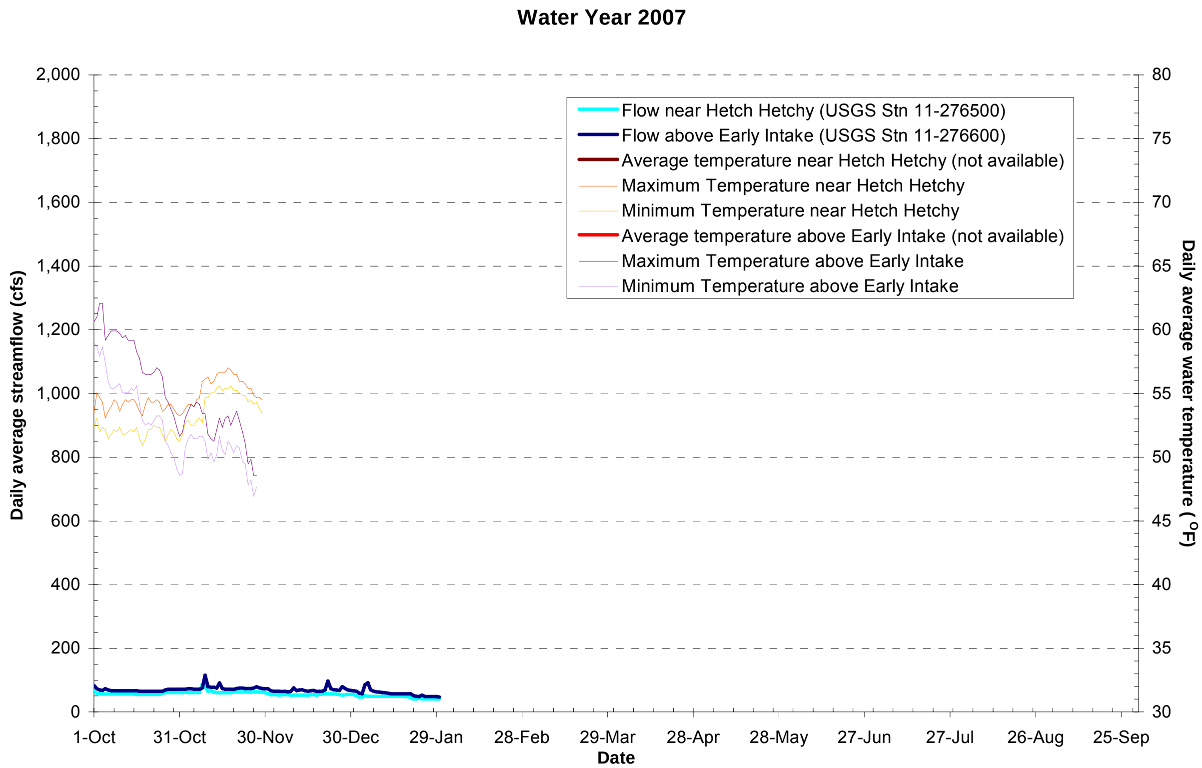

Water Year 2002
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Temperature above Early Intake
Temperature near Hetch Hetchy
Daily average streamflow (cfs)
Daily average water temperature (F)
Date
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
80
75
70
65
60
55
50
45
40
35
30
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep


Water Year 2003
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Temperature above Early Intake
Temperature near Hetch Hetchy
Daily average streamflow (cfs)
Daily average water temperature (F)
Date
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep

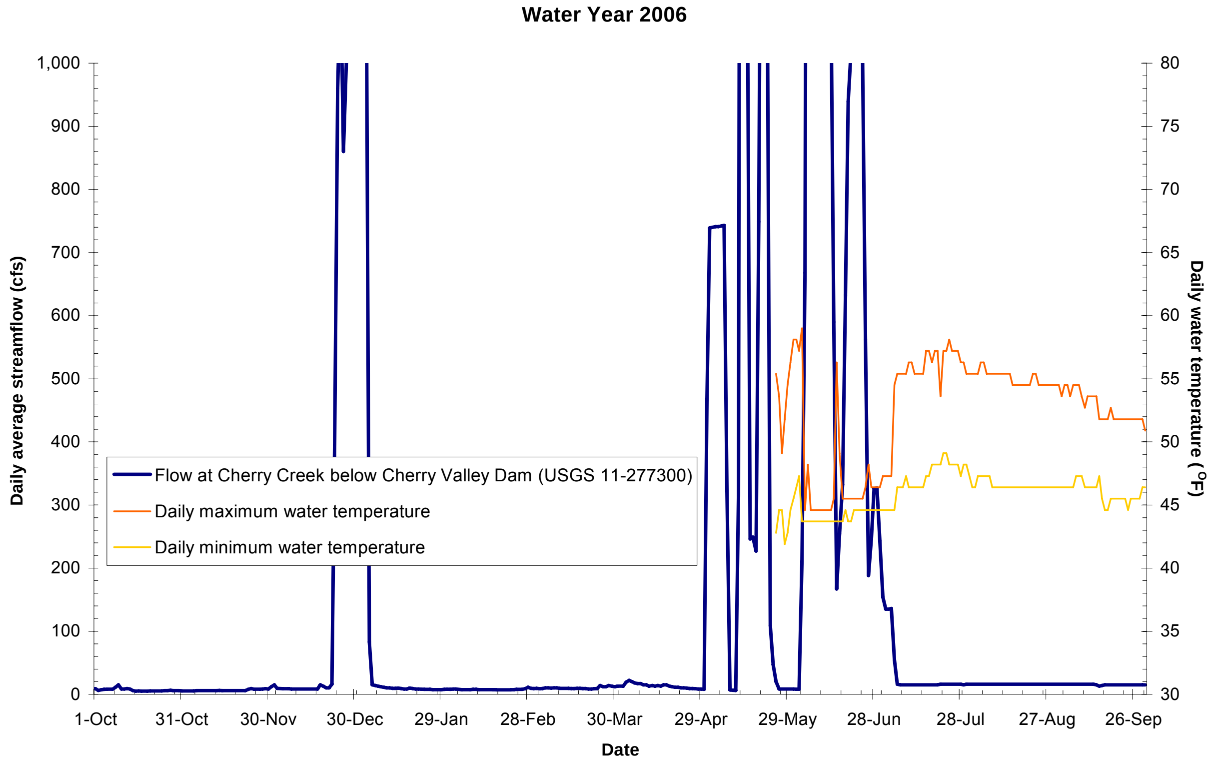

Water Year 2004
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Temperature above Early Intake
Temperature near Hetch Hetchy
Daily average streamflow (cfs)
Daily average water temperature (F)
Date
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep

