Yosemite National Park

Division of Resources
Management and Science

# Looking Downstream:

## Ecological Responses to an Altered Hydrologic Regime Downstream of Hetch Hetchy Reservoir, Yosemite National Park

2007

April 10, 2009

By Greg Stock, Ph.D., James Roche, Monica Buhler, Sarah Stock, Denise Della-Santina, and Laura Clor: National Park Service, Division of Resources Management and Science, Yosemite National Park

Jeff Holmquist, Ph.D., and Jutta Schmidt-Gengenbach: University of California White Mountain Research Station.

## TABLE OF CONTENTS

## APPENDICES



## LIST OF TABLES

**LIST OF FIGURES**

## Summary

The Looking Downstream project is an interdisciplinary study designed to collect baseline information on, and assess the overall condition of, the mainstem Tuolumne River corridor between O'Shaughnessy Dam and the Yosemite National Park boundary. The project consists of hydrology, vegetation, bird, and benthic macroinvertebrate study components. An overarching goal of the Looking Downstream project is to provide information that water managers can use to manage environmental water releases in a way that will more closely replicate natural physical processes and benefit dependent ecosystems downstream of the dam. This interim report details findings from the 2007 field season.

Poopenaut Valley represents the most ecologically diverse area between O'Shaughnessy Dam and the National Park boundary, and is likely the most sensitive area to changes associated with an altered hydrologic regime; we therefore focused our research on this area. Poopenaut Valley is a broad, low-gradient valley with extensive floodplain areas, alluvial terraces, sand bars, riparian vegetation, wetlands, and extensive wet and upland meadows. An unusual seasonal pond, separated from the river by a natural levee, is potentially important habitat for wetland vegetation, amphibians, and other wildlife.

Our hydrologic research verifies that relatively small increases in river stage immediately downstream of O'Shaughnessy Dam cause relatively large changes in river stage in Poopenaut Valley. This is due to the bedrock gorge immediately downstream that constricts river flow, creating a pronounced "backwater" effect. During the only substantial dam release in 2007 (which had a peak discharge of 3110 cubic feet per second on May 21), river stage at the U.S. Geological Survey gage just downstream of O'Shaughnessy Dam rose 1.9 m (6.4 ft), while river stage in Poopenaut Valley rose 3.4 m (11.3 ft). The May 2007 dam release did not inundate Poopenaut Valley meadows, nor did it elevate the level of the seasonal pond, but groundwater levels beneath the meadows responded rapidly to the increased stage, indicating relatively high transmissivity of floodplain sediments. Clearly, operations of O'Shaughnessy Dam have altered the hydrologic regime; for example, our analyses indicate that the stage generated by the 2007 dam release would be exceeded in approximately 30% of the growing season days under the pre-dam hydrologic regime, compared to only 14% under the existing regulated regime. However, science-based water management can do much to maintain and enhance riparian, meadow, and off-channel aquatic ecosystems in Poopenaut Valley. Dam releases in June 2006, peaking at roughly 8170 cubic feet per second, inundated much of Poopenaut Valley, indicating an approximate discharge needed to inundate the floodplain. Due to the high transmissivity of floodplain sediments, maintaining or enhancing riparian and wet meadow habitat likely does not necessarily require complete inundation. Additional monitoring in future water years should define the effective discharge range needed.

Despite the reduction in available water during the growing season, there remains a diverse mix of riparian, wetland, and upland plant communities in Poopenaut Valley. Wetland and upland meadows comprise most of the valley floor in Poopenaut Valley, with relatively extensive riparian vegetation adjacent to the river and tributary streams. There has been some encroachment of conifers into meadows. Several wetland areas in Poopenaut Valley exhibit an unusual assemblage of plants, and certain upland areas exhibit hydric soils and some hydrophytic vegetation despite a lack of

hydrologic indicators. These conditions suggest that wetlands were more extensive in the past and may reflect an ongoing transition to upland-type plant communities in response to reduced spring flooding; that these areas are still in transition suggests that they are tenuously maintained by periodic dam releases during high water years.

Many passerine bird species depend on riparian-associated vegetation for breeding habitat. Results from bird surveys indicate that Poopenaut Valley provides important breeding areas for a diverse group of birds representing a variety of breeding niches and differing seasonal strategies (resident species, short-distance, and long-distance migrants). Birds observed in Poopenaut Valley's riparian-associated habitats occupy breeding niches of differing heights in the vertical strata, including understory, mid-story, and canopy. This finding suggests that the available habitat in Poopenaut Valley provides structural integrity beneficial to a wide diversity of birds. Six Riparian Focal Species were present in Poopenaut Valley in 2007. With only one year of data, we are unable to determine bird population trends; future monitoring will investigate if bird populations in Poopenaut Valley are undergoing population fluctuations due to expected inter-annual variation, or experiencing population declines.

Benthic macroinvertebrate surveys revealed relatively high diversity and abundance, with 69 taxa representing 25 families and eight orders. Rank-abundance plots indicate relatively high richness and evenness, minimal niche preemption, and relatively uniform division of resources. There were many intolerant fauna, which cannot live in degraded habitat. The assemblage of macroinvertebrates between O'Shaughnessy Dam and Poopenaut Valley is similar in character to the assemblage in the analogous sections of the upper Merced River. Although this first year of study was not specifically designed to assess the impacts of dam operations on benthic macroinvertebrates, our results suggest that dam operations are not exerting a strong negative effect. Of the various alterations to the natural hydrologic regime, benthic macroinvertebrates may be most sensitive to pronounced water temperature depression during the summer months, and also to the reduction in seasonal variability of water quality. Year to year variability in stream macroinvertebrate fauna can be substantial, so additional data are needed to reliably detect effects due to dam operations. Follow-up studies in 2008 will more directly investigate the effects of varying discharge on benthic macroinvertebrate assemblages.

O'Shaughnessy Dam has clearly altered the hydrologic regime in Poopenaut Valley, with resulting changes in aquatic, riparian, and meadow ecosystems. However, our initial studies suggest that because of several factors unique to this setting (e.g., a low overall gradient, a downstream bedrock constriction that promotes floodplain inundation, upslope glacial moraines that contribute sediment to the river, etc.), Poopenaut Valley and its ecosystems have largely been spared the severe impacts seen downstream of other dams. Riparian and meadow ecosystems in Poopenaut Valley continue to provide important habitat for a variety of plant and animal species, many of them sensitive indicators of habitat quality.

Habitats that have only been moderately impacted by human activity, as opposed to those that have been substantially impacted, are considered to be the best candidates for restoration efforts. In most respects, Poopenaut Valley appears to have sustained moderate impacts from an altered hydrologic regime, and thus is a prime candidate for careful, science-based management of flows from O'Shaughnessy Dam. Future work in

Poopenaut Valley will help to inform the timing, duration, and magnitude of flows that will maximize benefits to downstream ecosystems.

# Chapter 1  Introduction

## 1.1  Effects of dams on rivers and river ecosystems

Dams and water diversion projects are widespread across the American West, impacting virtually every major river system.  These projects afford many benefits to society, but they also have detrimental affects on the downstream physical and ecological systems that evolved under free-flowing river conditions.

Altered hydrologic regimes downstream of dams affect physical processes and ecological systems in many ways (e.g., Collier et al. 1996, Ligon et al 1995, Allan 1995, Ward 1979). Daily discharges from dams may vary wildly, while the distinctive seasonal pattern of spring floods and low winter flow may be severely impaired.  Rivers emerging from dams may be significantly warmer or colder than pre-dam flows would have been, and typically have increased water clarity due to storage of fine sediment in reservoirs. Sediment storage can cause downstream scouring of river beds and banks (Andrews, 1986, Williams and Wolman 1984), prompting actions such as the recent controlled floods of the Colorado River in Grand Canyon National Park designed to replenish degraded beaches (Webb et al. 1999).

Altered hydrologic and geomorphic regimes can initiate ecological changes that can cascade throughout the food web and up and down the river corridor (e.g., Greathouse et al. 2006a, b, Holmquist et al. 1998, Ligon et al. 1995).  Altered hydrologic and geomorphic regimes can cause changes in plant community species composition, dominance, and density (e.g., Dwire et al. 2004). They can also cause extirpation of aquatic and riparian species adapted to naturally varying river discharges (e.g., Lytle and Poff, 2004, Poff et al. 1997), and an entirely new succession of species may move into these disturbed areas.  Altered water temperatures, water clarity, and other factors may cause native species of fish may relocate, become severely stressed, or perish (e.g., Clarkson and Childs 2000, Vanicek and Kramer 1969, Vanicek et al. 1970).  These impacts are often interrelated; for example, dam operations can alter the timing, duration, frequency, and magnitude of floodplain inundation, which can, in turn, alter riparian plant species composition and age class structure, thus altering habitat suitability for breeding passerine bird species (e.g., McBain and Trush, 2007a). Although the era of building large dams in the United States has passed, much work is still needed to fully understand the environmental legacy of these dam and water diversion projects.

Authorized by the U.S. Congress via the Raker Act in 1913 and completed in 1923, O'Shaughnessy Dam impounds the Tuolumne River in the Hetch Hetchy Valley within Yosemite National Park, forming Hetch Hetchy Reservoir.  The dam and reservoir are part of the Hetch Hetchy Water and Power Project, operated by the San Francisco Public Utilities Commission (SFPUC) with the primary purpose of providing water to San Francisco and other Bay Area cities, and with the secondary purpose of generating hydropower for City and County of San Francisco municipal uses.  This complex system includes dams and water diversion projects on the main stem of the Tuolumne River, Cherry Creek (a tributary to the Tuolumne River), Eleanor Creek (a tributary to Cherry Creek), and Moccasin Creek.

Because concern about the environmental impacts of O'Shaughnessy Dam has typically been focused on the inundation of Hetch Hetchy Valley, there have been few studies of the impacts of the dam on the downstream hydrologic processes, geomorphic processes, and related ecosystems. In this report, we “look downstream”, focusing on these interrelated downstream impacts. Our primary objective in this work, which was funded by the SFPUC, is to assess the condition of the Tuolumne River corridor between O’Shaughnessy Dam and the Yosemite National Park boundary to determine the extent of impacts to hydrologic processes and ecosystems as a result of dam operations. Clearly the dam and water diversions have altered the hydrologic regime, but to what extent? And how has this alteration affected adjacent riparian habitats and the wildlife that depend on them, all of which were formerly adapted to a free-flowing Tuolumne River?

Until now, even the basic information needed to begin to address these questions has been lacking. Our primary goals in the Looking Downstream project were to fill in the first-order information gaps by collecting baseline information on the hydrology, vegetation, birds, and benthic-macro invertebrates tied to stream flow downstream of O’Shaughnessy Dam, provide a general characterization of the river reach, and assess its overall hydrological and ecological condition. The overarching goal of these studies is to provide science-based information that SFPUC water managers can use to design environmental water releases that would be most beneficial to maintain and enhance ecosystems downstream of the dam.

In the river reach between O’Shaughnessy Dam and the Yosemite National Park boundary, the Poopenaut Valley appears to be one of the most ecologically diverse and productiveareas, and is therefore most sensitive to habitat disruption resulting from an altered hydrologic regime. For these reasons, we have focused our research efforts primarily in Poopenaut Valley, specifically on the meadow and riparian ecosystems found there, though in some instances (for example, our benthic macroinvertebrate studies) we found it necessary to expand the study area upstream. Most aspects of the study were completed between March and October of 2007, with the exception of the benthic macroinvertebrate sampling, which took place between March 2007 and February 2008 because we wanted to understand variation in the invertebrate assemblage throughout the year, including winter. Much of this work was intended to provide preliminary “baseline” information and a general characterization of the physical processes and ecology of Poopenaut Valley. This work was the first phase of a multi-year study, part of an adapative management and monitoring plan.

Our research in Poopenaut Valley consisted of four main subject areas: 1) surface and ground water hydrology, 2) upland, meadow, wetland, and riparian vegetation, 3) riparian-dependent bird species, and 4) benthic macroinvertebrate assemblages. In terms of the effects of dam operation and water diversion, these topics are closely linked. This report presents each subject area in a separate chapter. Preliminary discussions of subject material conclude each chapter, but a more thorough discussion of these subject areas, with emphasis on their interrelations, along with proposed additional work, is presented in Chapter 7: Discussion and recommendations for future work

## 1.2 Physical setting of Poopenaut Valley

Of the 9.7 kilometers (6 miles) of Tuolumne River corridor from O’Shaughnessy Dam to the boundary of Yosemite National Park, the most ecologically diverse section of the corridor is in the Poopenaut Valley area. Poopenaut Valley is a broad, low elevation (1,020 meters, [3,347 feet]) valley 4.6 kilometers (2.8 miles) downstream of O'Shaughnessy Dam (Figure 1-1). In many respects, Poopenaut Valley is a unique setting within the Tuolumne River corridor in Yosemite National Park. The valley owes its broad shape to a combination of the structure of the underlying granitic bedrock and the fact that it was repeatedly glaciated during the Pleistocene period. The most recent glaciation in the Yosemite region, the "Tioga" glaciation of approximately 18,000 years ago, filled the Tuolumne River canyon downstream of O'Shaugnessy Dam to the canyon rim, scouring the bedrock of the canyon and depositing extensive lateral moraines along the rim (Dodge and Calk, 1987). These moraines likely provide a wide range of sediment sizes to tributary streams draining into the Tuolumne River corridor downstream of the dam, offsetting to some degree the storage of fine sediment in Hetch Hetchy Reservoir (McBain and Trush 2007b).

**Figure 1-1. Photograph of Poopenaut Valley looking northwest from Hetch Hetchy Road showing broad valley, extensive wetland, meadow and riparian habitats, and downstream bedrock gorge.**

The narrow bedrock gorge bounding Poopenaut Valley on the downstream end (Figures 1-1, 1-2, 1-3) acts as a constriction point, creating a significant backwater effect during even moderate discharges. As flood waters back up behind this constriction, flow velocities decrease and fine sediment is deposited on the floodplains. As a result, much of Poopenaut Valley is composed of floodplains and terraces with a low overall gradient (< 1%; McBain and Trush 2007a). The extensive wetland, meadow, and riparian areas on these floodplains and adjacent to the river exist in large part because of this backwater effect and resulting floodplain inundation (Figure 1-4).

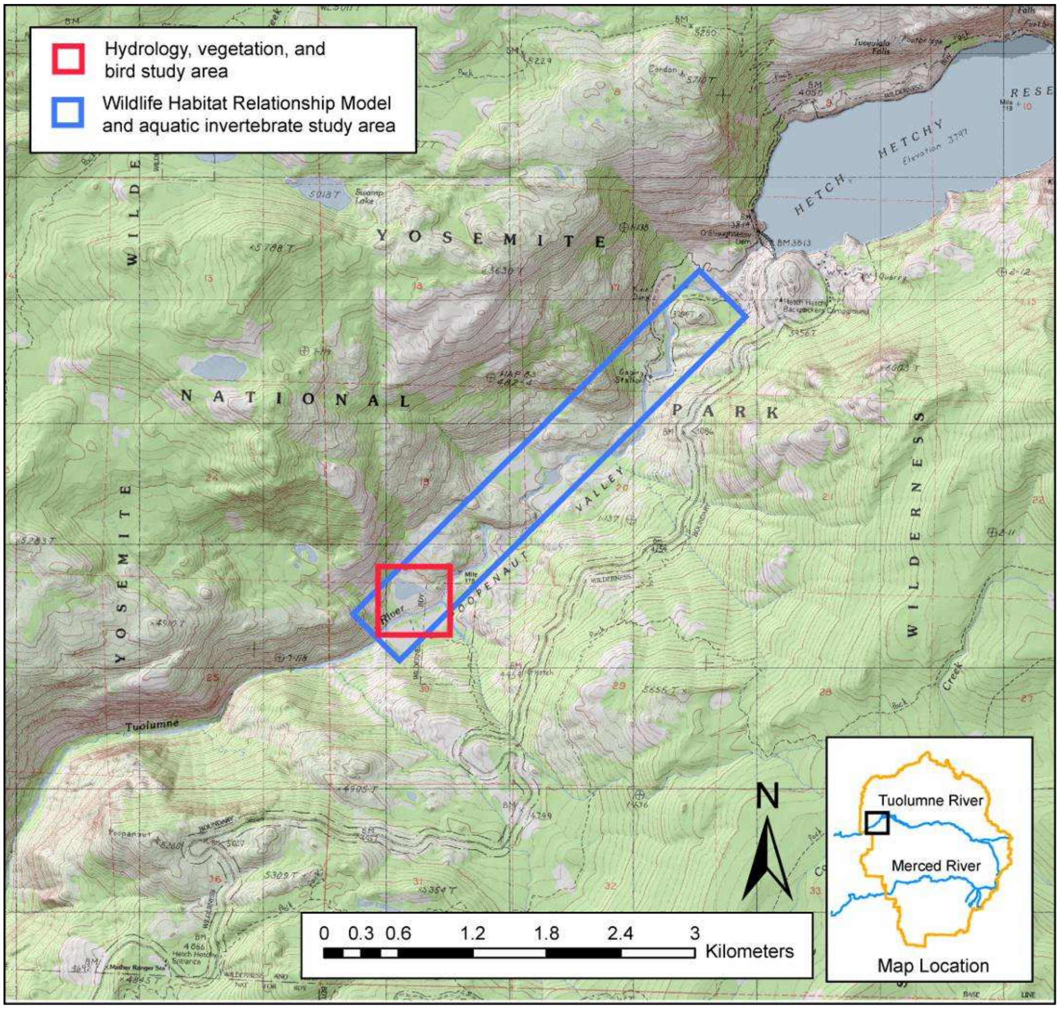


**Figure 1-2. Topographic map of the Tuolumne River Corridor downstream of O'Shaughnessy Dam and Hetch Hetchy Reservoir showing project study areas.**

The Tuolumne River generally flows from east to west through the study area. The river is perennial (flows year-round) but the magnitude, frequency, timing, duration and rate of change of the hydrologic regime is influenced by management of water releases from O'Shaughnessy dam. The other hydrologic features in the study area include tributary streams fed by run-off from surrounding slopes and a groundwater seep associated with groundwater flow underneath granite benches. One tributary stream originates on the north slopes (Tributary 1) and flows intermittently into the Tuolumne River. An intermittent drainage (Tributary 2), a perennial drainage (Tributary 3) and a spring-fed drainage (Tributary 4) originate on the south slopes and drain into the Tuolumne River.