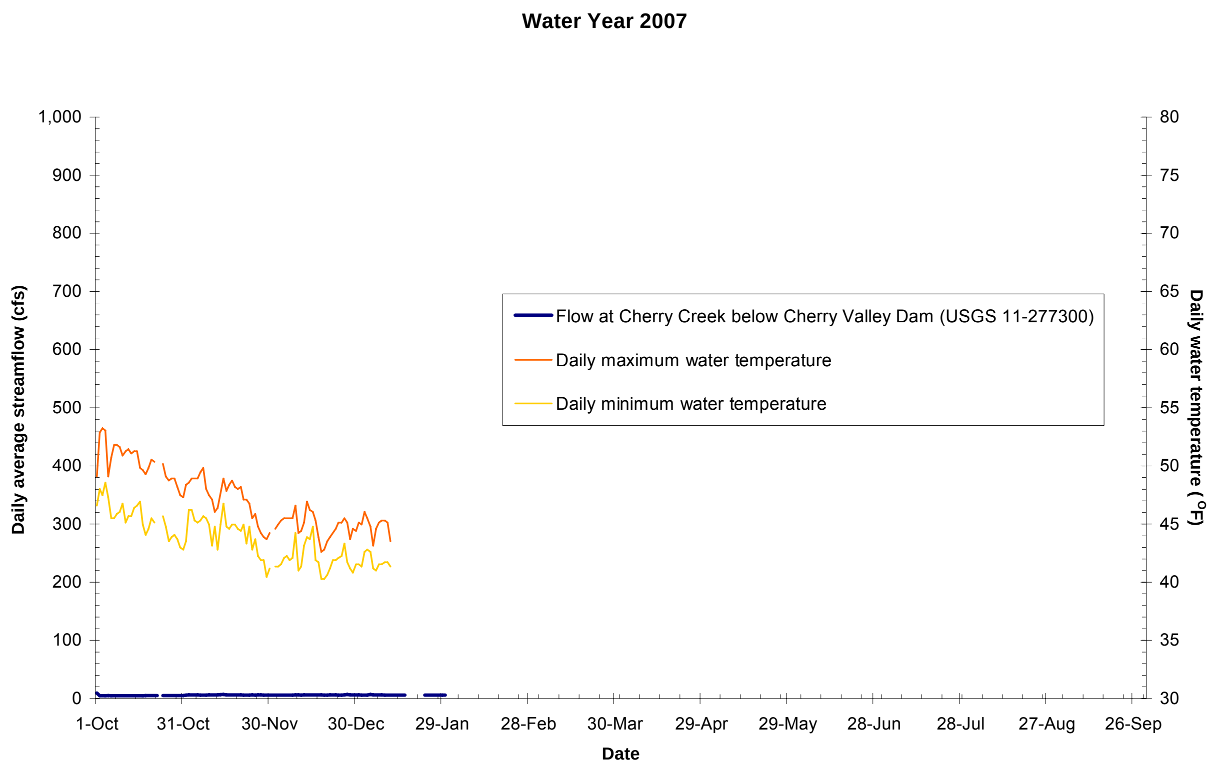

Water Year 2005
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Temperature above Early Intake
Temperature near Hetch Hetchy
Daily average streamflow (cfs)
Daily average water temperature (F)
Date
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
80
75
70
65
60
55
50
45
40
35
30
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep


Water Year 2006
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Temperature above Early Intake (not available)
Temperature near Hetch Hetchy
Daily average streamflow (cfs)
Daily average water temperature (F)
Date
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
80
75
70
65
60
55
50
45
40
35
30
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep

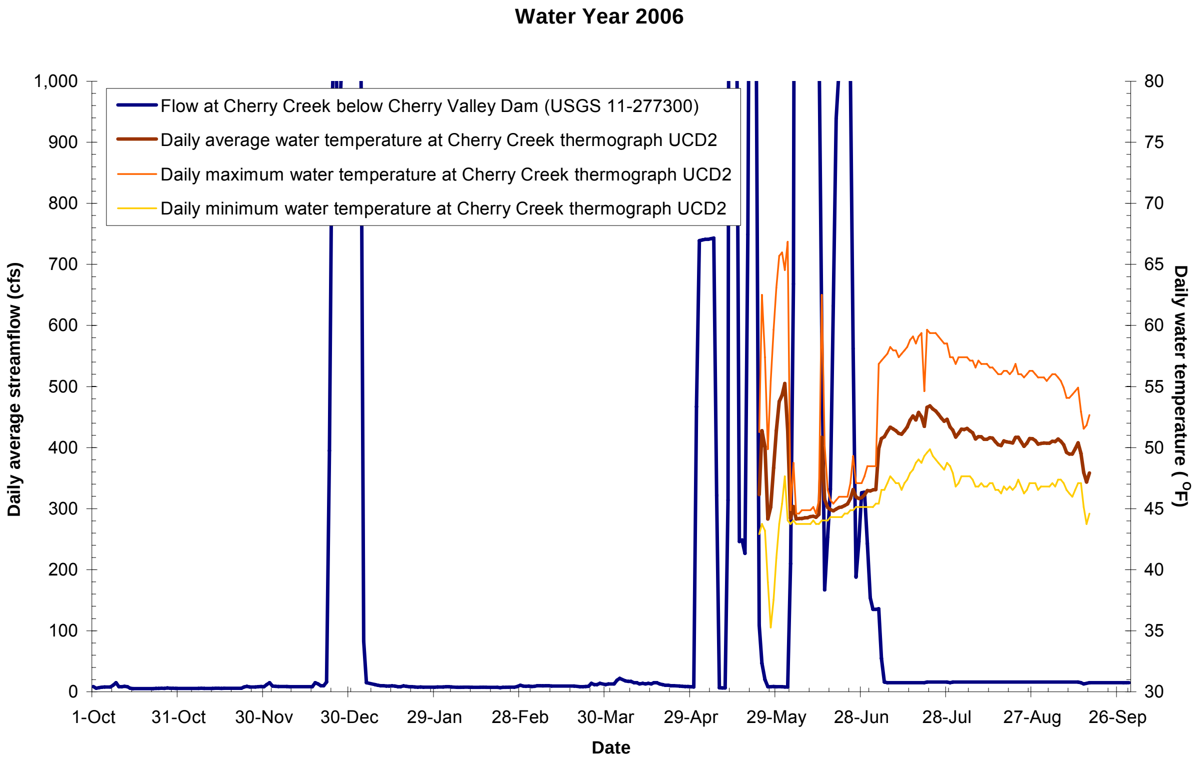

Water Year 2007
Flow near Hetch Hetchy (USGS Stn 11-276500)
Flow above Early Intake (USGS Stn 11-276600)
Average temperature near Hetch Hetchy (not available)
Maximum Temperature near Hetch Hetchy
Minimum Temperature near Hetch Hetchy
Average temperature above Early Intake (not available)
Maximum Temperature above Early Intake
Minimum Temperature above Early Intake
Daily average streamflow (cfs)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Daily average water temperature (°F)
80
75
70
65
60
55
50
45
40
35
30
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep
Date

Appendix F: Daily average streamflows and water temperatures for Cherry Creek below Valley Dam (USGS 11-277300) WY2006 – WY2007