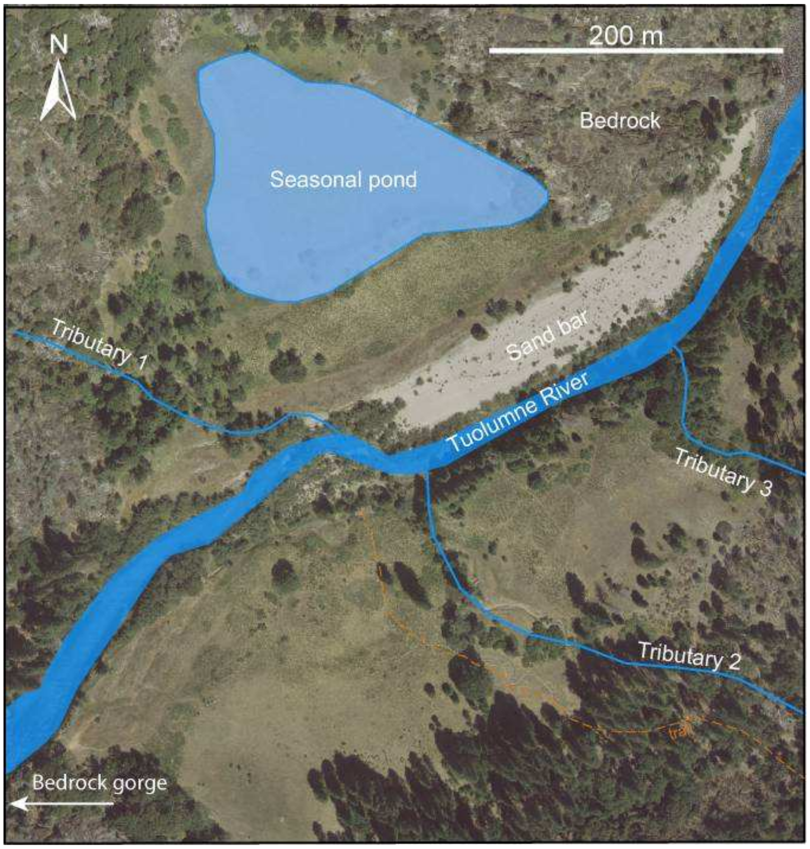


**Figure 1-3. Map of Poopenaut Valley showing major hydrologic and geomorphic features.**

**Figure 1-4. Flooding of Poopenaut Valley riparian and wet meadow habitats during June 2006 discharge of ~240 cubic meters per second (~8400 cubic feet per second).**

### 1.3 Biological setting of Poopenaut Valley

The north bank of the Tuolumne River in Poopenaut Valley is characterized by stepped benches of riparian vegetation, a large sand/gravel bar, a unique seasonal pond, wetland and upland meadows. The seasonal pondis essentially an off-channel wetland, fed both by hillslope drainage from the north wall of the canyon and by groundwater. At high flows in the mainstem Tuolumne River, the pond is inundated via a backwater effect that travels upstream in the north tributary (Tributary 1) and spills into the pond. A pre-dam floodplain with a combination of riparian, wetland and upland meadows and higher benches of conifer-dominated forests characterize the south bank. Current base flow levels of 2-3.5 cubic meters per second (cms) (75-135 cubic feet per second [cfs]) define the typical channel characteristics and river stage of the Tuolumne River in Poopenaut Valley.

Relative to other areas along the Tuolumne River corridor downstream of O'Shaughnessy Dam, Poopenaut Valley contains extensive riparian and wet meadow habitats. Wetland habitats, including riparian plant communities, provide the most productive habitats in the Sierra Nevada and play a unique and vital role in the life history and ecology of several groups of Sierra Nevada wildlife. Riparian habitats harbor a rich assemblage of grasses, sedges, and willows that support a diverse community of wildlife species, from prey species such as arthropods and small mammals, to predators such as weasels and raptors. Riparian-associated meadow habitat has been identified as the first priority habitat for conserving and restoring in the Sierra Nevada (Siegel and DeSante 1999).

# Chapter 2: Characterizing surface water and ground water regimes in Poopenaut Valley

## 2.1 Introduction

Assessing the potential impacts of dams and water diversion projects on ecosystems requires an understanding of how these structures have altered the hydrologic and geomorphic regimes downstream (e.g., Ligon et al. 1995). For this study, staff scientists from McBain and Trush, Inc., assumed the lead role on geomorphic investigations in Poopenaut Valley (e.g., McBain and Trush 2007a, b) and the National Park Service assumed the lead role on hydrologic investigations, with considerable cross-collaboration. Our goal was to understand how the hydrologic regime, including both surface water and ground water, has changed as a result of dam operations. To do this, we must first characterize the physical and hydrological settings in Poopenaut Valley, understand how the modern hydrologic regime operates, and have at least a general understanding of how the pre-dam hydrologic regime functioned. This chapter relates our findings on these subjects, setting the stage for the biologic assessments presented in subsequent chapters.

The specific hydrologic objectives of this study are:

1) To determine floodplain (meadow) inundation frequencies, and to understand the degree to which O'Shaughnessy Dam alters inundation frequencies and timing.
2) To determine the relationship between river stage and groundwater levels in adjacent meadows, and to what extent regulated discharges have altered this relationship.
3) To establish, where possible, minimum soil saturation/duration relations for existing and potential meadow vegetation assemblages.
4) To quantify the temporal and spatial effects of water impoundment in Hetch Hetchy Reservoir on river water temperatures.
5) To characterize water quality conditions upstream and downstream of Hetch Hetchy Reservoir.

To meet these objectives, our hydrologic research in Poopenaut Valley utilized three basic approaches: 1) Quantifying groundwater and river levels using groundwater monitoring wells and river stage recorders, 2) collection and analysis of river water temperature data from upstream and downstream of O'Shaughnessy Dam, and 3) collection and analysis of water quality data from upstream and downstream of O'Shaughnessy Dam. In the following sections, we present our methods, results, and a brief discussion of each study component. More detailed discussion of the hydrologic data, and how those data relate to other aspects of the overall study (e.g., vegetation, wildlife) is presented in Chapter 6.

### 2.1.1 Summary of alterations to the natural hydrologic regime

O'Shaughnessy Dam has influenced the magnitude, timing, duration, frequency and rate of change of the hydrologic regime (McBain and Trush 2007). This section provides a brief summary of these alterations, as determined by McBain and Trush (2007).

A timeline of the construction of, and modifications to, the O'Shaughnessy Dam can be summarized as follows:

- **1923:** O'Shaughnessy Dam (Hetch Hetchy Reservoir [260,000 acre-feet]) begins storing runoff from the upper 1,184 square kilometers (457 square miles) of the Tuolumne River watershed.
- **1938**: O'Shaughnessy Dam crest is 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 San Francisco Bay Area. Aqueduct connection to the Bay Area was completed in 1934.
- **1967:** The Canyon Power Tunnel begins operating and diverts water from Hetch Hetchy Reservoir to the Kirkwood Powerhouse, bypassing the mainstem river reach between O'Shaugnessy Dam and Early Intake, further reducing the amount of water flowing in the Tuolumne River and through Poopenaut Valley.

Between 1923 and 1967, summer base flows downstream of O'Shaughnessy Dam were typically elevated (600 cfs to 700 cfs) above pre-dam levels in order to deliver water to the Hetch Hetchy Aqueduct and diversion at Early Intake. After completion of the Canyon Power Tunnel in 1967, summer base flows were reduced to between 75 cfs and 125 cfs (Mcbain and Trush 2007).

Over the past 30 years, the mean daily Tuolumne River discharge downstream of O'Shaughnessy Dam has typically peaked in June and July, but is dependent on reservoir levels, drought status and weather patterns. (For comparison, the average daily discharge for the unregulated portion of the Merced River, the next river south of the Tuolumne, typically peaks in May.) Required minimum flows downstream of O'Shaughnessy Dam range from 35 cfs to 125 cfs depending on time of year and water year type (dry, normal or wet). Discharge in this reach is typically maintained at or near stipulated minimum flows, except during spring and summer spills. Spill releases increase discharges well above the minimum flow stipulation but were uncommon until operations were modified in 1993. Since that time, spring spills were released in 10 of 13 years with the only one winter spill occurring in water year 1997 (McBain and Trush 2007a).

Based on comparisons between two similar water years (1917 and 1999), dam operations had the following effects on hydrograph components (McBain and Trush 2007a):

- Reduced winter baseflows
- Delayed onset of spring snowmelt from late March (water year1917)/mid-April (Pohono Bridge, Merced River) to mid-May;
- Truncated end of the snowmelt hydrograph
- Reduced snowmelt peak by about 2,000 cfs (30%);
- Increased snowmelt recession rate
- Increased summer base flow

Measurements of pre-dam discharges of the Tuolumne River span only 12 years (water year 1911 through water year 1923). To provide a longer-term unimpaired flow record to compare pre-dam and post dam flows, annual flood data from the Merced River at Pohono Bridge near Yosemite gage (USGS station 11283500) were scaled by drainage area at the Tuolumne River at Hetch Hetchy gage (USGS station 11276500)

(McBain and Trush 2007a). The Merced gage has a long period of record (water year 1917 to the present), and its elevation and drainage area are similar to the Tuolumne River Hetch Hetchy gage. 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 4–33%. The scaled unimpaired record underestimates Tuolumne River flood peaks and the effects of project operation on annual flood magnitude. Despite this, these data still provide a useful benchmark to compare pre-dam and managed flow conditions but this error must be considered when interpreting results (McBain and Trush 2007a).

Prior to dam construction, annual peak floods were typically in spring, but the largest and most geomorphically significant floods were (and continue to be) winter rain-on-snow events. Pre-dam snowmelt peak floods recorded by the Hetch Hetchy gage all occurred in May and June and ranged from 6,202 cfs (water year 1913) to 11,400 cfs (water year 1919). Annual floods scaled from the Merced River at Pohono Bridge gage were in spring (April–June) in 79 of 89 (89%) years of record. Spring annual peaks were most common in May and June, which accounted for 68% and 19% of spring peaks, respectively. Spring peaks ranged from 2,093 cfs in water year 1934 to 17,796 cfs (a 12.7-year flood) in water year 1996. The longer unimpaired period of record at the Merced River at Pohono Bridge gage records several large winter floods that are not included in the pre-dam period of record. Winter rain-on-snow events generated annual floods in 7 of 89 (8%) years of record and occurred from November through January. These floods accounted for the six largest floods for the period of record (water year 1917 through water year 2005) and all floods exceeding the 13-year recurrence interval (McBain and Trush 2007a).

Dam operation since the completion of the Canyon Tunnel in 1968 has reduced flood magnitude for all flood recurrence intervals evaluated. Small, frequent floods (<2.33-year pre-dam recurrence interval) and floods exceeding 10,700 cfs (pre-dam 6.2-year recurrence interval) appear to be the most affected. Compared to the pre-dam record, the 1.5- and 2.33-year floods decreased 58% and 33%, respectively (McBain and Trush, 2007a). Moderate floods (2.8-year to 7-year recurrence interval) decreased approximately 10-40%. Larger floods are limited by the infrastructure at Early Intake, which is approximately 10,000 cfs. Since water year 1939, annual floods exceeded 10,700 cfs in three years (water years 1943, 1995, 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 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. At the Tuolumne River near Hetch Hetchy gage, the 1997 flood peaked at 16,400 cfs (an unimpaired 12-year flood and a post-dam 67-year 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).

## 2.2. Surface Water and Groundwater Assessment

O'Shaughnessy Dam and Hetch Hetchy Reservoir have clearly altered the hydrologic regime in Poopenaut Valley (McBain and Trush, 2006, 2007a). We established a hydrologic monitoring network in Poopenaut Valley in order to understand the current relationship between river stage and meadow (floodplain) saturation, to relate this to historic meadow saturation frequencies and how this correlates with existing vegetation, and to evaluate the possibility of achieving a more effective saturation frequency of the meadow.

### 2.2.1 Methods

In order to characterize channel morphology and groundwater and surface water regimes, we established two cross-valley transects of shallow (≤ 5 m deep) groundwater monitoring wells in the meadow areas at the downstream end of Poopenaut Valley (Fig. 2-1). Transect 1, the downstream transect, consisted of three wells on the south side of the river (well numbers 1, 2, and 3) and a river stage recorder placed in the bed of the Tuolumne River at river left (Fig. 2-1). Transect 2, the upstream transect, consisted of three wells on the south side of the river (wells 4, 5, and 6) and two more on the north side (wells 7 and 11), as well as one river stage recorder placed in the bed of the Tuolumne River at river left and another stage recorder at the southern margin of the seasonal pond (Fig. 2-2). A third transect of three wells was installed on the south side, and parallel to, the river (wells 8, 9, and 10) in order to evaluate the contributions to groundwater made by tributaries draining the south wall of Poopenaut Valley (Fig. 2-2). Coordinates for these installations are listed in Table 2-1.