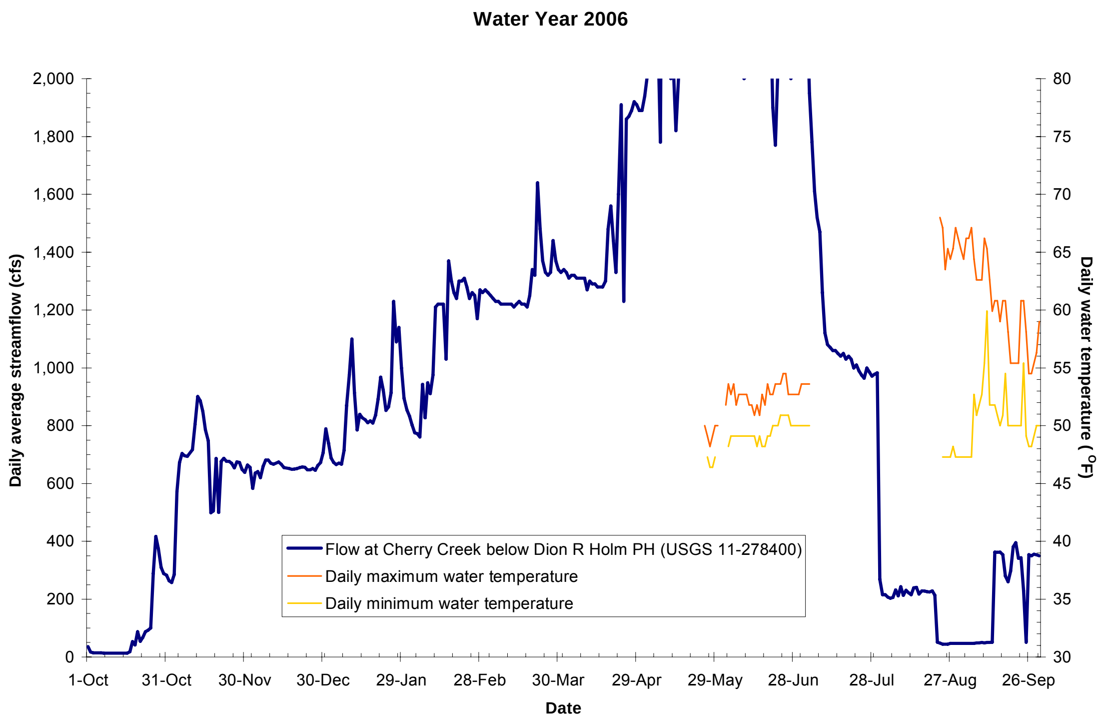

Water Year 2006
Daily average streamflow (cfs)
Daily water temperature (°F)
Date
1,000
900
800
700
600
500
400
300
200
100
0
80
75
70
65
60
55
50
45
40
35
30
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
28-Jun
28-Jul
27-Aug
26-Sep
Flow at Cherry Creek below Cherry Valley Dam (USGS 11-277300)
Daily maximum water temperature
Daily minimum water temperature

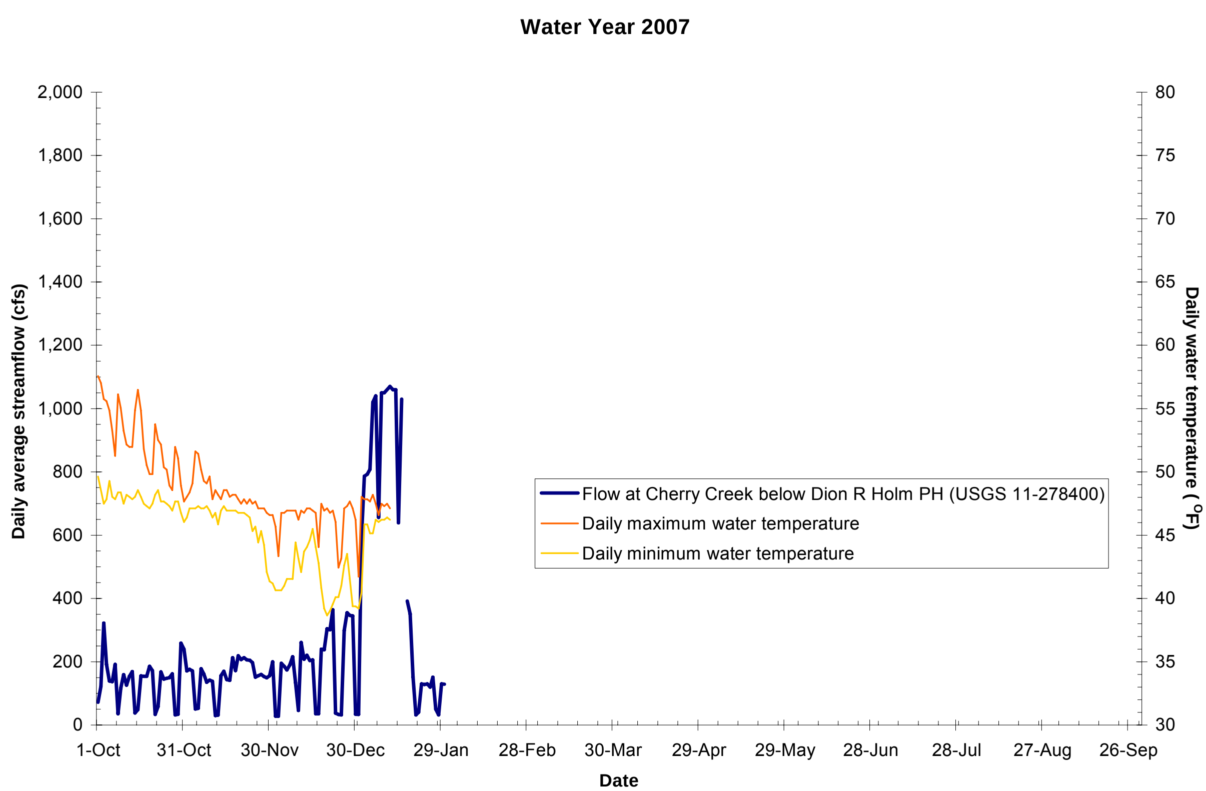

Water Year 2007
Daily average streamflow (cfs)
Daily water temperature (°F)
Date
1,000
900
800
700
600
500
400
300
200
100
0
80
75
70
65
60
55
50
45
40
35
30
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
28-Jun
28-Jul
27-Aug
26-Sep
Flow at Cherry Creek below Cherry Valley Dam (USGS 11-277300)
Daily maximum water temperature
Daily minimum water temperature

Appendix G: Daily average streamflows and water temperatures for Cherry Creek downstream of Cherry Valley Dam, McBain & Trush Thermograph UCD2, May-September 2006.

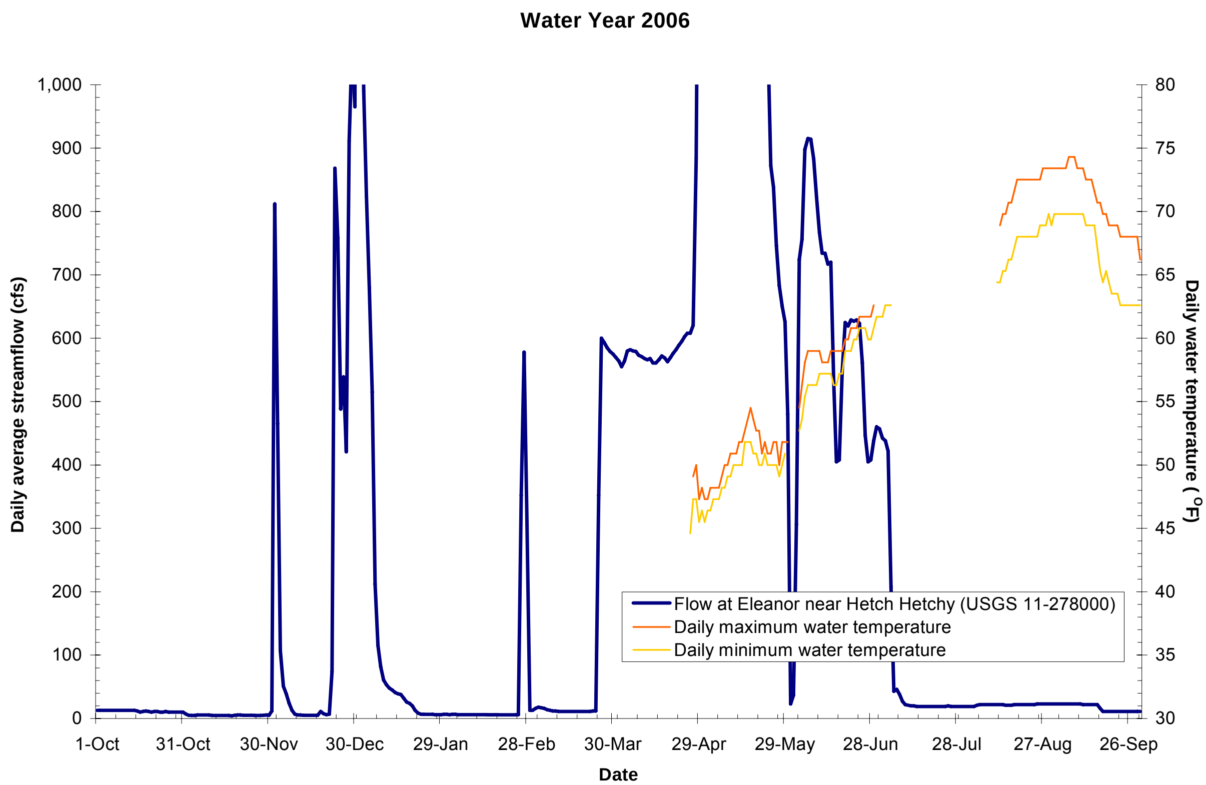

Water Year 2006
Flow at Cherry Creek below Cherry Valley Dam (USGS 11-277300)
Daily average water temperature at Cherry Creek thermograph UCD2
Daily maximum water temperature at Cherry Creek thermograph UCD2
Daily minimum water temperature at Cherry Creek thermograph UCD2
Daily average streamflow (cfs)
Daily water temperature (°F)
Date
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
28-Jun
28-Jul
27-Aug
26-Sep

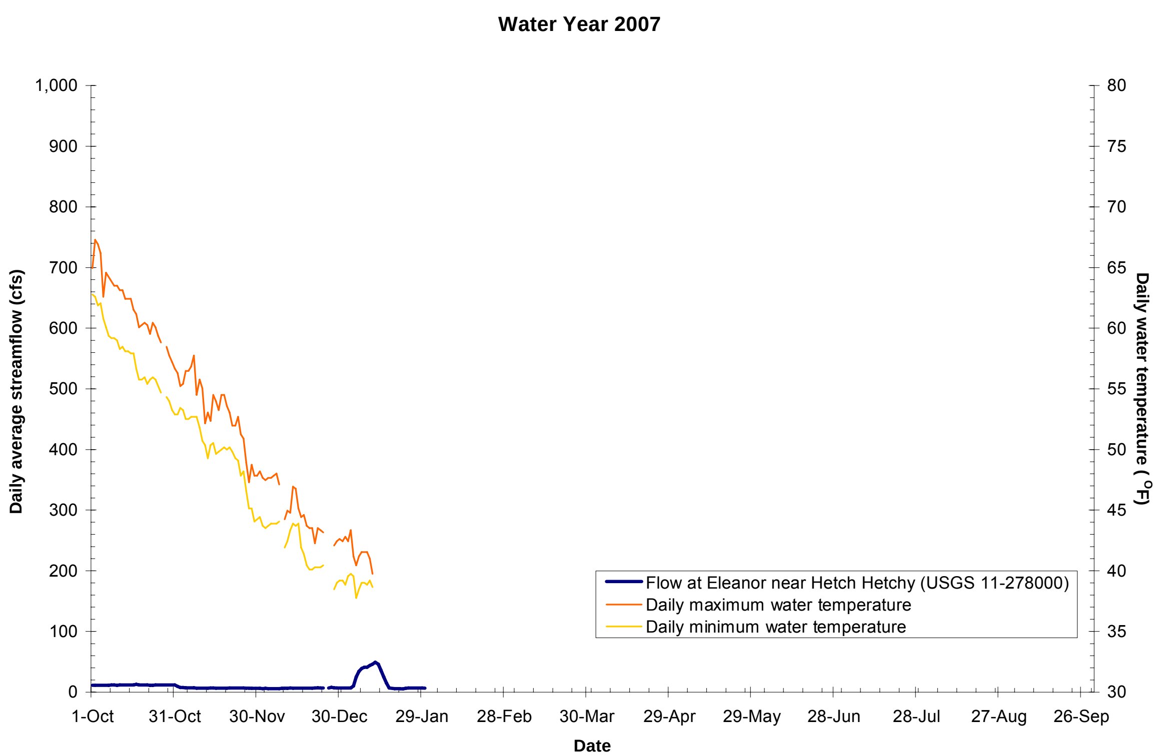
Appendix H: Daily average streamflows and water temperatures for Cherry Creek below Dion R Holm PH (USGS 11-278400) WY2006-WY2007.


Water Year 2006
Daily average streamflow (cfs)
Daily water temperature (°F)
Date
Flow at Cherry Creek below Dion R Holm PH (USGS 11-278400)
Daily maximum water temperature
Daily minimum water temperature
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
28-Jun
28-Jul
27-Aug
26-Sep

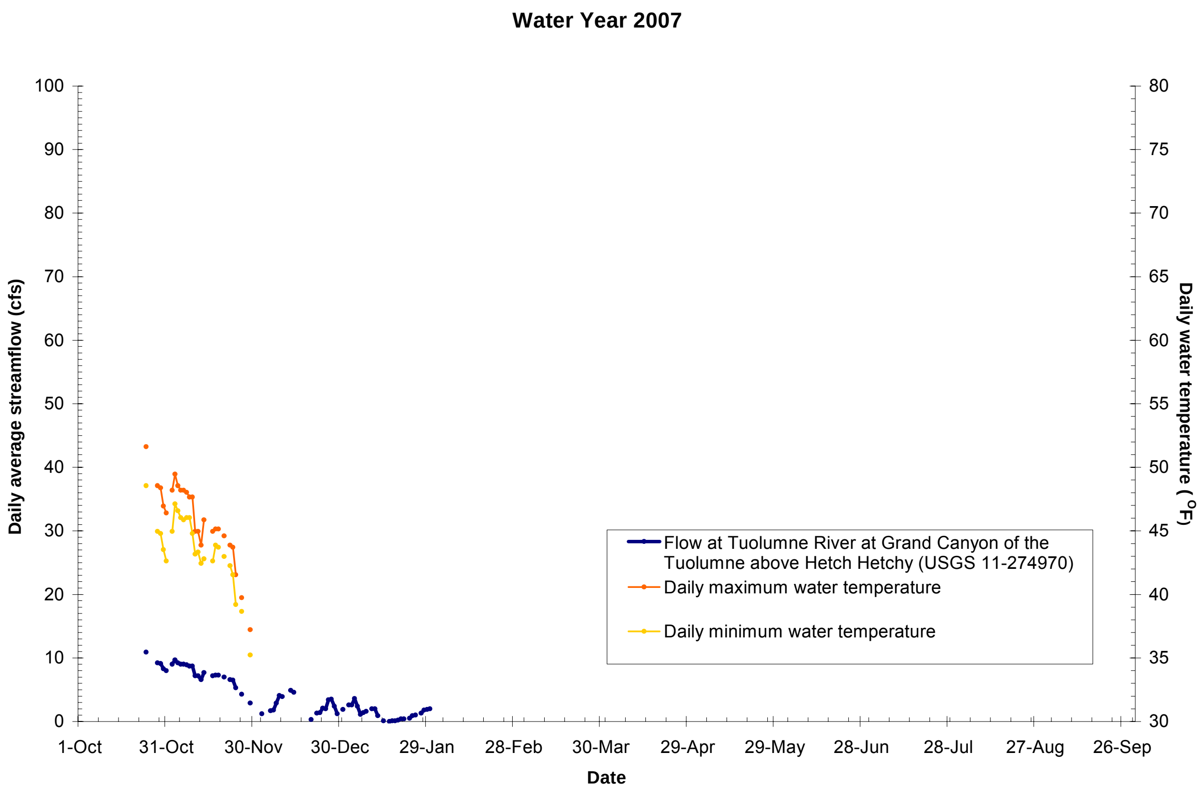

Water Year 2007
Daily average streamflow (cfs)
Daily water temperature (°F)
Date
Flow at Cherry Creek below Dion R Holm PH (USGS 11-278400)
Daily maximum water temperature
Daily minimum water temperature
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
28-Jun
28-Jul
27-Aug
26-Sep

Appendix I: Daily average streamflow and water temperatures for Eleanor Creek near Hetch Hetchy (USGS 11-278000) WY2006 – WY 2007.