**Table 2-1. UTM coordinates of all hydrologic installations in Poopenaut Valley.**

| | UTM NAD 83, Zone 11N | |
|---|---|---|
| Instrument | Easting | Northing |
| Well 1 | 252075.472 | 4200422.407 |
| Well 2 | 252011.377 | 4200453.790 |
| Well 3 | 251951.551 | 4200482.433 |
| Well 4 | 252266.530 | 4200541.228 |
| Well 5 | 252250.683 | 4200575.590 |
| Well 6 | 252226.651 | 4200611.366 |
| Well 7 | 252127.096 | 4200778.104 |
| Well 8 | 252214.578 | 4200549.771 |
| Well 9 | 252159.616 | 4200517.858 |
| Well 10 | 252074.847 | 4200480.958 |
| Well 11 | 252158.190 | 4200726.830 |
| Barometric Logger | 252080.445 | 4200401.435 |
| Downstream Stage Recorder | 251919.656 | 4200506.212 |
| Upstream Stage Recorder | 252214.111 | 4200640.437 |
| Pond Recorder | 252104.450 | 4200806.350 |

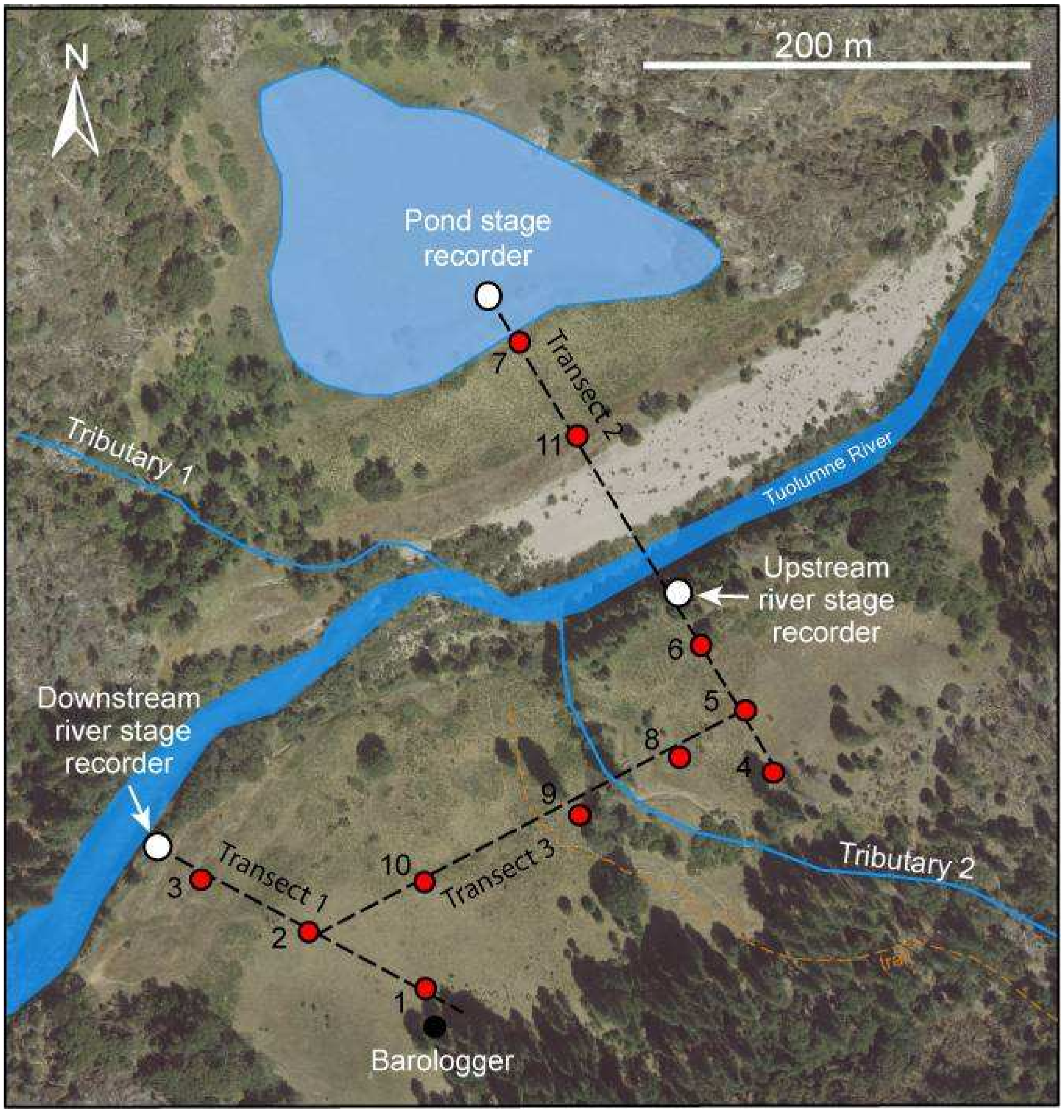


**Figure 2-1. Locations of groundwater monitoring wells (red circles), stage recorders (white circles), and logging barometer/RH and temperature logger (black circle) in Poopenaut Valley.**

We hand-augured holes for the groundwater monitoring wells, fit them with 2-inch PVC casing screened over the entire length, and backfilled the annulus between casing and augured hole with soil from the hole. We installed sealed water level data loggers (HOBO® Water Level Logger) in each well to collect water level data at 15-minute intervals. We logged each hole for soil texture, color, and moisture. The soil profile from Well 1 represents a typical example from Poopenaut Valley showing relatively uniform, fine-grained sediment characteristic of river floodplains (Table 2-2). As with most groundwater monitoring wells we constructed, Well 1 contained no standing water at the time the well was installed.

**Table 2-2. Soil layer description for groundwater monitoring Well 1.**

| Depth (cm) | Soil Layer Description |
|---|---|
| 0 – 227 | Sandy Clay Loam, color: 10YR 2/2 |
| 227 – 252 | Sandy Loam with scattered coarse sand; 2 colors: 10YR 2/2 and 10 YR 3/4 |
| 252 – 320 | Sandy Loam finer sand grading to next unit, color: 5Y 5/3 |
| 320 – 373 | Sandy Loam coarser sand graded from above unit; color: 10YR4/4; sand saturated but no standing water |

We installed sealed water level data loggers (Solinst® Leveloggers) at each river stage recorder site inside a 1-foot length of black PBS pipe and secured this assembly to the bottom of the river channel via rebar driven into the alluvial bed. The Leveloggers recorded stage and temperature data at 15-minute intervals. Barometric pressure was measured with a Solinst® Barologger, and air temperature and relative humidity with a HOBO® H8 Pro, both installed in a tree at the margin of the main meadow (Figure 2-1). We installed instruments at the downstream and upstream stage recorders, well 3, and the barometer site on March 23, 2007. The pond recorder and wells 2 and 6 were instrumented on April 6, 2007. Wells 1, 4, 5, 7, 8, 9, and 10 were instrumented on June 15, 2007, and well 11 on July 13, 2007.

Throughout the duration of the study period, we hand-read groundwater wells and stage recorders on a monthly basis, and sometimes more frequently. We used these manually collected data to correct electronically logged data and assured accuracy of logged data.

### 2.2.2 Results and Analysis

We were able to collect only limited hydrologic data during the study period due to very dry conditions in water year 2006-2007 and the beginning of water year 2007-2008. Merced River runoff as measured at the U.S. Geological Survey (USGS) Happy Isles Gage was the eighth lowest annual average since measurements began in 1916, and April 1, 2007 snowpack in the Tuolumne River Basin upstream of Hetch Hetchy Reservoir was the tenth lowest since 1948. The low precipitation amounts, coupled with an earlier-than-average onset of spring runoff, resulted in very limited releases from O'Shaughnessy Dam, which mostly were required to maintain regulated minimum flows.

Due to these factors, we did not have the opportunity to fully test the response of groundwater in Poopenaut Valley meadows to a typical range of discharges on the Tuolumne River. Wells 1, 4, 5, 7, 8, 9, and 10 were dry throughout the study period, except during the brief interval of May 21-24 during and immediately following the only substantial dam release for the year (see below). In the downstream well transect (Transect 1; Figure 2-1), Well 2 contained water until June 27, and Well 3 contained water entire time (Figure 2-2). The downstream river stage recorder became dry on October 2. In the upstream well transect (Transect 2; Figure 2-2), Well 6 was dry nearly the entire time, except for a small spike in late May discussed below (Figure 2-3). Well 11 contained water throughout the study period, but was not instrumented until July 13 (Figure 2-3). The stage recorder in the seasonal pond indicates the pond went dry on May 21, and did not respond to subsequent hydrologic events (Figure 2-3). A photographic time series from Well 7 shows the evolution of the seasonal pond and associated vegetation between March and October, 2007 (Figure 2-4).

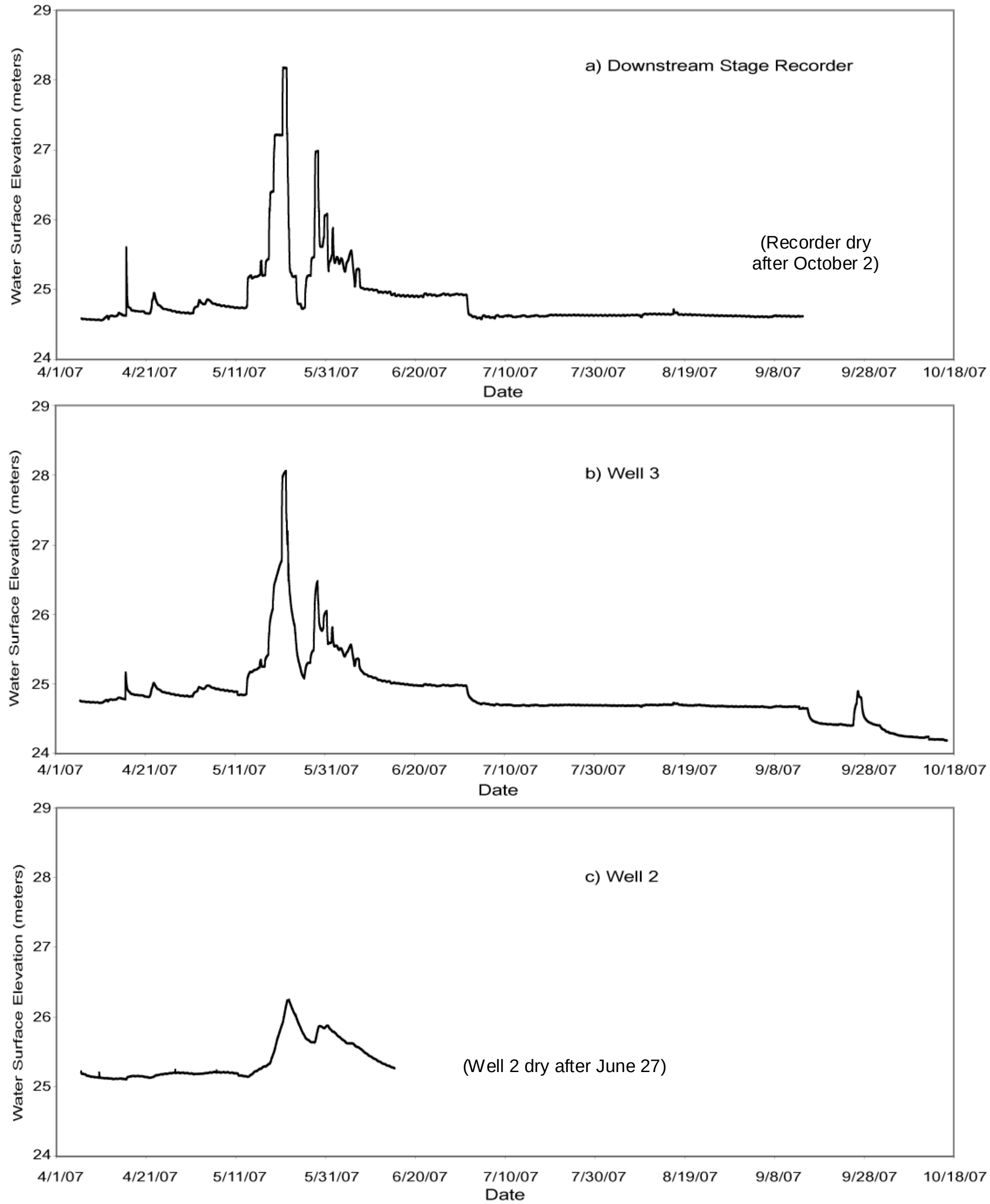


**Figure 2-2. Hydrologic data from Transect 1 throughout study period, from north to south: a) Downstream Stage Recorder; b) Well 3; c) Well 2.**

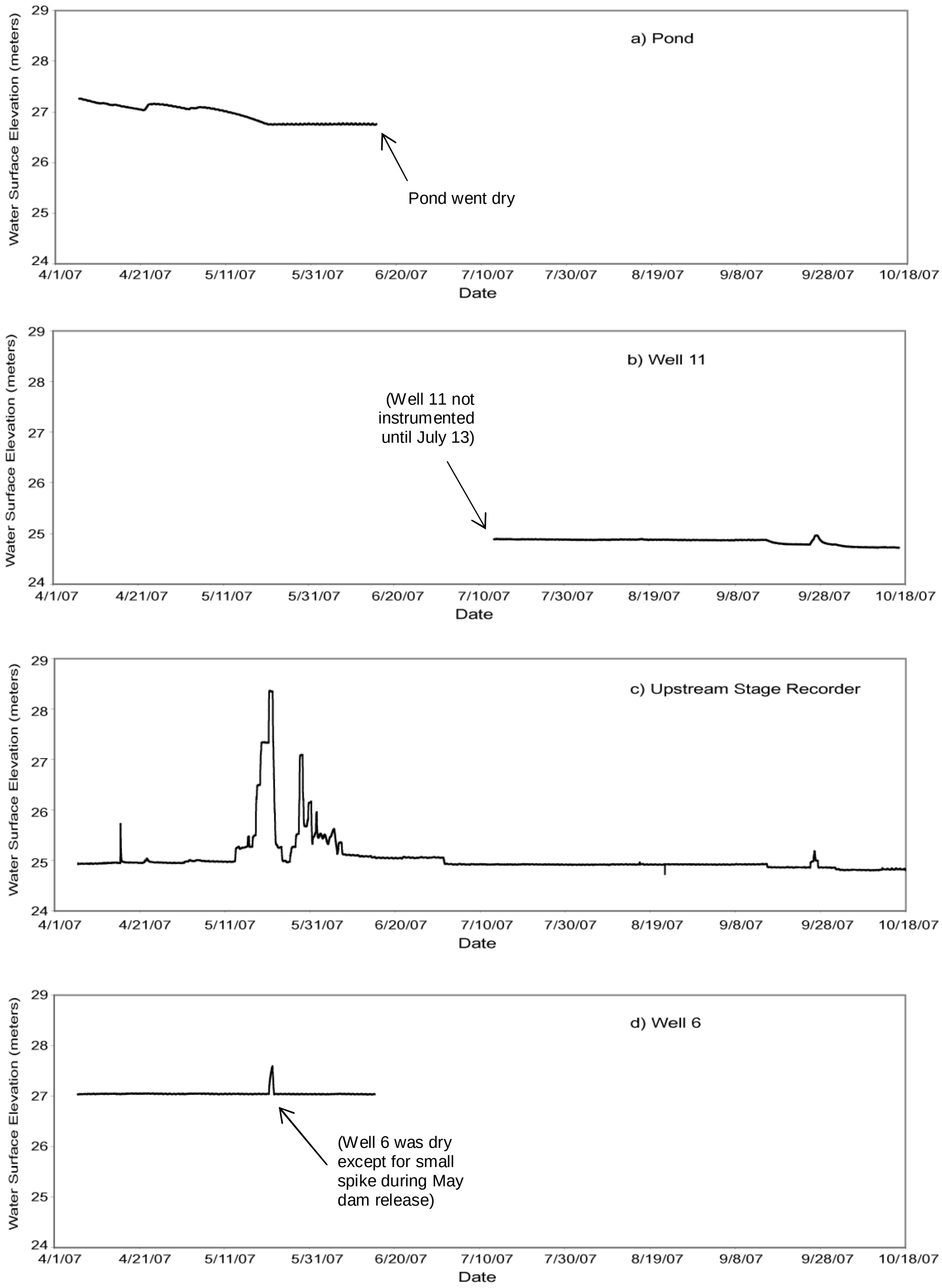


**Figure 2-3. Hydrologic data from Transect 2 throughout study period, north to south: a) Seasonal pond stage recorder; b) Well 11; c) Upstream stage recorder; d) Well 6.**