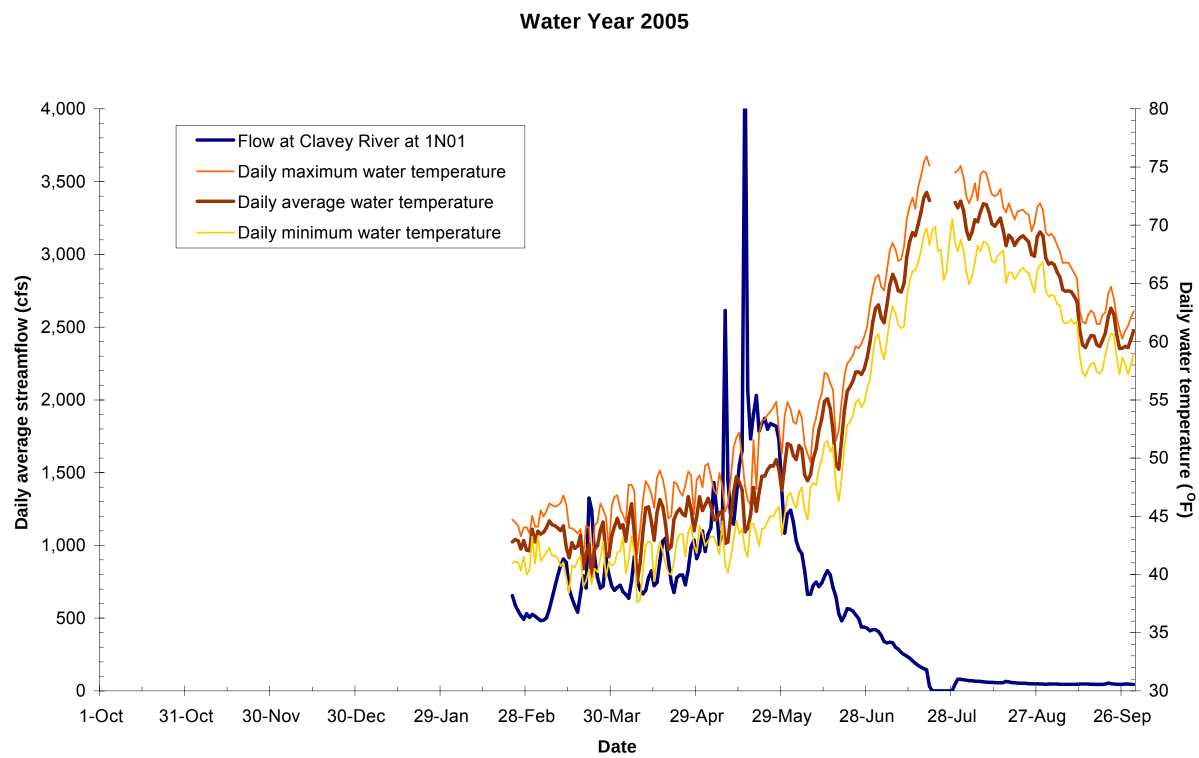

Water Year 2006
Daily average streamflow (cfs)
1,000
900
800
700
600
500
400
300
200
100
0
80
75
70
65
60
55
50
45
40
35
30
Daily water temperature (°F)
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
28-Jun
28-Jul
27-Aug
26-Sep
Date
Flow at Eleanor near Hetch Hetchy (USGS 11-278000)
Daily maximum water temperature
Daily minimum water temperature

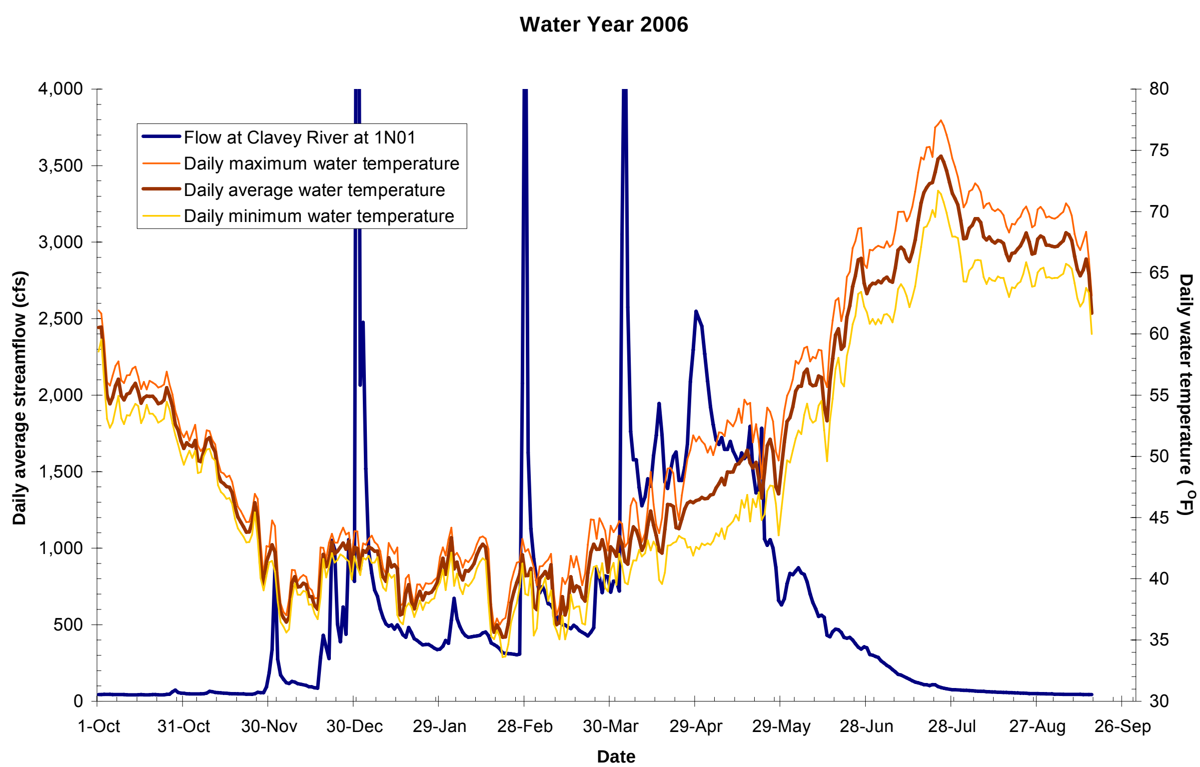

Water Year 2007
Daily average streamflow (cfs)
1,000
900
800
700
600
500
400
300
200
100
0
80
75
70
65
60
55
50
45
40
35
30
Daily water temperature (°F)
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
28-Jun
28-Jul
27-Aug
26-Sep
Date
Flow at Eleanor near Hetch Hetchy (USGS 11-278000)
Daily maximum water temperature
Daily minimum water temperature

Appendix J: Daily average streamflows and water temperatures for Tuolumne River at the Grand Canyon of the Tuolumne above Hetch Hetchy (USGS 11-274790) Oct. 24, 2006 – Jan. 11, 2007.


Water Year 2007
Daily average streamflow (cfs)
Daily water temperature (°F)
Date
100
90
80
70
60
50
40
30
20
10
0
80
75
70
65
60
55
50
45
40
35
30
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
28-Jun
28-Jul
27-Aug
26-Sep
Flow at Tuolumne River at Grand Canyon of the Tuolumne above Hetch Hetchy (USGS 11-274970)
Daily maximum water temperature
Daily minimum water temperature

Appendix K: Daily average streamflows and water temperatures for Clavey River at 1N01 Bridge (M&T gage) Feb. 23, 2005 – Sept. 15, 2006.


Water Year 2005
Flow at Clavey River at 1N01
Daily maximum water temperature
Daily average water temperature
Daily minimum water temperature
Daily average streamflow (cfs)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Daily water temperature (°F)
80
75
70
65
60
55
50
45
40
35
30
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
28-Jun
28-Jul
27-Aug
26-Sep
Date


Water Year 2006
Flow at Clavey River at 1N01
Daily maximum water temperature
Daily average water temperature
Daily minimum water temperature
Daily average streamflow (cfs)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Daily water temperature (°F)
80
75
70
65
60
55
50
45
40
35
30
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
28-Jun
28-Jul
27-Aug
26-Sep
Date

Appendix L: Hypotheses of Potential Project Effects on Geomorphic and Ecological Conditions in the Study Reaches.

Effect on Hydrograph Component	Reach						Hypothesized Effect on Geomorphic and Ecological Conditions		
	Hetchy	Upper Cherry	Lower Cherry	Eleanor	Holm	Lumsden	Geomorphic	Vegetation	Fish, Amphibians, and Invertebrates
Reduced winter peak flood magnitude	○	●	○	○	○	○	• reduc ed frequency and duration of sediment scour and re-deposition necessary to maintain channel morphology • w oody riparian encroachment increases the flow magnitude required to scour the channel bed	• ripari an vegetation encroachment onto formerly active depositional surfaces • reduced riparian habitat complexity	• reduced habitat area for species/life stages that require open bars and channel margins, such as foothill yellow-legged frog and salmonid fry • reduced cobble surface area suitable for macroinvertebrate production, and thus reduced food supply for native fish, bats, and other species • reduced habitat for riparian nesting bird species that occupy lower (sub-canopy) vegetation strata
	○	●	○	○	-- --		• sand deposition and accumulation in pools	N/A	• reduced habitat for adult rainbow trout, California roach, and Sacramento sucker
Reduced magnitude and duration of snowmelt flows	●	●	○	○	○	○	• reduc ed depth and duration of inundation of depositional surfaces (such as lateral bars) and side channels	• reduced area suitable for riparian seedling germination and initiation during spring seed release • encroachment of upland vegetation into the riparian corridor and onto formerly active bar surfaces	• reduced oviposition and tadpole rearing habitat for native amphibians that breed on cobble bars and in side channels • reduced fry early rearing habitat for trout, California roach, and Sacramento sucker • reduced macroinvertebrate

Effect on Hydrograph Component	Reach						Hypothesized Effect on Geomorphic and Ecological Conditions		
	Hetchy	Upper Cherry	Lower Cherry	Eleanor	Holm	Lumsden	Geomorphic	Vegetation	Fish, Amphibians, and Invertebrates
									production area
Earlier and increased rate of snowmelt recession	●	●	●	●	●	○	N/A	• if stage drop exceeds seedling root growth, seedlings die of desiccation	• stage drop could desiccate amphibian eggs and tadpoles incubating or rearing on bar surfaces, in side channels, and in isolated pools
Cold-water dam and powerhouse releases and changes in flow magnitude alter water temperature regimes	●	●	○	○	●	●	N/A N/A		• alteration of temperature regime to which native species are adapted, potentially affecting the breeding timing, embryo and larvae development rates, and survival • cooler or warmer water temperatures may shift fish distribution and alter habitat suitability
Reduced summer and winter baseflows	-- --	-- --			--	--	N/A	• lowering of shallow groundwater table elevation causes desiccation of mature riparian vegetation and (possibly in floodplains	• reduced habitat area (wetted channel) for native species • increased temperatures (depending on location

Effect on Hydrograph Component	Reach						Hypothesized Effect on Geomorphic and Ecological Conditions		
	Hetchy	Upper Cherry	Lower Cherry	Eleanor	Holm	Lumsden	Geomorphic	Vegetation	Fish, Amphibians, and Invertebrates
								and low terraces, leading to encroachment by conifers)	relative to cold-water releases from the dams and powerhouse) may reduce or improve habitat suitability for native trout.
Frequent (daily or weekly), rapid flow fluctuations during spring and summer	-- --	-- --			●	●	N/A	• reduced initiation and establishment of woody riparian vegetation.	• scour and/or desiccation of redds and egg clusters • reduced benthic macroinvertebrate biomass • reduced foodweb support
Infrequent rapid flow fluctuations during spring and summer	○	●	○	○	-- --		N/A	• reduced initiation and establishment of woody riparian vegetation.	• scour and/or desiccation of redds and egg clusters

Footnote:

● high probability and magnitude
○ moderate probability or magnitude
-- low or no probability or magnitude

Appendix M: Summary of Reach-Scale Study Plan Recommendations for Eleanor Creek to Evaluate Hypotheses of Project Induced/Influenced Negative Impacts and Provide Recommendations on Improved Operations to Reduce Negative Impacts.

Table M-1: Summary of Reach-Scale Study Plan Recommendations for Eleanor Creek to Evaluate Hypotheses of Project Induced/Influenced Negative Impacts and Provide Recommendations on Improved Operations to Reduce Negative Impacts.

Hypothesis	Recommendation	Timing
Spring, summer, and early fall baseflow releases may be warmer than under unregulated conditions.	• Temperature monitoring upstream of Lake Eleanor and at USGS gage immediately downstream of dam. Temperature profile monitoring in Lake Eleanor to document thermal stratification and relate to elevation of outlet works. • Compare observed water temperatures for 2006 and 2007 to known thermal criteria and life history timing for native fish and amphibian analysis species (see below).	Spring/summer 2007
	• Develop temperature model to the Cherry Creek confluence.	Spring/summer 2007
Lake Eleanor has caused large changes in the frequency of smaller floods and small changes in the frequency of large floods, yet has altered the spring snowmelt hydrograph. Net result has been small to no changes in channel geometry. Project has had no effect on coarse sediment supply.	• Reconnaissance level description of channel morphology to evaluate potential changes in channel geometry and sediment supply.	Summer/fall 2007
Lake Eleanor historically trapped a portion of large wood from upstream sources, and the dam further reduced large wood supply (although some still likely goes down the spillway).	• Evaluate how Hetch Hetchy Operations manage large wood supply in Lake Eleanor. If removed from the system, then evaluate change in large wood supply and storage in the downstream reach by comparing with reach upstream of Lake Eleanor (and any operations records if available)	Summer/fall 2008
The reduction in spring and summer flow magnitude downstream of Eleanor Dam (and resulting increase in water temperature) limits rainbow trout habitat. Trout abundance in Eleanor Creek, therefore, is lower than in Clavey River reference reaches but higher than in Cherry Creek.	• Snorkel surveys to inventory fish species presence/absence, abundance, and size class distribution. Pair with similar surveys on Clavey River at Cottonwood Bridge and 1NO1 Bridge for comparison. • Develop flow-habitat rating curves and habigraphs for native fish in representative and/or important reaches.	Spring/summer 2007
Lower spring and early summer flows and warmer water temperatures favor California roach over rainbow trout. Roach occur farther upstream (i.e., at higher elevations) in Cherry Creek than in Clavey River reference reaches.		