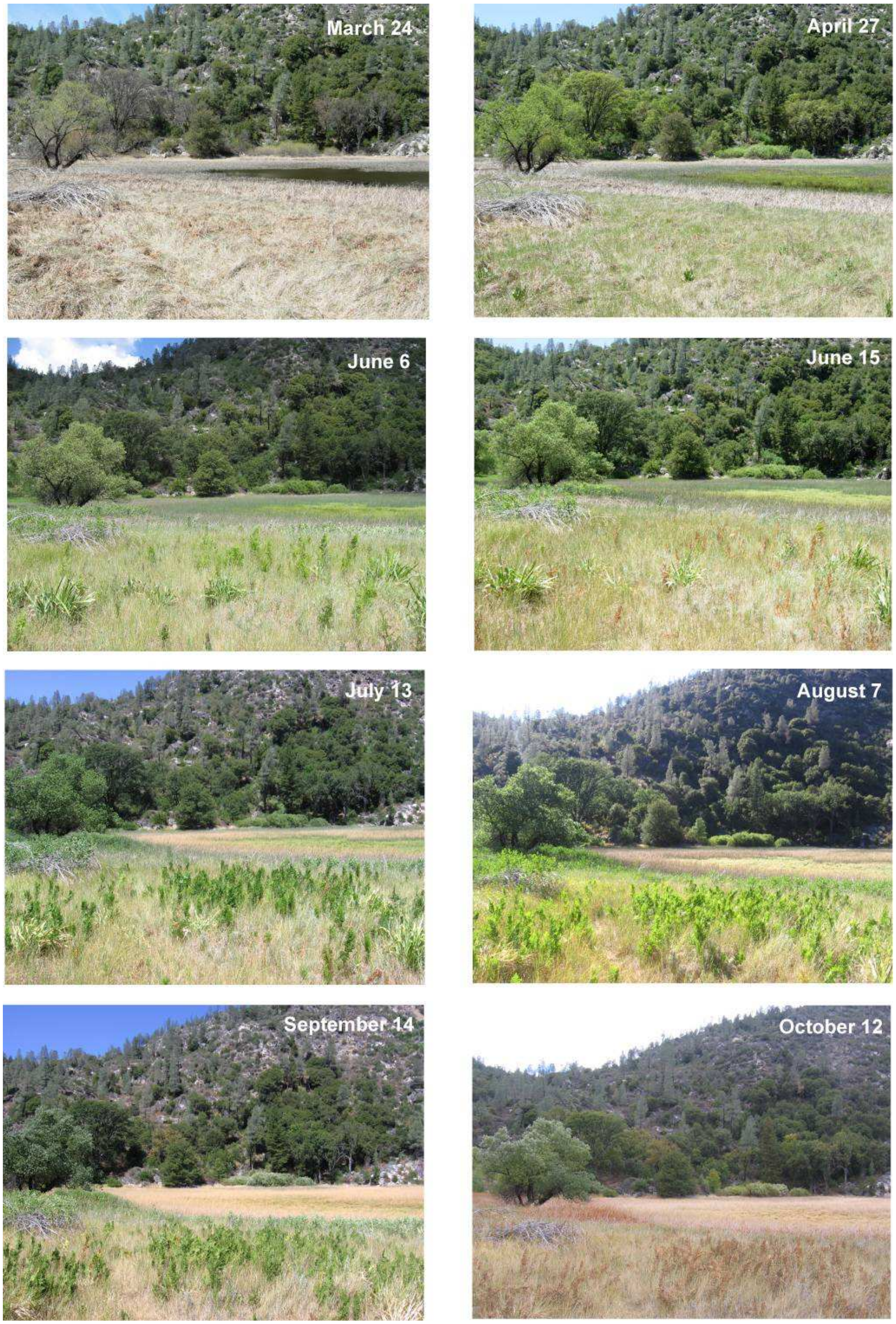


**Figure 2-4. Time-lapse series of photographs from well 7 looking northwest to seasonal pond. The pond went dry on May 21, 2007 and did not respond to late May dam release.**

The dominant hydrologic event during the 2007 study period was an 85 cubic meters per second (3000 cubic feet per second) release from O'Shaughnessy Dam in late May. Based on the discharge data from the U.S. Geological Survey (USGS) gaging station downstream of the dam, the release occurred in two discrete pulses beginning on May 13 and lasting, overall, almost three weeks (Figure 2-5). Unfortunately, this release occurred with little advance notice, and we were not able to fully observe hydrologic conditions in Poopenaut Valley until after the peak discharge on May 21. This "pulse flow" event was recorded in Groundwater Wells 2, 3, and 6, as well as both river stage recorders. It was observable elsewhere in the meadow, but wells 1, 4, 5, 7, 8, 9, 10, and 11 were not yet instrumented at that point. However, wells were hand-read several times beginning the day after the peak flow (Table 2-3).

During the late May dam release, river stage in Poopenaut Valley rose 3.43 m (11.25 ft) at the downstream river stage recorder and peaked at 12:00 PST on May 21. The groundwater response to this increase in flow was immediate at Well 3 nearest the river, but delayed and diminished in magnitude at Well 2, located farther from the river (Figure 2-2). Water levels rose 3.20 m (10.50 ft) at Well 3 to a high on May 21 at 13:00 PST, just two hours after the river peaked at this transect, while water in Well 2 rose only 1.0 m (3.28 ft) and peaked on May 22 at 18:15 PST, 31 hours after the peak in river discharge. The dam release event was not well represented in Transect 2, which captured it only at Well 6 and at the upstream river stage recorder. Prior to the dam release, Well 6 had been dry, but during the release it showed a small spike in groundwater level of 0.55 m (18.04 ft) (Figure 2-3d). This well contained water for 29 hours and returned abruptly to dryness afterward.

**Table 2-3. Hand-read water table elevations taken during May 2007 dam release.**

| | Water Surface Elevation (m) | | | | | |
|---|---|---|---|---|---|---|
| | May 11, 2007 | May 22, 2007(~13:00) | May 22, 2007(~20:00) | May 23, 2007 | May 24, 2007 | June 6, 2007 |
| Well 1 | Dry | 26.859 | 26.599 | 26.199 | 25.979 | 25.599 |
| Well 2 | 25.161 | 26.211 | 26.211 | 26.141 | 25.961 | 25.601 |
| Well 3 | 24.840 | 27.358 | 26.893 | 25.658 | 25.658 | 25.368 |
| Well 4 | Dry | 27.459 | 27.449 | 27.409 | 27.354 | Dry |
| Well 5 | Dry | 26.924 | 26.594 | 26.884 | 26.704 | Dry |
| Well 6 | Dry | 27.257 | Dry | Dry | Dry | Dry |
| Well 7 | Dry | | | | | Dry |
| Well 8 | Dry | 27.231 | 26.911 | 26.581 | Dry | Dry |
| Well 9 | Dry | 27.083 | 26.893 | Dry | Dry | Dry |
| Well 10 | Dry | 26.247 | 26.197 | 26.097 | 25.947 | Dry |
| Well 11 | 25.102 | | | | | 25.499 |

Note: Readings taken on May 11 were prior to the dam release, May 22-24 during the dam release, and June 6 after the dam release. Wells 7 and 11 could not be safely read during the dam release as they are located on the opposite side of the river from the access trail.

Figure 2-6 shows a generalized schematic diagram of the groundwater response along Transect 1 to the dam release. On May 11, the water table surface in the meadows was at its pre-release levels. By May 20 water level had risen significantly in the river and at Well 3, but was lagging behind at Well 2. River stage peaked on May 21 and was recorded by the river stage recorders and data loggers in Wells 2, 3, and 6.

Hand measurement of groundwater wells began on May 22 after the river stage had decreased by about 1.5 m (4.92 ft) from its peak level (Table 2-3). The meadow seems to have been partially flooded in the vicinity of Well 3. Interestingly, the water surface was lower at Well 2, in the middle of the meadow, than at Well 1, farthest from the river. By May 23 the water had receded in the river and was beginning to drain from the meadow as well; the water level at Well 3 had dropped quickly following the drop in river level, but was slower to respond at Well 1, and had only decreased slightly in the middle of the meadow at Well 2.

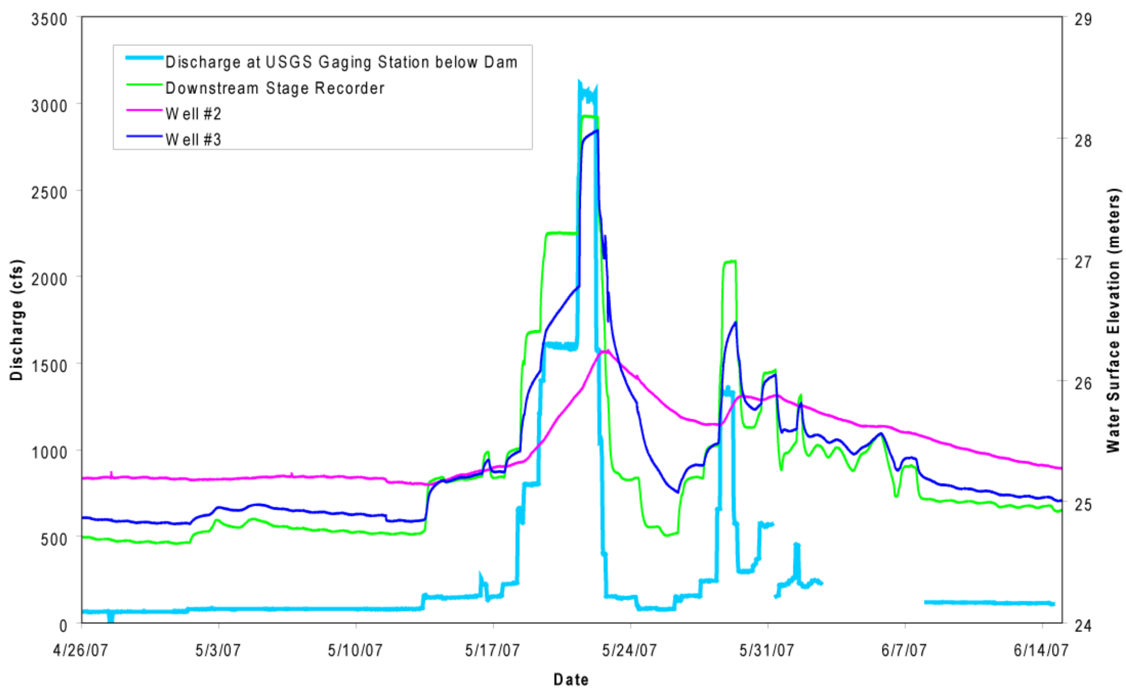


**Figure 2-5. Responses of downstream stage recorder and groundwater wells 2 and 3 to ~ 3100 cfs release from O'Shaughnessy Dam in late May 2007. River discharge data from the USGS gaging station downstream of dam is shown in cfs on left y-axis. River stage and groundwater data from Poopenaut Valley are presented as water surface elevation on right y-axis.**

We used data from the river stage recorders and groundwater wells along Transect 1 to estimate the minimum increase in water table elevation in the meadow on the southwest edge of Poopenaut Valley as a result of the May 2007 dam release. Figure 2-7 shows the difference in water table elevation as measured on May 11, prior to any discharge increases, and May 22, one day after the peak dam release discharge. If a well was dry on May 11, the value used was the difference between the water table surface on May 22 and the elevation of the bottom of the well. For many wells, this means that the values represented by the contours are minimum values because the wells were dry prior to the peak discharge. In order to create a realistic interpolation of water table elevations, we created additional river elevation points (dark circles on the northwest side of the interpolated water surface in Figure 2-7) with elevations between those of the upstream and downstream stage recorders. We then used a natural neighbor interpolation technique (Simpson, 1981) to calculate the water table surface shown in Figure 2-7. Note that the effect of the tributary creek in this area is not taken into account. Nevertheless, this illustrates the rapid and significant response of groundwater throughout the meadow to a relatively small and short-lived flood event.

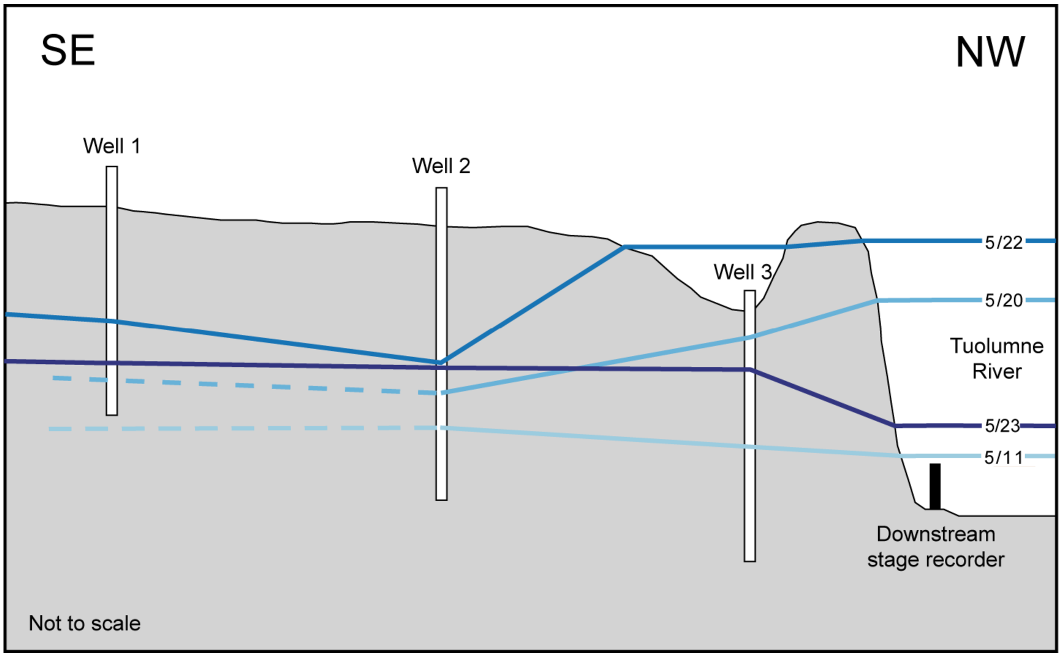


**Figure 2-6. Schematic diagram of groundwater response to May 2007 dam release along Transect 1 in Poopenaut Valley. Generalized water surfaces on May 11, May 20, May 22, and May 23 are shown with blue lines. Ground surface (gray) is estimated.**

The most striking feature of the May 2007 release was the significant backwater effect observed in Poopenaut Valley. Between May 11 and the peak discharge on May 21, Tuolumne River stage rose 3.43 meters (11.25 ft) at the downstream stage recorder, and 3.39 meters (11.12 ft) at the upstream stage recorder. In contrast, Tuolumne River stage at the USGS gage downstream of O'Shaughnessy Dam rose just 1.94 meters (6.36 ft). Given the dry year, tributary inputs between the USGS gage and Poopenaut Valley were minimal, so we assume that both reaches experienced very nearly the same increase in river discharge. The difference in river stage between Poopenaut Valley and the USGS gage at this relatively modest discharge demonstrates the unique backwater effect that enables flooding of Poopenaut Valley meadows.

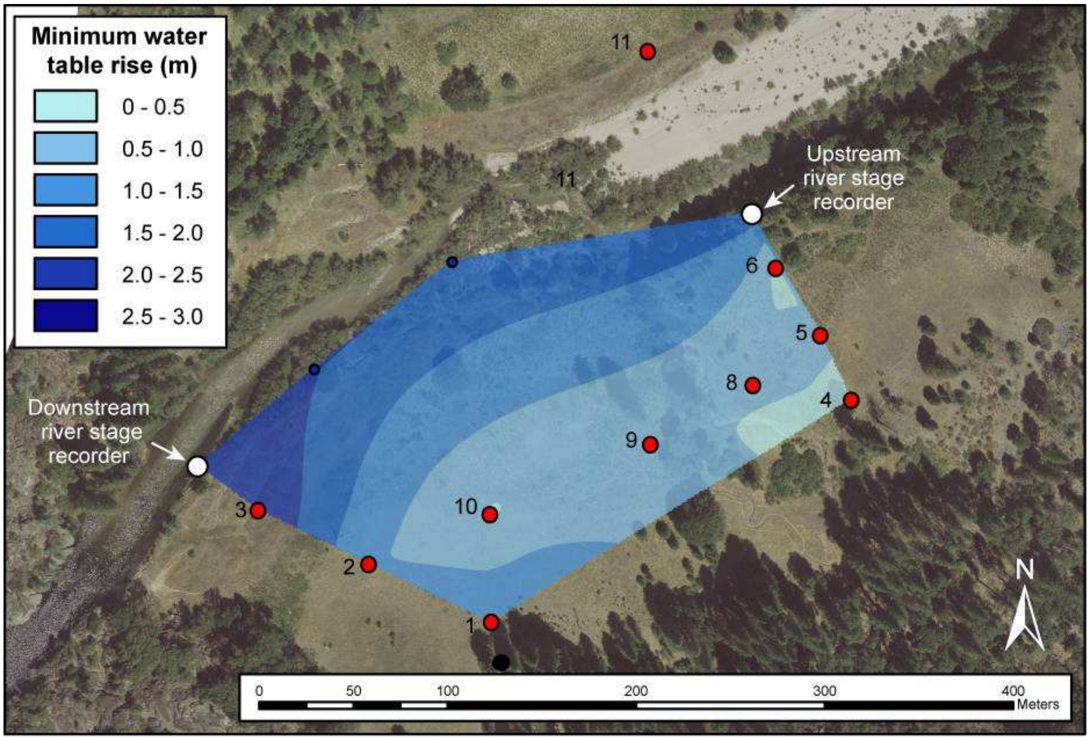


**Figure 2-7. Minimum rise in groundwater levels in meters from the May 2007 dam release as measured by subtracting groundwater monitoring well levels measured on May 22 during peak discharge from those measured on May 11 prior to release.**

An examination of dam discharge as recorded at the USGS gage downstream of O'Shaughnessy Dam, and of the associated stages at the USGS gage and in Poopenaut Valley, quantifies the magnitude of the backwater effect over a range of discharges (Figure 2-8). Changes in discharge as recorded at the dam take 3.5 - 4 hours to propagate downstream to Poopenaut Valley. We isolated a range of stages recorded in Poopenaut Valley as a function of discharge at the USGS gage when discharge had been steady for a period of 4 or more hours for the period of this study. The peak stage recorded in 2007 was 28.18 meters (92.43 ft), which corresponded to a discharge of approximately 88 cms (3100 cfs). The peak stage in 2006 on June 7, recorded by drift lines near Transect 1 (Scott McBain, pers. comm., 2007), measured 29.71 meters (97.45 ft), which corresponded to a discharge of approximately 238 cms (8400 cfs). The line connecting points is a simple interpolation. Future data will help refine this relationship, as it is likely affected by antecedent moisture conditions in the meadow and whether a stage is recorded during the rising or the receding limb of the hydrograph. Nevertheless, Figure 2-8 provides a first-order assessment of the relationship between discharge from O'Shaughnessy Dam and the resulting stage and degree of meadow saturation in Poopenaut Valley. Overall, river stage in Poopenaut Valley appears to be particularly sensitive to river discharge, an encouraging result in terms of maximizing the ecological benefits of water releases from O'Shaughnessy Dam.

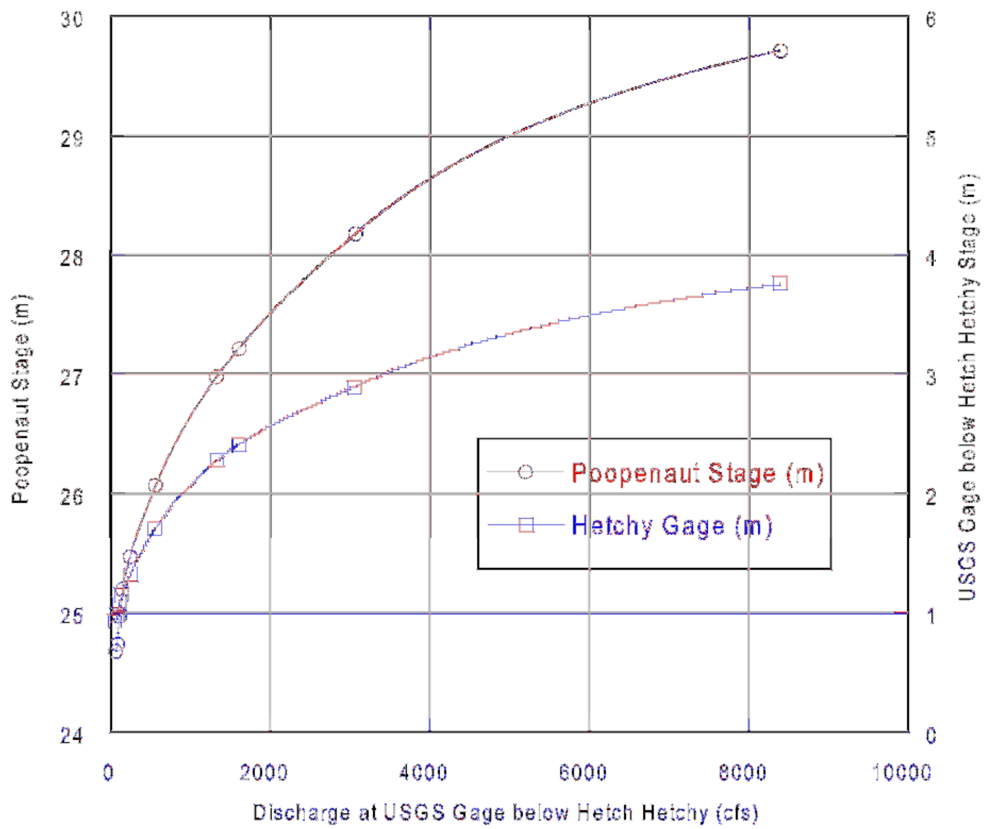


**Figure 2-8. Tuolumne River stage at Poopenaut Valley (Transect 1) and at USGS gage downstream of Hetch Hetchy Reservoir versus Tuolumne River discharge at USGS gage downstream of Hetch Hetchy Reservoir.**

Given the relationship between stage in Poopenaut Valley and discharge at the USGS gage below O'Shaughnessy Dam (Figure 2-8), it is possible to construct stage duration frequencies for impaired flows and compare those to unimpaired (reconstructed) discharges (Figure 2-9). For this analysis, we converted daily-averaged river discharges from the USGS gage below O'Shaughnessy Dam to river stages in Poopenaut Valley, and then compared these results with reconstructed pre-dam river stages in Poopenaut Valley converted from reconstructed pre-dam discharges at the USGS gage below O'Shaughnessy Dam. Reconstructed discharges downstream of O'Shaughnessy dam were created by scaling the daily-average river discharges from the USGS gage at Pohono Bridge on the Merced River by the ratio of the Tuolumne River/Merced River drainage areas following McBain and Trush (2006). This reconstruction method may underestimate actual discharges by 4-33% (McBain and Trush, 2007a). We limited our analysis to months within the approximate vegetation growing season in Poopenaut Valley (March - June), and to the years 1968-2007, a period when reservoir management, particularly high river discharge, has been relatively consistent (McBain and Trush, 2007a). Figure 2-9 shows that during pre-dam conditions the lower range of meadow elevations along Transect 1 in Poopenaut Valley was wet about 55% of the growing season, whereas under the present regulated conditions these areas are wet only about 22% of the growing season. The difference between impaired and reconstructed flow duration represents the maximum deviation from 'normal' (unimpaired) conditions. It is possible that flow durations necessary for ecological benefit could be somewhat less than the reconstructed values.

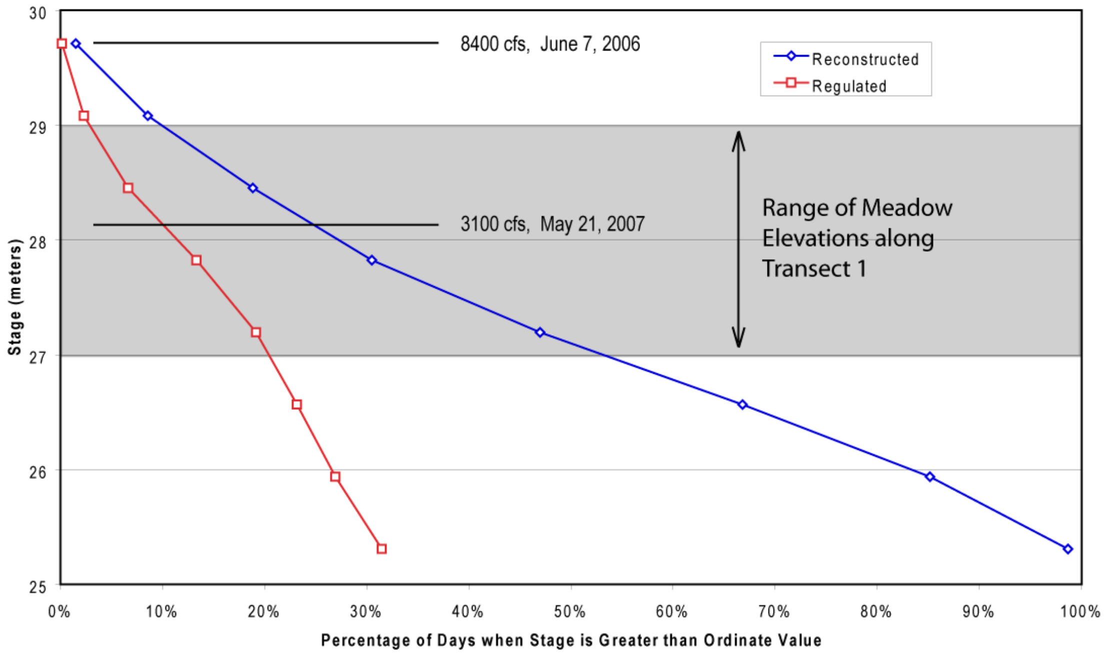


**Figure 2-9. Stage-duration frequency in Poopenaut Valley under regulated and reconstructed (pre-dam) flow regimes, March through July, 1968–2007. Example comparison: Approximately 28% of regulated discharges exceed a stage of 26 m, whereas 87% of reconstructed discharges exceed 26 m. Gray area represents the range of meadow surface elevations along Transect 1 (Well 1 ≈ 27.0 m, Well 2 ≈ 28.7 m, Well 3 ≈ 29.0 m).**

Following the peak discharge of the May dam release, there was a subsequent, smaller dam release beginning on May 26 (Figures 2-2 and 2-5). River stage at the downstream recorder rose 2.16 m (7.08 ft) and peaked on May 28 at around 16:00 PST. Well 3 responded quickly with a rise in groundwater level of 1.40 m (7.87 ft) that peaked 14 hours later on May 29 at 06:15 PST. Well 2 responded more slowly (peaking at 14:30 PST on May 29) and with a smaller water level increase of 0.24 m (0.79 ft), as it had not yet fully recovered from the previous inundation. There was no response from any of the groundwater wells along Transect 2.

After the May events there were no other major releases from the dam, aside from the minimum required flows. Data covering the remainder of the study period indicate a gradual drying of the meadows over the course of the summer. On July 1, the USGS gaging station below the dam recorded a shift in discharge from Hetch Hetchy Reservoir from 3.1 to 2.8 cms (111 to 77 cfs). This stepped decrease in flow was detected in Poopenaut Valley at both stage recorders and in Well 3. The groundwater level at Well 3, which had been steady since the end of May, abruptly dropped 0.27 m (0.88 ft), and afterward maintained a new steady plateau of values (Figure 2-2). On September 15 another stepped decrease in Tuolumne River flow (from 2.8 cms to 1.5 cms [77 cfs to 53 cfs]) is apparent in the data from Wells 3 and 11, as well as the upstream stage recorder. The groundwater response was a 0.24 m (0.79 ft) drop at Well 3 (Figure 2-2) and 0.09 m (0.30 ft) at Well 11 (Figure 2-3).

A late-season precipitation event is also visible in Figures 2-2 and 2-3. Approximately 2 cm (0.8 in) of rain (as measured at O'Shaughnessy Dam) fell between September 21 and September 24, 2007. The river stage rose about 0.33 m (1.08 ft) at the upstream stage recorder, while the downstream stage recorder remained dry. Groundwater responded quickly to this rain event by rising 0.50 m (1.64 ft) at Well 3 and 0.18 m (3.28 ft) at Well 11.

### 2.2.3 Discussion

The primary result from our 2007 hydrology work is that relatively small floods can cause large changes in river stage in Poopenaut Valley, which in turn cause relatively rapid saturation of meadow soils. An examination of Figure 2-8 reveals that the river stage generated by the May 21, 2007 event would be exceeded in approximately 30% of growing season days if the river were unregulated compared to 14% under existing conditions. Given that our reconstructed discharges likely underestimate discharges by 4-33%, a 30% exceedence under unregulated conditions can be regarded as a minimum. Even though the duration of the May 2007 dam release was only a few days (with the peak lasting less than a day), this event was sufficient to induce a >1 m (3.28 ft) increase in the water table at Well 1, located approximately 160 m (524.8 ft) away from the river.

Given these results, it is reasonable to assume that a flood of slightly greater duration and magnitude than the May 2007 dam release would be sufficient to saturate most meadow areas, and contribute water to the seasonal pond. Unfortunately, neither the duration nor the magnitude of the May 2007 dam release were sufficient to confirm this assumption. However, simple observations suggest that a flood event such as the June 7, 2006 release of approximately 240 cms (8400 cfs) is probably more than is absolutely necessary to maintain riparian and wet meadow habitat in Poopenaut Valley (at least from the standpoint of water availability), as this event fully inundated much of the western half of the valley (Figures 2-10, 2-11). By combining information on the extent of wetlands, the extent of meadow vegetation exhibiting some wetland characteristics, and information on the hydrologic requirements of wetland soils and plants, it is possible to identify a range of stage-duration frequencies necessary to sustain and/or improve existing conditions.

Goals of future experimental dam releases should include 1) quantifying the time needed to achieve equilibrium between river stage and water table elevation in Poopenaut Valley at a number of different river stages, 2) attain adequate water table elevations in order to create a two-dimensional groundwater model of the area, and 3) identify the magnitude and duration of flooding necessary to saturate all areas exhibiting some wetland characteristics.

**Figure 2-10. Inundation of southwest corner of Poopenaut Valley on June 9, 2006 (left) during ~240 cms (~8400 cfs) event and the same location on May 24, 2007 (right). Wells 1 and 2 are located just beyond the logs in the foreground.**

**Figure 2-11. Inundation of southwest corner of Poopenaut Valley on June 9, 2006 (left) during ~240 cms (~8400 cfs) event and the same location on May 24, 2007 (right).**

## 2.3 Water temperature characterization and comparison

Water impoundment behind dams often has a significant and well-documented affect on downstream river temperatures. Hypolimnial release of water from reservoirs results in depressed water temperatures during periods when natural water temperatures are generally significantly warmer. A typical temperature depression of 5-10 ºC has been documented to have a significant effect on native fish populations including increased juvenile mortality, delayed embryonic development, and depressed swimming performance on fishes in the Colorado River system (e.g. Clarkson and Childs 2000). Aquatic ecosystems downstream of O'Shaughnessy Dam and Hetch Hetchy Reservoir may be impacted by the unnatural (at least during certain times of year) temperature of water flowing down river channel, but the magnitude and duration of temperature depression has not been well documented in the river reach downstream of O'Shaughnessy Dam. For this reason, we collected additional temperature data from the Tuolumne River in Poopenaut Valley, and from the adjacent Merced River.

### 2.3.1 Methods

We recorded water temperature in the Tuolumne River at both river stage recorders in Poopenaut Valley throughout the season, collected concurrently and with the same instrumentation as the river stage data. To quantify the impact of Hetch Hetchy Reservoir, we compared water temperature data from Poopenaut Valley to water temperature data from the Tuolumne River where it enters the upstream end of Hetch Hetchy Reservoir [1167 m (3830 ft)]. In order to compare river temperatures downstream of O'Shaugnessy Dam to those of an unregulated river, we collected equivalent water temperature data from the Merced River with HOBO® Water Temp Pro data loggers at one-hour intervals at three locations on the Merced River (Figure 2-12). These locations were: 1) Foresta Bridge in El Portal [elevation 503 m (1650 ft)], 2) Arch Rock Entrance Station [elevation 869 m (2850 ft)], and 3) Pohono Bridge [elevation 1176 m (3860 ft)]. These three locations were selected because they span a similar elevation to Poopenaut Valley [1012 m (3320 ft) at the stage recorders].