Hypothesis	Recommendation	Timing
Lower spring and summer flows and rapid changes in flow stage during late spring and early summer reduces suitable habitat for foothill yellow-legged frog. Foothill yellow-legged frogs are less abundant in Eleanor Creek than in Clavey River reference reaches at similar elevations but are more abundant than in Cherry Creek.	• Snorkel surveys to inventory amphibian species presence/absence, abundance, and size class distribution. Pair with similar surveys on Clavey River at Cottonwood Bridge and 1NO1 Bridge for comparison. • Develop flow-habitat rating curves and habigraphs for foothill yellow-legged frog representative and/or important reaches.	Spring/summer 2007
Invertebrate biomass and species diversity are lower in upper Eleanor Creek than lower Eleanor Creek.	• Benthic macroinvertebrate surveys immediately below dam and just upstream of confluence with Cherry Creek. • Develop flow-habitat rating curves and habigraphs for macroinvertebrates in representative and/or important reaches.	Summer/fall 2007
Operation of Lake Eleanor has modestly altered the spring snowmelt hydrograph, yet changes in riparian and conifer vegetation dynamics are small.	• Conduct riparian assessment similar to that proposed for Cherry Creek but less intensive.	Summer/fall 2007

Table M-2: Summary of Reach-Scale Study Plan Recommendations for Cherry Creek to Evaluate Hypotheses of Project Induced/Influenced Negative Impacts and Provide Recommendations on Improved Operations to Reduce Negative Impacts.

Hypothesis	Reach[1]			Recommendation
	Upper Cherry	Lower Cherry	Below Holm	
Releases from the hypolimnion of Cherry Lake cause colder water temperatures immediately downstream of the dam but warmer water temperatures downstream during spring, summer, and early fall due to lower flow volumes. Temperatures near the dam will affect benthic macroinvertebrate production and trout growth rates. Note: that we are waiting for 2006 data that could be applied to some of this.	H	H		• Install temperature monitors above Cherry Lake (at USGS gage) and continue temperature monitoring at USGS gages in the Upper Cherry and Lower Cherry reaches. Install a temperature monitor on Clavey River at 1N04 (Cottonwood Road) bridge and maintain monitoring on the Clavey River at the 1NO1 bridge as a reference condition. Evaluate if current flow releases are causing problems in lower Cherry Creek down to Holm Powerhouse – if yes, then need to do a temperature model to evaluate if altered operations can improve conditions.
	H	H	H	• Develop temperature model for Cherry Creek from Cherry Valley Dam to the Tuolumne River confluence.
				• Compare observed water temperatures for 2006 and 2007 to known thermal criteria and life history timing for native fish and amphibian species (see below).
Daily flow fluctuations from Holm Powerhouse cause large-scale temperature fluctuations, possibly impacting native fish, amphibian, and/or benthic macroinvertebrate habitat quantity and quality.			H	• Continue temperature monitoring upstream and downstream of Holm Powerhouse at lower USGS gages.
Cherry Lake traps all coarse and fine sediment from upstream sources. The coarse and fine sediment budgets, however, are not in deficit (e.g., not sediment starved for post-dam flow regime) due to reduced high flow regime.	H	M	M	• Develop sediment supply and storage model immediately downstream of Cherry Lake Dam. Reconnaissance-level initially (economical sediment transport capacity computations initially), then revisit if more rigorous analysis is needed.
Riparian encroachment and changed sediment supply have reduced the area and volume of active depositional features, increased channel confinement, and simplified channel cross section and planform morphology.	H			• Identify and quantify (where feasible) changes in channel morphology at index reaches where adequate historical data and/or photographs are available (such as at USGS gaging station cableways).

Hypothesis	Reach[1]: Upper Cherry	Reach[1]: Lower Cherry	Reach[1]: Below Holm	Recommendation
Cherry Lake flood management has reduced the frequency of exceeding geomorphic thresholds.	H M		M	• Identify geomorphic thresholds in index reaches that represent the variety of depositional features observed in the study reach. Conduct bed mobility experiments and analyses (e.g., Barta 2000) to observe and predict gravel pocket thresholds at different flood magnitudes.
Cherry Valley Dam traps all large wood from upstream sources, reducing large wood supply and associated fish habitat benefits immediately downstream.	H H			• Document how Hetch Hetchy Operations manage large wood supply in Cherry Lake. If large wood is removed from the system, then evaluate changes in large wood supply and storage in downstream reach by comparing with reach upstream of Cherry Lake (and available operations records)
The reduction in spring and summer flow magnitude downstream of Cherry Valley Dam (and resulting increase in water temperature) limits rainbow trout habitat. Trout abundance in Cherry Creek, therefore, would be lower than in Clavey River reference reaches.	H H		H	• Snorkel surveys to inventory fish species presence/absence, abundance, and size class distribution. Pair with similar surveys on Clavey River at Cottonwood Bridge and 1NO1 Bridge for comparison. • Develop flow-habitat rating curves and annual habigraphs for native fish in representative and/or important reaches.
Reduced flows and increased water temperatures favor California roach over rainbow trout. Roach occur farther upstream (i.e., at higher elevations) in Cherry Creek than in Clavey River reference reaches.	M M			
Colder water temperatures near the dam, rapid spring/summer changes in flow stage, loss of active depositional surfaces, and limited inundation of depositional surfaces during late spring and early summer reduces the area of suitable reproductive habitat for foothill yellow-legged frog. Foothill yellow-legged frogs are less abundant in Cherry Creek than in Clavey River reference reaches at similar elevations.	H H			• Snorkel surveys to inventory amphibian species presence/absence, abundance, and size class distribution. Pair with similar surveys on Clavey River at Cottonwood Bridge and 1NO1 Bridge for comparison. • Develop flow-habitat rating curves and annual habigraphs for foothill yellow-legged frog representative and/or important reaches.

Hypothesis	Reach[1] Upper Cherry	Lower Cherry	Below Holm	Recommendation
Benthic macroinvertebrate habitat quantity and quality is lower in upper Cherry Creek than lower Cherry Creek. Daily flow fluctuations and cold water releases from Holm Powerhouse reduce invertebrate biomass and species diversity. Differences in fish abundance and size are related to benthic macroinvertebrate productivity.	H H		H	• Benthic macroinvertebrate surveys immediately below dam, just upstream of Holm Powerhouse, and just upstream of confluence with Tuolumne River. Correlate with fish surveys. Pair with similar surveys on Clavey River at Cottonwood Bridge and 1NO1 Bridge for comparison. • Develop flow-habitat rating curves and annual habigraphs for trout, amphibians, and benthic macroinvertebrates in representative and/or important reaches
Cherry Lake flood management and alteration of the spring snowmelt hydrograph have allowed riparian and conifer encroachment into the low flow channel, causing changes in channel geometry.	H M		M	• Identify lower gradient less confined reaches from air photos. In these key reaches, quantify riparian vegetation extent, species composition, and location relative to flow stage. Conduct comparable surveys on the Clavey River at Cottonwood Bridge and 1NO1 Bridge for comparison.

Notes:
1 - H = high priority
M = medium priority
Blank = low priority or not applicable

Table M-3: Summary of Reach-Scale Study Plan Recommendations for the Hetchy Reach of the Tuolumne River to Evaluate Hypotheses of Project Induced/Influenced Negative Impacts and Provide Recommendations on Improved Operations to Reduce Negative Impacts.