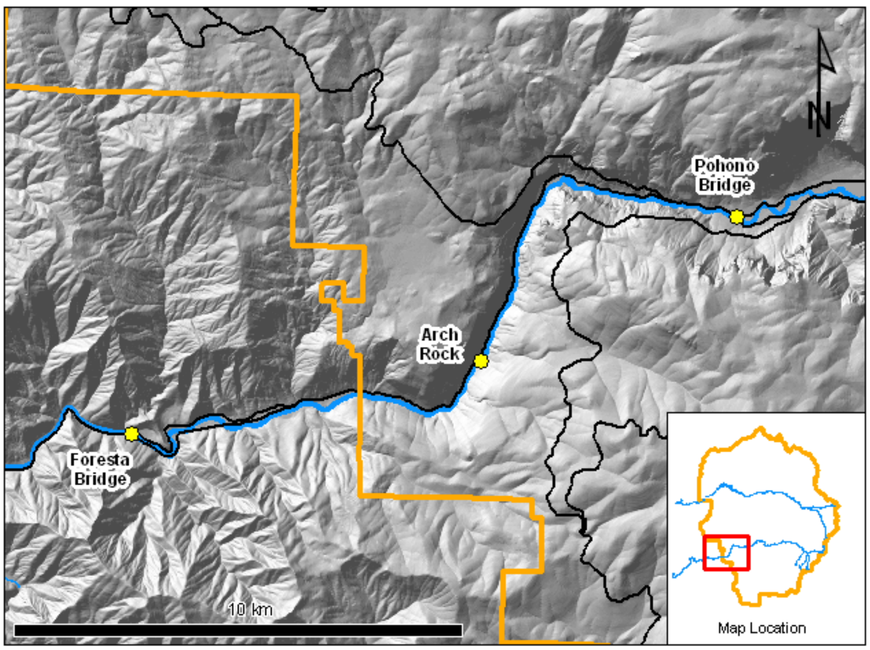


**Figure 2-12. Location of water temperature measuring sites on the Merced River. Heavy black lines are roads, blue are rivers, orange is boundary of Yosemite National Park, yellow dots indicate measurement sites.**

### 2.3.2 Results and Analysis

A comparison of Merced and Tuolumne River temperatures during the study period is displayed in Figure 2-13 along with air temperatures in Poopenaut Valley. The average daily temperatures of the Merced River at the three monitoring locations generally increased from June 15 until July 7, at which point the trend generally leveled off until September 12 and then abruptly decreased until approximately October 12. Over the same period, Tuolumne River daily average temperatures in Poopenaut Valley displayed much less variability and held essentially steady, with a gently decreasing overall trend. Importantly, water temperatures on the Tuolumne River above Hetch

Hetchy reservoir closely matched those observed at Pohono Bridge in Yosemite Valley, at the most similar elevation to Poopenaut Valley. This indicates that water temperature comparisons between the Tuolumne and Merced Rivers are valid, at least for that elevation range.

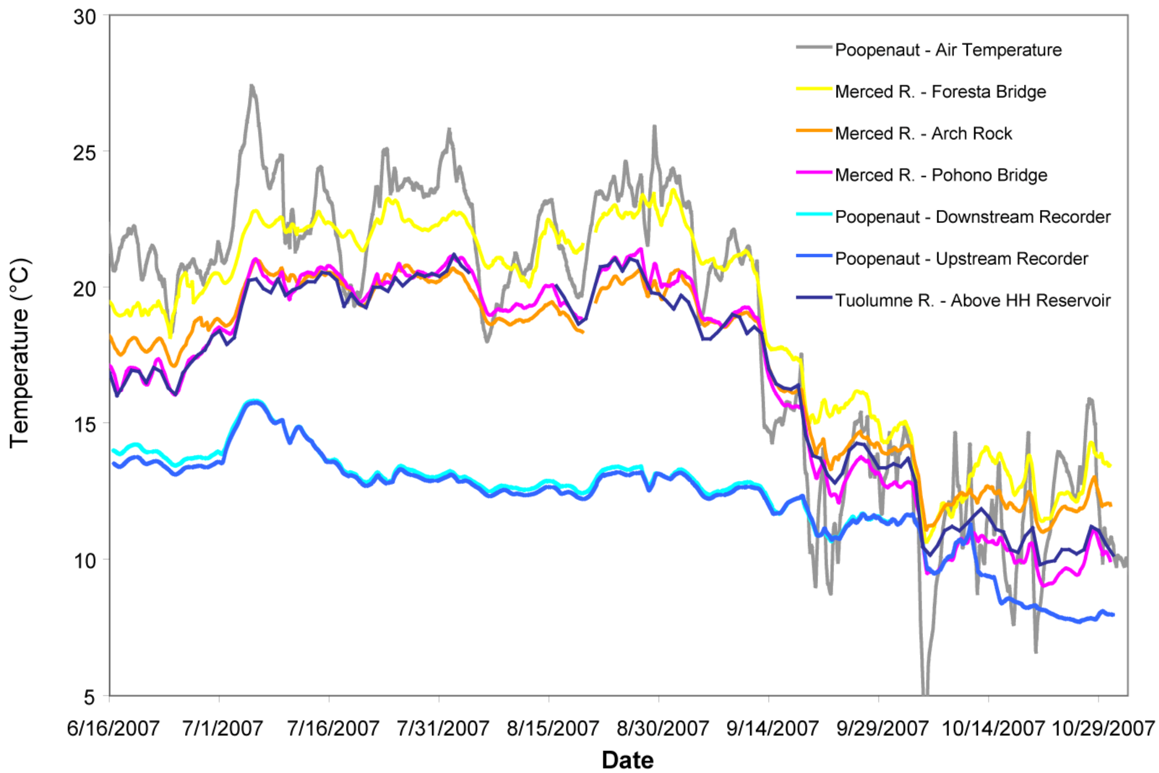


**Figure 2-13. Daily average water temperatures in the Tuolumne and Merced Rivers. Tuolumne River temperatures collected just upstream of Hetch Hetchy Reservoir (dark purple) and at Poopenaut Valley (1012 m, 3320 ft) river stage recorders (light and dark blue). Air temperatures at Poopenaut Valley shown in gray. Merced River temperatures (yellow, orange, and pink) collected at Foresta Bridge (503 m, 1650 ft), Arch Rock (870 m, 2850 ft), and Pohono Bridge (1175 m, 3860 ft).**

The Merced River sites during the summer months in 2007 tended to be about 6-10°C warmer than the Tuolumne River sites below Hetch Hetchy Reservoir (Figure 2-13). Water temperature averaged 20.0°C at Pohono Bridge on the Merced River from July 7 to September 12, 19.8°C at Arch Rock, and 22.0°C at Foresta Bridge. Over the same period, the Tuolumne River was 13.0°C and 13.2°C at the upstream and downstream stage recorders, respectively. However, after September 12, the Merced River temperature decreased markedly while the Tuolumne continued its gradual decline, and the difference in temperature became much less significant (Figure 2-13). The daily average water temperatures for the Merced sites on September 12 were 18.9°C, 18.8°C, and 20.7°C (at Pohono, Arch Rock, and Foresta, respectively). In Poopenaut Valley on that same day, the average water temperature in the Tuolumne was 12.6°C at the upstream site and 12.7°C at the downstream. By October 6, the Merced average daily temperatures had dropped approximately nine degrees (to 9.5°C, 11.2°C, and 10.8°C, respectively) while the Tuolumne had decreased only three degrees at the upstream site (to 9.6°C). The stilling well at the downstream location had gone dry by October 6 and was therefore no longer recording the water temperature, but on October 1 it recorded an average temperature of 11.4°C .

### 2.3.3 Discussion

Water temperatures in the Tuolumne River in Poopenaut Valley were generally 6-8°C below unregulated waters upstream of Hetch Hetchy Reservoir and similar elevational zones on the Merced River during most of the summer. This difference narrowed by mid-September, and future monitoring will elucidate the relationship during the balance of the year. The timing, duration, and magnitude of water temperatures observed in Poopenaut Valley need to be matched with biological requirements of native fauna in order to understand the significance of these findings.

## 2.4 Water quality characterization upstream and downstream of Hetch Hetchy Reservoir

Reservoirs potentially affect water quality conditions downstream of dams by increasing salinity, decreasing dissolved oxygen content, and altering nutrient flux through the system (Collier et al, 2000). In order to establish baseline water quality conditions and assess the first-order impacts of Hetch Hetchy Reservoir on water quality, we sampled for water quality at three locations both upstream and downstream of Hetch Hetchy Reservoir.

### 2.4.1 Methods

We collected water quality samples monthly at one location in the study area and analyzed them for major ion chemistry, nutrients, and dissolved organic carbon. In addition, we measured water temperature, specific conductivity, pH, and dissolved oxygen at each location. Sampling protocols were similar to the Yosemite National Park Visitor Experience and Resource Protection Program (VERP) (NPS, 2006a), that are based on the USGS National Field Manual for the collection of water quality data (USGS, variously dated). The USGS performed all analyses at their National Water Quality Laboratory in Denver, Colorado.

The results from water quality sampling in Poopenaut Valley can be compared with results from sampling upstream of the reservoir and also immediately downstream of the dam, conducted as part of Yosemite's Visitor Experience and Resource Protection (VERP) program (Figure 2-14). Each month, a duplicate sample and a blank (de-ionized water) were also collected at one of these three sites for quality control purposes.

### 2.4.2 Results

The results from the water quality analysis are given in Table 2-4. Values lower than the reporting limit are reported as 'ND' or non-detect. Blank fields indicate that either the sample was not taken or the laboratory did not report a value. In general, the results confirm low levels of nitrogen and phosphorous, similar to those recorded along the Merced River in Yosemite Valley (NPS, 2006b), indicating the overall high water quality in the Tuolumne River basin.

The buffering effect of Hetch Hetchy reservoir with respect to calcium ion and dissolved organic carbon (DOC) data is shown in Figure 2-15. Calcium ion concentration generally increases from 0.90 to 2.81 mg/l through the season in the unregulated part of the river, a function of decreasing river discharge. In contrast, downstream of O'Shaughnessy Dam, calcium ion concentrations are steady through the summer season (ranging from 1.20 to 1.28 mg/l after June 1), reflecting mixing in the reservoir. Other cations exhibit similar behavior.

DOC content shows an inverse trend (Fig. 2-15). DOC is thought to result primarily from soil water contributions to river discharge (Boyer et al, 1997). Upstream of Hetch Hetchy Reservoir, DOC values decrease through the season from 1.82 to 0.54 mg/l. Downstream of O'Shaugnessy Dam, DOC values are nearly constant throughout the season, ranging from 1.12 to 1.45 mg/l. This also reflects mixing in the reservoir.

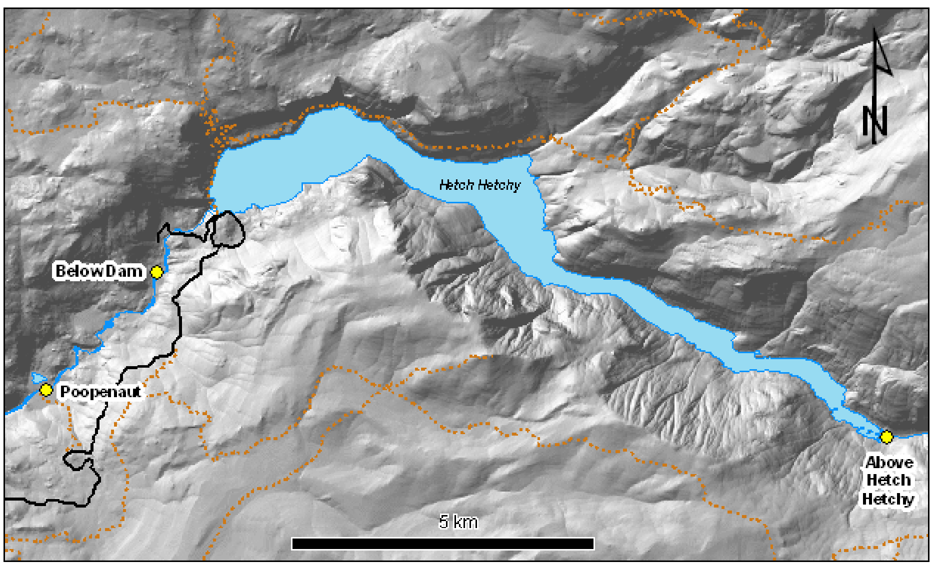


**Figure 2-14. Location map of Tuolumne River water quality sampling sites. Symbols as in Figure 2-10, brown dashed lines are trails.**

### 2.4.3 Discussion

Results of water quality analyses reveal generally good water quality, and this data set provides a baseline against which future analyses can be compared. However, the data also show that water storage in Hetch Hetchy Reservoir significantly alters the natural ebb and flow of water quality downstream of the reservoir. A cursory examination of dissolved oxygen (DO) data suggests no significant depression due to water storage in Hetch Hetchy Reservoir. However, concentrations of other analytes such as calcium ion and DOC clearly show the effects of river water mixing in the reservoir. Future work might examine the ecological effects of DOC in the river during the late dry season, at which time DOC levels downstream of Hetch Hetchy Reservoir are nearly three times greater than levels upstream of the reservoir.

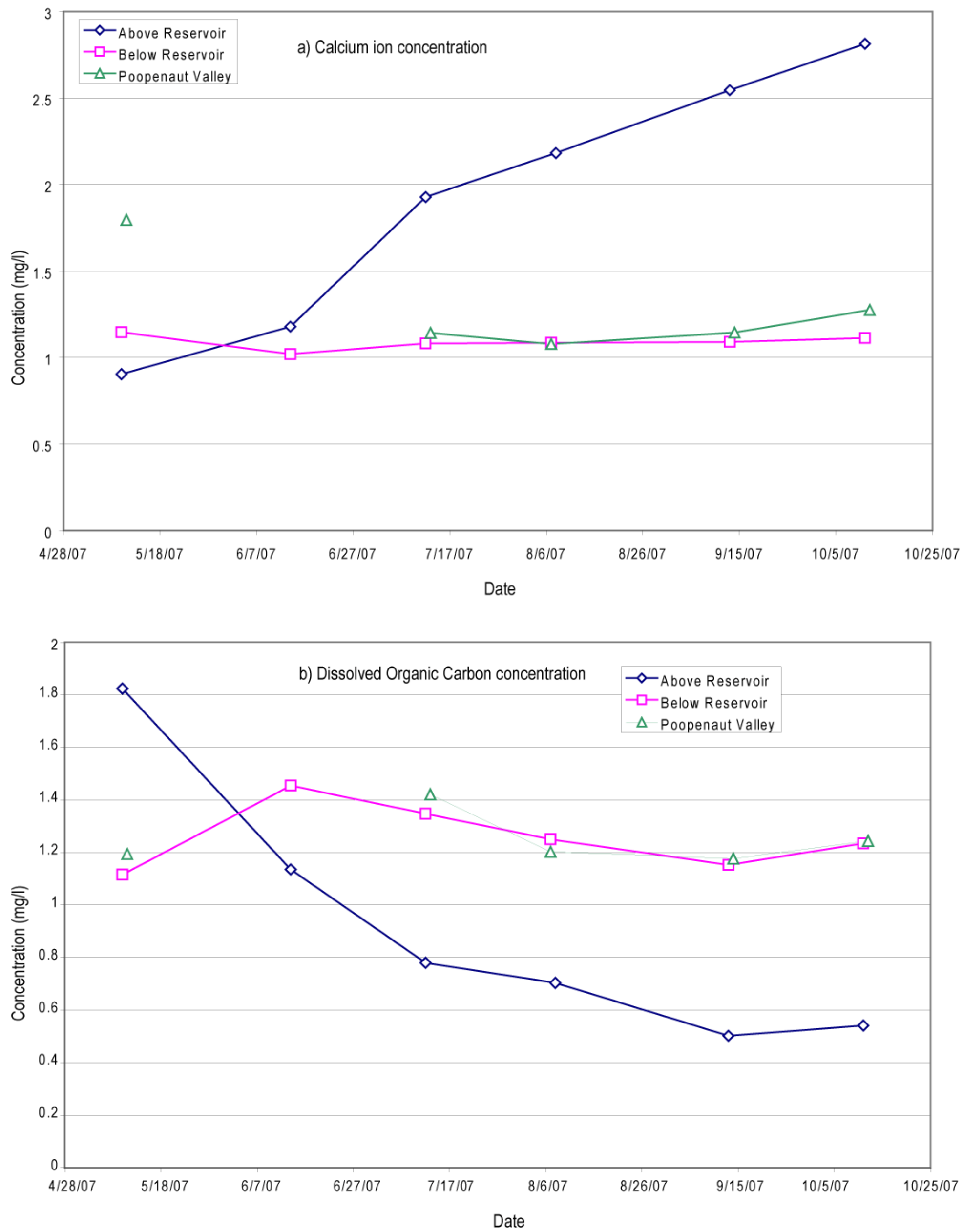


**Figure 2-15. Calcium ion (top) and Dissolved Organic Carbon (DOC) (bottom) concentrations in Tuolumne River, April through October, 2007, as measured upstream and downstream of Hetch Hetchy Reservoir.**

**Table 2-4. Water quality data for 2007 sampling season from Poopenaut Valley and two nearby NPS water sampling sites upstream and downstream of Hetch Hetchy reservoir.**

| Station Name | Date Time (PST) | Temp* (℃) | pH* | DO* (mg/L) | SC* (µS/cm) | Ca (mg/L) | Mg (mg/L) | Si (mg/L) | Na (mg/L) | K (mg/L) | Cl (mg/L) | SO4 (mg/L) | DOC (mg/L) | TDN (mg/L) | NO2+NO3 (mg/L) | TDP (mg/L) | TP (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tuolumne River above Hetch Hetchy | 5/10/07 9:44 | 7.7 | 7.4 | 10.8 | 13 | 0.904 | 0.109 | 4.695 | 1.042 | 0.209 | 0.56 | 0.401 | 1.8238 | 0.069 | ND | ND | ND |
| Tuolumne River below O'Shaughnessy Dam | 5/10/07 13:11 | 11.33 | 8.69 | 7.41 | 11 | 1.146 | 0.135 | 3.713 | 0.854 | 0.249 | 0.432 | 0.45 | 1.1155 | ND | 0.018 | ND | ND |
| Tuolumne River at Poopenaut Valley | 5/11/07 9:08 | 10.9 | | 8.5 | 11 | 1.795 | 0.246 | 6.043 | 1.162 | 0.379 | 0.427 | 0.444 | 1.1939 | ND | ND | ND | ND |
| Tuolumne River at Poopenaut Valley (duplicate) | 5/11/07 9:22 | 10.9 | | 8.5 | 11 | 1.79 | 0.255 | 6.168 | 1.246 | 0.367 | 0.426 | 0.446 | 1.1706 | ND | ND | ND | ND |
| BLANK | 5/10/07 10:07 | | | | 3.33 | 0.053 | ND | 0.076 | ND | | ND | ND | ND | ND | ND | ND | ND |
| | | | | | | | | | | | | | | | | | |
| Tuolumne River above Hetch Hetchy | 6/14/07 10:05 | 14.97 | 7.1 | 8.45 | 10.8 | 1.179 | 0.131 | 3.933 | 1.11 | 0.228 | 0.68 | 0.72 | 1.1354 | ND | ND | | ND |
| Tuolumne River below O'Shaughnessy Dam | 6/14/07 13:00 | 16.1 | 7.4 | 7.2 | 8.6 | 1.02 | 0.129 | 3.882 | 0.875 | 0.234 | 0.471 | 0.437 | 1.4543 | ND | ND | | ND |
| Tuolumne River below O'Shaughnessy Dam (duplicate) | 6/14/07 13:05 | 16.1 | 7.4 | 7.2 | 8.6 | 1.036 | 0.131 | 3.874 | 0.882 | 0.224 | 0.473 | 0.437 | 1.4045 | 0.066 | ND | ND | ND |
| Tuolumne River at Poopenaut Valley | 6/15/07 12:40 | 14.6 | | | 9.57 | 1.166 | 0.151 | 4.243 | 0.947 | 0.256 | 2.34 | 2.163 | 1.4303 | 0.068 | ND | | ND |
| BLANK | 6/14/07 10:10 | | | | | 0.023 | ND | ND | ND | ND | ND | ND | ND | ND | ND | | ND |
| | | | | | | | | | | | | | | | | | |
| Tuolumne River above Hetch Hetchy | 7/12/07 9:36 | 19.02 | 6.41 | 7.07 | 20.1 | 1.928 | 0.2131 | 4.101 | 2.224 | 0.414 | 1.867 | 1.13 | 0.7801 | ND | ND | | ND |
| Tuolumne River above Hetch Hetchy (duplicate) | 7/12/07 9:40 | 19.02 | 6.41 | 7.07 | 20.1 | 1.889 | 0.2163 | 4.056 | 2.281 | 0.406 | 1.876 | 1.153 | 0.7335 | ND | ND | | ND |
| Tuolumne River below O'Shaughnessy Dam | 7/12/07 13:07 | 14.56 | 5.07 | 6.79 | 9.2 | 1.082 | 0.1341 | 3.951 | 0.933 | 0.244 | 0.501 | 0.433 | 1.3472 | 0.076 | ND | | ND |
| Tuolumne River at Poopenaut Valley | 7/13/07 11:49 | 14.5 | | | 8.7 | 1.142 | 0.1429 | 3.998 | 0.9586 | 0.257 | 0.5 | 0.435 | 1.4213 | 0.075 | ND | | ND |
| BLANK | 7/12/07 13:15 | | | | | 0.2861 | 0.0341 | 0.3848 | ND | 0.017 | 0.087 | 0.088 | ND | ND | ND | | ND |
| | | | | | | | | | | | | | | | | | |
| Tuolumne River above Hetch Hetchy | 8/8/07 9:55 | 18.36 | 7.22 | 7.76 | 30 | 2.182 | 0.247 | 4.163 | 2.801 | 0.523 | 2.822 | 1.483 | 0.7037 | 0.071 | 0.034 | | ND |
| Tuolumne River above Hetch Hetchy (duplicate) | 8/8/07 9:59 | 18.36 | 7.22 | 7.76 | 30 | 2.204 | 0.251 | 4.171 | 2.857 | 0.538 | 2.817 | 1.482 | 0.5576 | 0.07 | 0.032 | | ND |
| Tuolumne River below O'Shaughnessy Dam | 8/7/07 15:02 | 12.27 | 7.2 | 9.06 | 11 | 1.086 | 0.13 | 4.161 | 0.921 | 0.24 | 0.525 | 0.454 | 1.2501 | 0.076 | ND | | ND |
| Tuolumne River at Poopenaut Valley | 8/7/07 11:02 | 12.33 | 6.9 | 9.45 | 8 | 1.078 | 0.136 | 4.17 | 0.937 | 0.246 | 0.525 | 0.45 | 1.2026 | 0.071 | ND | | ND |
| BLANK | 8/8/07 9:43 | | | | | 0.184 | 0.028 | 0.267 | ND | | | | ND | ND | ND | | ND |
| | | | | | | | | | | | | | | | | | |
| Tuolumne River above Hetch Hetchy | 9/13/07 11:40 | 18.78 | 7.46 | 7.4 | 36 | 2.545 | 0.294 | 4.729 | 3.454 | | 3.876 | 1.849 | 0.5026 | 0.084 | 0.059 | | ND |
| Tuolumne River below O'Shaughnessy Dam | 9/13/07 14:28 | 13.72 | 7.47 | 5.95 | 13 | 1.091 | 0.137 | 4.145 | 0.903 | | 0.517 | 0.445 | 1.1526 | 0.065 | ND | | ND |
| Tuolumne River below O'Shaughnessy Dam (duplicate) | 9/13/07 14:30 | 13.72 | 7.47 | 5.95 | 13 | 1.089 | 0.136 | 4.134 | 0.9 | | 0.522 | 0.447 | 1.1866 | 0.062 | ND | | ND |
| Tuolumne River at Poopenaut Valley | 9/14/07 10:26 | 12.04 | | 9.53 | 10 | 1.144 | 0.141 | 4.135 | 0.914 | | 0.517 | 0.444 | 1.1766 | ND | ND | | ND |
| BLANK | 9/13/07 11:46 | | | | | 0.22 | 0.026 | 0.304 | ND | | 0.103 | 0.086 | ND | ND | ND | | ND |
| | | | | | | | | | | | | | | | | | |
| Tuolumne River above Hetch Hetchy | 10/11/07 13:05 | 11.81 | 7.46 | 6.98 | 40 | 2.813 | 0.329 | 5.973 | 4.304 | 0.671 | | 1.898 | 0.5413 | ND | 0.038 | | ND |
| Tuolumne River above Hetch Hetchy (duplicate) | 10/11/07 13:10 | 11.76 | 7.47 | 6.64 | 40 | 3.133 | 0.323 | 6.114 | 4.241 | 0.662 | | 1.904 | 0.6145 | ND | 0.039 | | ND |
| Tuolumne River below O'Shaughnessy Dam | 10/11/07 16:37 | 12.11 | 6.98 | 6.94 | 11 | 1.113 | 0.132 | 4.149 | 0.913 | 0.231 | 0.505 | 0.441 | 1.2343 | ND | ND | | ND |
| Tuolumne River at Poopenaut Valley | 10/12/07 13:58 | 12.09 | | 7.76 | 10 | 1.275 | 0.136 | 4.114 | 0.88 | 0.244 | 0.497 | 0.443 | 1.244 | ND | ND | | ND |
| BLANK | 10/11/07 17:29 | | | | | | | | | | | | ND | ND | ND | | ND |
| | | | | | | | | | | | | | | | | | |
| Detection Limit | | | | | | 0.01 | 0.007 | 0.009 | 0.1 | 0.002 | 0.01 | 0.01 | 0.2 | 0.03 | 0.008 | 0.03 | 0.004 |
| Reporting Limit | | | | | | 0.02 | 0.014 | 0.018 | 0.2 | 0.004 | 0.01 | 0.01 | 0.4 | 0.06 | 0.016 | 0.06 | 0.008 |

*** Water temperature, pH, dissolved oxygen, and specific conductivity data measured in field; all other parameters measured at USGS National Water Quality Lab in Denver, CO. Lab detection and reporting limits given as reference. SC = specific conductivity, DO = dissolved oxygen, DOC = dissolved organic carbon, TDN = total dissolved nitrogen, TDP = total dissolved phosphorous, TP = total phosphorous.**

## Chapter 3: Vegetation mapping, wetland delineation, and rare and invasive plant surveys in Poopenaut Valley

### 3.1 Introduction

Altered river flow regimes can initiate profound changes in vegetation, plant community diversity and habitat types. Analyses of the natural flow regime in free-flowing rivers indicate that variability is critical to ecosystem function and biodiversity (Poff et al. 1997). The relationship between the Tuolumne River, its tributaries and adjacent wetlands, uplands, forests and riparian areas in Poopenaut Valley, must be better understood to recognize the magnitude of these changes. Inferences about the conditions of existing plant communities, as related to the current hydrologic regime in Poopenaut Valley, are limited because of the lack of reference sites and knowledge of the plant communities prior to the construction of the O'Shaughnessy Dam. A basic understanding of the relationship between plants and the hydrologic regime is useful to interpret current conditions as well as investigate the potential changes an altered hydrologic regime may have effected.

In general, diminished seasonal flows and moderated floods cause vegetation to encroach on the river channel, thus affecting channel morphology and sediment transport (McBain and Trush 2007a). Wetland plant community composition is most influenced by water table level, canopy cover and amount of drawdown (Allen-Diaz 1991). Altered flows can adversely impact water delivery to wetlands and encourage the spread of invasive plants or those adapted to drier conditions. Changes in vegetation translate to changes in habitat condition and type, affecting wildlife species (Allen-Diaz 1991).

The operations of most dams influence the magnitude, timing, frequency, duration and rate of change or flashiness of the natural flow regime (Poff et al. 1997). All of these components of the hydrologic regime influence vegetation communities, both directly and indirectly. Discharge magnitude directly influences the level and extent of inundation, root saturation and ultimately, wetland extent. Discharge stabilization (both magnitude and frequency) changes the levels and extent of overbank flows and soil saturation, which influence the establishment and persistence of riparian and wetland plant communities. These plants have life cycles that are adapted to the seasonal timing components of the natural flow regime through their "emergence phenologies" – the seasonal sequence of flowering, seed dispersal, germination and seedling growth (Poff et al. 1997). The frequency of high discharge events influences vegetation composition and dominance through the inundation or saturation of the root zone required by hydrophytic plants and the development of hydric soils. Rate of change or flashiness of the hydrologic regime also influences vegetation. For example, a certain rate of floodwater recession is critical to seedling germination of certain species, such as cottonwoods, because seedling roots must remain connected to a receding water table as they grow downward (Rood and Mahoney 1990). Vegetation structure can have important feedbacks and influence future susceptibility to disturbance. For example, high-density vegetation is more resistant to flow than low-density vegetation, resulting in decreased flow velocities and increased sedimentation, both of which may reduce the disturbance effects of future floods (Shafroth et al. 2002). Flashy flows can also impact riverbanks, causing soil scouring, steep cutbanks and decreasing the ability of vegetation to establish and persist.

We mapped plant communities and delineated wetlands in Poopenaut Valley in order to characterize the current conditions in Poopenaut Valley, and to better understand the relationship between plant communities and surface water and groundwater flow regimes.

Between March and October, 2007, we mapped and characterized plant cover and diversity in wetland, upland, forest and riparian ecosystems in Poopenaut Valley. We also conducted surveys of invasive and rare plants, expanding on a rare plant survey of the Tuolumne River corridor completed in 2006. Identification of over one hundred tree, shrub and herbaceous plant species comprise a preliminary list of plant species present in Poopenaut Valley (Table 3-1). Forty-one plots document the vegetation (e.g. plant community composition, plant species abundance, foliar cover) and the physical characteristics (e.g. soils, hydrology, bare ground) that we observed. Eleven vegetation plots are associated with the ground water monitoring wells described in Chapter 2, and 30 vegetation plots are part of the wetland delineation and vegetation mapping efforts.

Wetland and upland meadows comprise most of the valley floor in Poopenaut Valley. Meadows, generally defined as "treeless areas" and dominated by herbaceous vegetation, may describe wetland (inundated for a portion of the year and exhibiting wetland characteristics) or upland (inundated for short periods and not exhibiting wetland characteristics) plant communities. Riparian plant communities, dominated by willows, white alder and black cottonwood, characterize the edges of the Tuolumne River and its tributaries. Forested areas, dominated by ponderosa pine and incense-cedar, border (and have encroached upon) both wetland and upland plant communities and extend to higher elevations above Poopenaut Valley. For the purposes of this report, rather than use the term 'meadow," we refer to herbaceous plant communities as wetland or upland. The observed plant communities are either wetland [Palustrine Emergent (herbaceous)], riparian [Palustrine Shrub/Scrub (riparian shrubland) forested [Palustrine Forested (riparian forest)] or upland [herbaceous and forested]. Plant communities (alliances and associations) follow the most recent Yosemite Floristic Classification system, based on the U.S. National Vegetation Classification (USNVC) and developed by NatureServe (formerly The Nature Conservancy) (NatureServe 2007). A summary of vegetation types (APPENDIX 1) describes the identified alliances and associations in Poopenaut Valley. A formal wetland delineation report (APPENDIX 2) provides information on the extent, species composition and conditions of existing wetlands and deepwater habitats.