Hypothesis	Recommendation	Timing
Hypolimnial releases result in colder-than-natural water temperatures near O'Shaughnessy Dam during spring, summer, and early fall.	• Continue temperature monitoring at USGS gages above Hetch Hetchy, below Hetch Hetchy, above Early Intake, and below Early Intake.	Summer/fall 2007
While hypolimnial releases are colder than pre-dam water temperatures, the lower summer baseflows cause higher than natural temperatures from O'Shaughnessy Dam to the Cherry Creek confluence during spring, summer, and early fall.	• Compare observed water temperatures for 2006 and 2007 to known thermal criteria and life history timing for native fish, benthic macroinvertebrates, and amphibian analysis species (see below). • Temperature model from Hetch Hetchy to Early Intake (may also need temperature model for Hetch Hetchy Reservoir). Assess benefit of riparian encroachment (if any), as well as effect of project on downstream temperatures.	Summer 2006-2008
O'Shaughnessy Dam has trapped all sediment from upstream sources, causing bed armoring and reduction in dynamics immediately downstream. In addition, flood management (reduction) has reduced sediment transport capacity, which has likely changed sediment budget in the Poopenaut Valley	• Develop sediment supply and storage story immediately downstream of O'Shaughnessy Dam to evaluate how the dam has changed coarse sediment budget. Was Poopenaut Valley originally gravel bedded, was Hetch Hetchy Valley naturally a cobble trap prior to the dam? Should spend some time in Yosemite Valley to look at this. Need to compare longitudinal profile before doing this to ensure reasonable comparability. Conduct bed mobility analyses (e.g., Barta 2000) to predict gravel pocket thresholds.	Summer/fall 2007
Riparian encroachment and changed sediment supply have reduced the area and volume of active depositional features, increased channel confinement, and simplified channel cross section and planform morphology.	• Use index monitoring reaches, USGS gaging station cableways, and historic photos to estimate channel morphology changes.	Summer/fall 2007
O'Shaughnessy Dam has trapped all large wood from upstream sources, reducing large wood supply and associated fish habitat benefits immediately downstream.	• Evaluate how Hetch Hetchy operations manage large wood supply in Hetch Hetchy Reservoir. If removed from the system, then evaluate change in large wood supply and storage in the downstream reach by comparing with reach upstream of Hetch Hetchy (and any operations records if available). Large wood supply would be most important for fish habitat in the reach between O'Shaughnessy Dam and Preston Falls, then moderately important farther downstream.	Summer/fall 2008

Hypothesis	Recommendation	Timing
Cold water temperatures immediately downstream of the dam limit rainbow trout growth rates and limit benthic macroinvertebrate productivity. Warmer water temperatures in the downstream portion of the reach favor brown trout over rainbow trout. Except in dry years, daily water temperatures remain suitable (<70°F) for adult rainbow trout throughout the spring summer and fall. In dry years, water temperatures may exceed optimal ranges for adult rainbow trout. California roach and Sacramento sucker do not occur upstream of Preston Falls due to the migration barrier posed by the falls and cold water temperatures upstream of the falls. Colder water temperature near the dam, rapid spring/summer changes in flow stage, loss of active depositional surfaces, and limited inundation of depositional surfaces during late spring and early summer reduces suitable reproductive habitat for foothill yellow-legged frog. Foothill yellow-legged frogs are less abundant in the Hetchy Reach than in Clavey River reference reaches at similar elevations, but more abundant than in Cherry Creek.	• Snorkel surveys to inventory fish and amphibian species presence/absence, abundance, and size class distribution. Pair with similar surveys on Clavey River at Cottonwood Bridge and 1NO1 Bridge for comparison. • Compare observed water temperatures for 2006 and 2007 to known thermal criteria and life history timing for native fish and amphibian species. • Develop flow-habitat rating curves and annual habigraphs for trout and amphibians in representative and/or important reaches.	Spring/summer 2007
Benthic macroinvertebrate abundance and species diversity are lower in upper Tuolumne River than downstream reaches of the Tuolumne River.	• Invertebrate surveys immediately below Poopenaut Valley and just upstream of confluence with Cherry Creek to compare longitudinal differences. Conduct comparable survey on the Clavey River at Cottonwood Bridge and 1NO1 Bridge for comparison.	Summer/fall 2007
Post-dam summer baseflows provide less/more habitat than pre-dam summer baseflows (needs to also incorporate temperature into "habitat").	• Develop flow-habitat rating curves and annual habigraphs for trout, amphibians, benthic macroinvertebrates in representative and/or important reaches to evaluate summer baseflow releases, need to integrate with water temperature models.	Summer/fall 2007

Hypothesis	Recommendation	Timing
O'Shaughnessy Dam flood management and alteration of winter floods and the spring snowmelt hydrograph have allowed both riparian and conifer encroachment into the low flow channel and floodplain, causing changes in channel geometry.	• Evaluate effects of flow regulation on riparian vegetation. First identify important reaches from air photos (wide spots like Poopenaut Valley), then quantify what is there with transects rather than planform maps. Also survey transects and do increment borings to determine plant age in the typical reaches to describe riparian vegetation (and changes) in these more typical reaches. Also go above Hetch Hetchy to evaluate comparable upstream-downstream reaches. Conduct comparable riparian transects on the Clavey River at Cottonwood Bridge and 1NO1 Bridge for comparison.	Summer/fall 2007
O'Shaughnessy Dam flood management and reduction of summer baseflows in 1967 have allowed both riparian and conifer encroachment to the low flow channel, causing changes in channel geometry.	• Conduct historical channel analysis to evaluate lateral channel dynamics by analyzing historical ground and air photos.	Winter 2007

Table M-4: Summary of Reach-Scale Study Plan Recommendations for the Lumsden Reach of the Tuolumne River to Evaluate Hypotheses of Project Induced/Influenced Negative Impacts and Provide Recommendations on Improved Operations to Reduce Negative Impacts.

Hypothesis	Recommendation	Timing
Summer water temperatures, on average, are lower now than prior to the Hetch Hetchy project due to hypolimnial releases from Holm Powerhouse. However, daily temperature fluctuations are wider and reversed due to the timing of daily flow fluctuations from Holm Powerhouse.	• Install temperature monitors below the Cherry Creek confluence, Lumsden Bridge above SF Tuolumne, Lumsden Bridge below SF Tuolumne, and upstream of New Don Pedro Reservoir backwater to evaluate the temperature effect, if any, of daily flow fluctuations on key species. • Compare observed water temperatures for 2006 and 2007 to known thermal criteria and life history timing for native fish and amphibian species (see below).	Spring 2007
Flow fluctuations from Holm Powerhouse reduce fine sediment (sand and small gravels) storage in the main channel.	• Evaluate effect of flow fluctuations on fine sediment storage (sand and small gravels) downstream of Cherry Creek confluence by assessing if the amplitude of flow fluctuations is sufficient to transport these fine sediments.	Summer/fall 2007
Flow and temperature fluctuations caused by daily flow fluctuations from Holm Powerhouse reduce reproduction and survival of native fish and amphibians via: (1) egg scour, (2) egg/larvae desiccation, (3) reduced food production, and (4) thermal shock.	• Establish cross sections in key habitats (depositional features) and quantify change/rate of change in flow stage, water temperature, and habitat suitability at each cross section during flow fluctuations to evaluate the stage/inundation effect, if any, of daily flow fluctuations on key species.	Summer/fall 2007
Benthic macroinvertebrate habitat quality and quantity is higher upstream than downstream. Historically, this may have been reversed.	• Invertebrate surveys immediately below Cherry Creek confluence and at Lumsden Bridge. Conduct comparable survey on the Clavey River at Cottonwood Bridge and 1NO1 Bridge for comparison.	Summer/fall 2007

Hypothesis	Recommendation	Timing
O'Shaughnessy Dam flood management and alteration of winter floods and the spring snowmelt hydrograph have allowed riparian and conifer encroachment into the low flow channel. The degree of encroachment is much smaller here due to tributary accretion.	• Evaluate effects of flow regulation on riparian vegetation and upland vegetation. First identify important reaches from air photos (wide spots), then quantify what is there with transects rather than planform maps. Also do a few transects and increment borings (to determine plant age) in the typical reaches to describe riparian vegetation (and changes) in these more typical reaches. May also want to look at the lower Merced River above New Exchequer Reservoir	Summer/fall 2007
Riparian encroachment caused by high flow regulation at O'Shaughnessy Dam, Eleanor Dam, and Cherry Valley Dam has caused minor changes in channel geometry.	• Document change in channel morphology, if any, in Lumsden Reach. Conduct simple cross section based analysis to evaluate how change in operations has changed channel geometry, and relate riparian vegetation and geomorphic surfaces to pre-and post-dam flow regime	Summer 2007