**Table 3-1. Plant species observed in Poopenaut Valley (Plant species listed in the Yosemite National Park Special Status Vascular Plant Species List database are BOLD). An asterisk (*) indicates invasive species.**

| Scientific names | Common names | Scientific names | Common names |
|---|---|---|---|
| **NON-NATIVE** | **NON-NATIVE** | **NON-NATIVE** | **NON-NATIVE** |
| **Agrostis gigantean* | Red top | *Brodieaea elegans* | Elegant brodeia |
| **Aira caryophylla* | Silver hairgrass | *Bromus carinatus* | California brome |
| **Avena barbata* | Slender wild oat | *Calamagrostis canadensis* | Blue-joint reedgrass |
| **Bromus arenarius* | Australian brome grass | *Carex athrostachya* | Carex athrostachya |
| **Bromus diandrus* | Ripgut brome | *Carex douglasii* | Douglas sedge |
| **Bromus hordeaceous* | Soft chess | *Carex feta* | Green-sheathed sedge |
| **Bromus tectorum* | Cheatgrass | *Carex fracta* | Carex fracta |
| **Cirsium vulgare* | *Bull thistle | *Carex integra* | Carex integra |
| **Erodium cicutarium* | Erodium | *Carex lanuginosa* | Wooly sedge |
| **Euphorbia crenulata* | *Chinese caps | *Carex pragracilis* | Clustered field sedge |
| **Galium aperine* | Goose grass | *Carex senta* | Rough sedge |
| **Holcus lanatum* | Velvet grass | *Carex sp.* | Sedge species |
| **Hypericum perforatum* | *Klamathweed | *Carex vesicaria* | Inflated sedge |
| **Lactuca tatarica ssp. pulchella* | Blue lettuce | *Carex whitneyi* | Whitney's sedge |
| **Mollugo verticillata* | Mollugo | *Chamaesyce serpyllifolia ssp. serpyllifolia* | Prostrate spurge |
| **Phleum pratense* | Sweet timothy | *Chlorogalum pomeridianium* | Soap plant |
| **Plantago lanceolata* | Plantain | *Clarkia williamsonii* | William's clarkia |
| **Poa bulbosa* | Bulbous bluegrass | *Claytonia parviflora* | Miner's lettuce |
| **Poa pratensis* | Kentucky bluegrass | *Collinsia parviflora* | Blue-eyed Mary |
| **Rumex acetocella* | Sheep sorrel | *Collinsia torreyi* | Torrey's Blue-eyed Mary |
| **Rumex crispis* | Curly dock | *Comandra umbellatum* | Bastard toad-flax |
| **Sonchus asper* | Prickly lettuce | *Conyza canadensis* | Horse weed |
| **Stellaria media* | Common chickweed | *Cordylanthus rigidus ssp. rigidus* | Bird's beak |
| **Sisimbrium officionale* | Hedge mustard | *Cryptantha sp.* | Popcorn flower |
| **Taraxacum officionale* | Dandelion | *Elymus glaucus* | Blue wildrye |
| **Tragopogon dubious* | Salsify | *Epilobium halleanum* | Willowherb |
| **Verbascum thapsis* | *Wooly mullein | *Equisetum arvense* | Common horsetail |
| **Vulpia microstachya* | Vulpia | *Equisetum laegivatum* | Smooth scouring rush |
| **Vulpia myuros* | Foxtail fescue | *Eriodycton californica* | Yerba santa |
| **HERBS** | **HERBS** | *Eriogonum nudum* | Buckwheat |
| *Achillea millefolia* | Yarrow | *Eriogonum sp.* | Buckwheat |
| *Achnatherum lemmonii* | Lemon's needlegrass | *Eriophyllum sp.* | Wooly sunflower |
| *Agastache urticifolia* | Horse mint | *Euthamia occidentalis* | Western goldenrod |
| *Agrostis scabra* | Bentgrass | *Galium bolanderi* | Bolander's bedstraw |
| *Agrostis sp.* | Bentgrass | *Galium trifidum* | Bedstraw |
| *Agrostis thruberiana* | Ticklegrass | *Galium triflorum* | Sweet scented bedstraw |
| *Apocynum cannabinum* | Indian hemp | *Gilia capitatum* | Blue gilia |
| *Arabis glabra var. glabra* | Tower mustard | *Gnaphalium palustre* | Lowland cudweed |
| *Artemisia douglasiana* | Mugwort | *Helenium bigelovii* | Bigelow's sneezeweed |
| *Artemisia dracunculus* | Tarragon | ***Helianthus californica*** | **California sunflower** |
| *Asarum hartwegii* | Wild ginger | *Heracleum lanceolata* | Cow parsnip |
| *Asclepias cordifolia* | Purple milkweed | *Heuchera micrantha* | Small-flowered alumroot |
| *Ascelepia speciosa* | Showy milkweed | *Hordeum brachyantherum* | Meadow barley |
| *Barbarea orthocerus* | Winter cress | *Hypericum formosum* | St. John's wort |
| *Botrychium multifidum* | Leathery grape-fern | *Iris missouriensis* | Meadow iris |

| Scientific names | Common names | Scientific names | Common names |
|---|---|---|---|
| *Juncus sp.* | Rush | *Stellaria longipes* | Long-stalked starwort |
| *Keckelia brevifolia* | Yawning penstemon | *Thalictrum fendleri var. fendleri* | Fendler's meadow rue |
| *Lessingia leptoclada* | Sierra lessingia | *Trichostema lanceolatum* | Vinegar weed |
| *Leymus triticoides* | Beardless wildrye | *Trifolium willdenovii* | Tomcat clover |
| *Linanthus dichotomus* | Evening snow | *Trifolium sp.* | Clover |
| ***Lindernia dubia var. anagallidea*** | **False pimpernel** | ***Trillium angustepetalum*** | **Giant trillium** |
| *Lotus purshianus* | Spanish clover | *Veratrum californica* | Corn lily |
| *Lupinus albicaulis* | Narrow-winged lupine | *Vicia americana* | American vetch |
| *Lupinus nana* | Sickle-keel lupine | *Viola macloskeyi* | White violet |
| *Lupinus stiversii* | Harlequin lupine | *Viola purpurea* | Mountain violet |
| *Madia elegans* | Tarweed | *Viola sheltonii* | Fan violet |
| ***Madia yosemitana*** | **Yosemite tarweed** | *Wyethia elata* | Mules ears |
| *Melica aristata* | Awned melic | *Zigadenus venenosus* | Death camas |
| *Mentha arvensis* | Field mint | **SHRUBS** | **SHRUBS** |
| ***Mimulus filicaulis*** | **Slender-stemmed monkeyflower** | *Alnus rhombifolia* | White alder |
| *Mimulus moschatus* | Musk monkeyflower | *Amelanchier utahensis* | Serviceberry |
| *Mimulus pulchellus* | Pansy monkeyflower | *Arctostaphylos viscida* | White-leaf manzanita |
| *Mimulus sp.* | Monkeyflower | *Ceanothus cuneatus var. cuneatus* | Little-leaf ceanothus |
| *Monardella sp.* | Pennyroyal | *Cornus sericea* | Red osier dogwood |
| *Oenothera elata* | Evening primrose | *Philadelphus californicus* | Mock orange |
| ***Orobanche californica ssp.grayana*** | **California broom rape** | *Prunus virginiana var demissa* | Western chokecherry |
| *Osmorhiza chilensis* | Sweet cicily | *Rhamnus rubra* | California coffeeberry |
| *Panicum acuminatum (Dichanthelium acuminatum)* | Panic grass | *Ribes roezlii* | Sierra gooseberry |
| *Penstemon sp.* | Penstemon | **Rubus discolor* | *Himalayan blackberry |
| *Phacelia sp.* | Phacelia | *Salix exigua* | Narrow-leafed willow |
| *Phacelia mutabilis* | Phacelia | *Salix laegivata* | Red willow |
| *Plagiobothrys/Cryptantha sp.* | Fiddleneck | *Salix lasiolepis* | Arroyo willow |
| *Polygonum sp.* | Knotweed | *Salix lucida ssp. lasiandra* | Shiny willow |
| *Potentilla gracilis* | Slender cinquefoil | *Salix melanopsis* | Dusky willow |
| *Prunella vulgaris* | Selfheal | *Sambucus mexicanum* | Elderberry |
| *Pteridium aqulinum* | Bracken fern | *Symphorocarpus mollis* | Snowberry |
| *Ranunculus sp.* | Buttercup | *Toxicodendron diversilobium* | Poison oak |
| *Rorripa curvasaliqua* | Western yellow cress | **TREES** | **TREES** |
| *Sarcodes sanguinea* | Snow plant | *Caloderus decurrens* | Incense-cedar |
| *Scirpis acutus var. occidentalis* | Tule | *Quercus chrysolepis* | Interior live oak |
| *Sisyrinchium bellum (or idahoense var. occidentalis)* | Blue-eyed grass | *Quercus kelloggii* | California black oak |
| *Solanum xanti* | Purple nightshade | *Pinus ponderosa* | Ponderosa pine |
| *Solidago californica* | California goldenrod | *Populus balsamifera ssp. trichocarpa* | Black cottonwood |
| *Solidago canadensis* | Canada goldenrod | *Pseudotsuga mensiezii* | Douglas-fir |
| *Stachys albens* | Hedgenettle | **166 species, 29 non-native** | |

### 3.2 Vegetation Mapping

We used the Yosemite floristic classification system (NatureServe 2007) to describe the plant communities observed in Poopenaut Valley. This classification system, including species lists, dichotomous keys, and community descriptions, is based on over 1900 vegetation sampling plots spread throughout Yosemite National Park and environs and represents the most current, comprehensive, and finest scale vegetation classification system for Yosemite National Park. The plant communities in Poopenaut Valley are comprised of nine plant communities described according to the Yosemite floristic classification system and two plant communities that were not ascribable to this classification system. Further investigations may prove that these two vegetation types, possibly unique, do in fact occur in other parts of the park but cover too small of an area, have not been sampled, or are a result of the impaired hydrologic regime in Poopenaut Valley.

Table 3-2 summarizes the eleven vegetation types described, including the name (common), area (in hectares), type (wetland, riparian or upland) and the dominant species observed. The two vegetation types with an asterisk (*) indicate those that are not supported by the Yosemite floristic classification. Refer to APPENDIX 1 for a complete description of these vegetation types and a list of observed plant species (scientific names). Figure 3-1 shows the spatial extent of these vegetation types in Poopenaut Valley.

**Table 3-2. Summary of vegetation types identified in Poopenaut Valley.**

| Vegetation Types | Area (ha) | Type | Dominant Species |
|---|---|---|---|
| * Beardless Wildrye – Mugwort - Western Goldenrod Herbaceous Vegetation | 3.1 | Wetland | Beardless wildrye, mugwort, western goldenrod, sedges |
| Tule Herbaceous Alliance | 2.85 | Wetland | Tule |
| Inflated sedge Herbaceous Association | 0.45 | Wetland | Inflated sedge |
| Kentucky Bluegrass Herbaceous Association | 0.77 | Wetland | Kentucky bluegrass, sedges, Indian hemp |
| Arroyo Willow Shrubland Alliance | 2.51 | Riparian | Arroyo willow, shiny willow, dusky willow |
| Sparsely Vegetated (Sandbar) | 1.34 | Riparian | Dusky willow, wooly mullein |
| Black Cottonwood Forest Association | 0.77 | Riparian | Black cottonwood |
| * Bracken Fern - Soap Plant Herbaceous Association | 4.82 | Upland | Bracken fern, soap plant |
| Ripgut - Soft Chess - Red Brome Herbaceous Alliance | 1.74 | Upland | Cheatgrass, sheep sorrel, Sierra lessingia |
| Ponderosa Pine- Incense-cedar – California Black Oak Forest Association | 5.7 | Upland | Ponderosa pine, incense cedar, California black oak |
| Incense Cedar – White Alder Forest | 0.61 | Upland | Incense cedar |

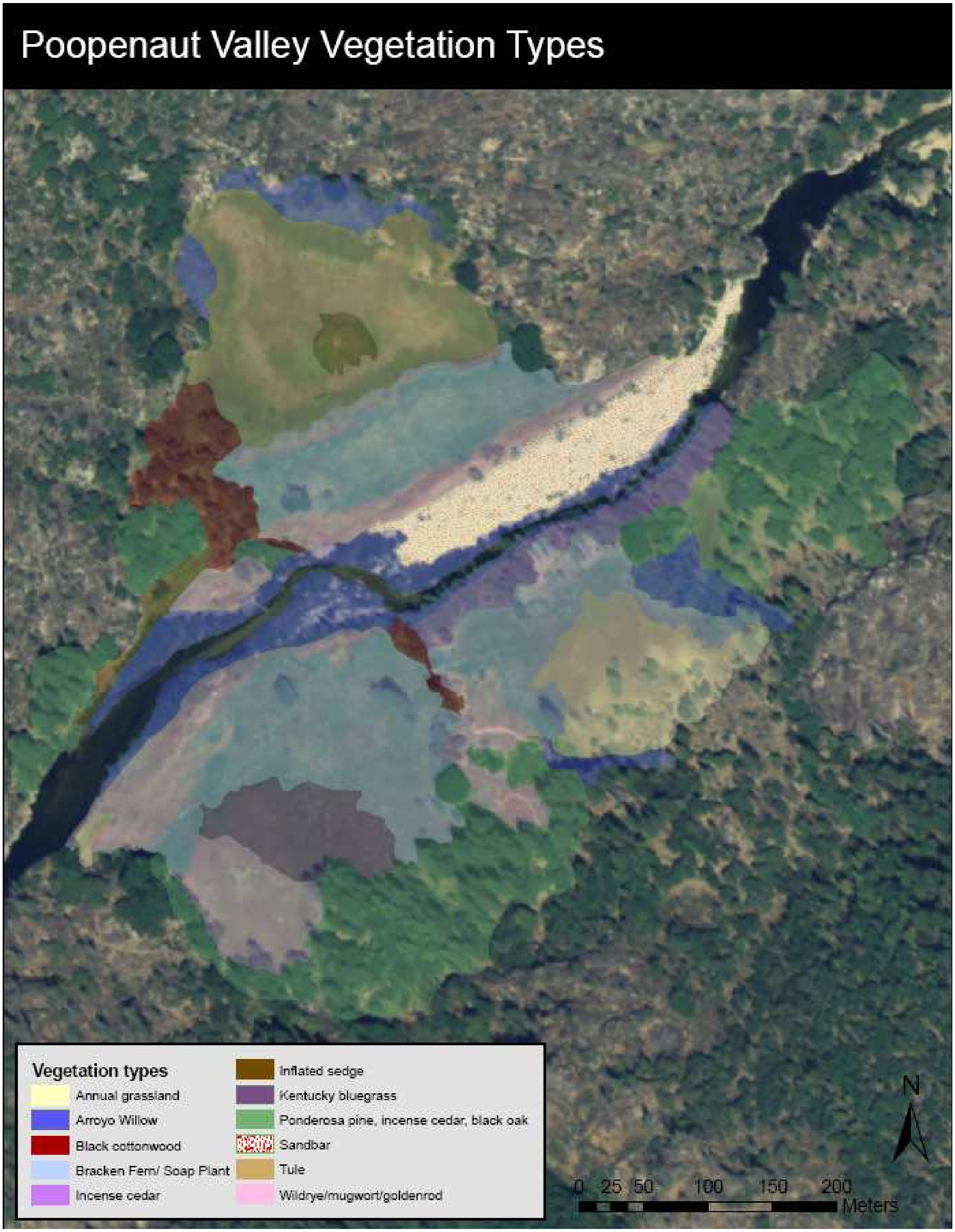


**Figure 3-1. Map of vegetation types in Poopenaut Valley.**

### 3.3 Wetland Delineation

In addition to mapping vegetation types in Poopenaut Valley, we delineated wetlands according to the Cowardin system (Cowardin et al 1979). A wetland delineation and classification of deepwater habitats based on this system provides a baseline of current wetland habitat extent in Poopenaut Valley. The Cowardin system is a hierarchical, ecosystem-based classification of wetlands and deepwater habitats that was developed by the United States Fish and Wildlife Service (USFWS) and other federal agencies for the purposes of wetland inventory, evaluation, and management (Cowardin et al. 1979). The system was formally adopted by the U.S. Department of the Interior in 1996 as a departmental standard for classifying and inventorying wetlands and deepwater habitats (National Park Service 1998a), and is cited as the preferred system of wetland classification in the National Park Service's procedural manual for wetland protection (National Park Service 1998b). To meet the requirements of both the Clean Water Act (CWA) Section 404 and NPS wetland protection policies and procedures described in NPS *Director's Order #77-1: Wetland Protection* (NPS 1998a), CWA Section 404 provides regulation to those areas meeting the federal jurisdiction criteria for waters of the United States (including applicable wetlands), and it defines wetlands as:

> "areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions" (Title 33, Code of Federal Regulations [CFR], Section 328.3 and 40 CFR 230.3).

The regulation authority of CWA Section 404 is upheld by the U.S. Army Corps of Engineers (USACE), which also is responsible for developing the current method of federal jurisdictional wetland determination and delineation: *Corps of Engineers Wetlands Delineation Manual* (1987 Manual), (Environmental Laboratory 1987).

A wetland is determined by dominance (greater than 50%) of hydrophytic vegetation (adapted to periods of inundation or saturation of the root zone), presence of hydric soils (exhibiting reducing or anoxic features) and evidence of or observed wetland hydrology (e.g., inundation/saturation of the root zone, water marks, sedimentation, oxidized root channels, local soil survey, driftlines, water-stained leaves, depressions and stream gauge data). The Natural Resources Conservation Services (NRCS) maintains a list of hydrophytic plants and their accordant wetland status (likelihood of occurring in a wetland), (NRCS 2008). These wetland indicators are coded as; obligate wetland (OBL), (> 99 percent occurrence), facultative wetland (FACW), (67-98 percent occurrence), facultative (FAC), (34-66 percent occurrence), facultative upland (FACU), (1-33 percent of the time) and obligate upland (UPL), (< 1 percent occurrence in wetlands), (Lewis 2003). A detailed scrutiny of the vegetation, soils, and hydrology, with formal representative wetland and upland sample plots, provide information to determine specific wetland boundaries. According to this assessment, eleven Palustrine Emergent Wetlands (8.09 hectares), seven Palustrine Shrub/scrub Wetlands (2.34 hectares) and one Palustrine Broad-leaved Forested Wetland (0.13 hectare) exhibited wetland conditions. Figure 3-2 shows the spatial distribution of delineated wetlands in Poopenaut Valley. The complete wetland delineation report (APPENDIX 2) describes the nineteen wetlands, the importance of wetland habitat and their relationship to the hydrologic regime.

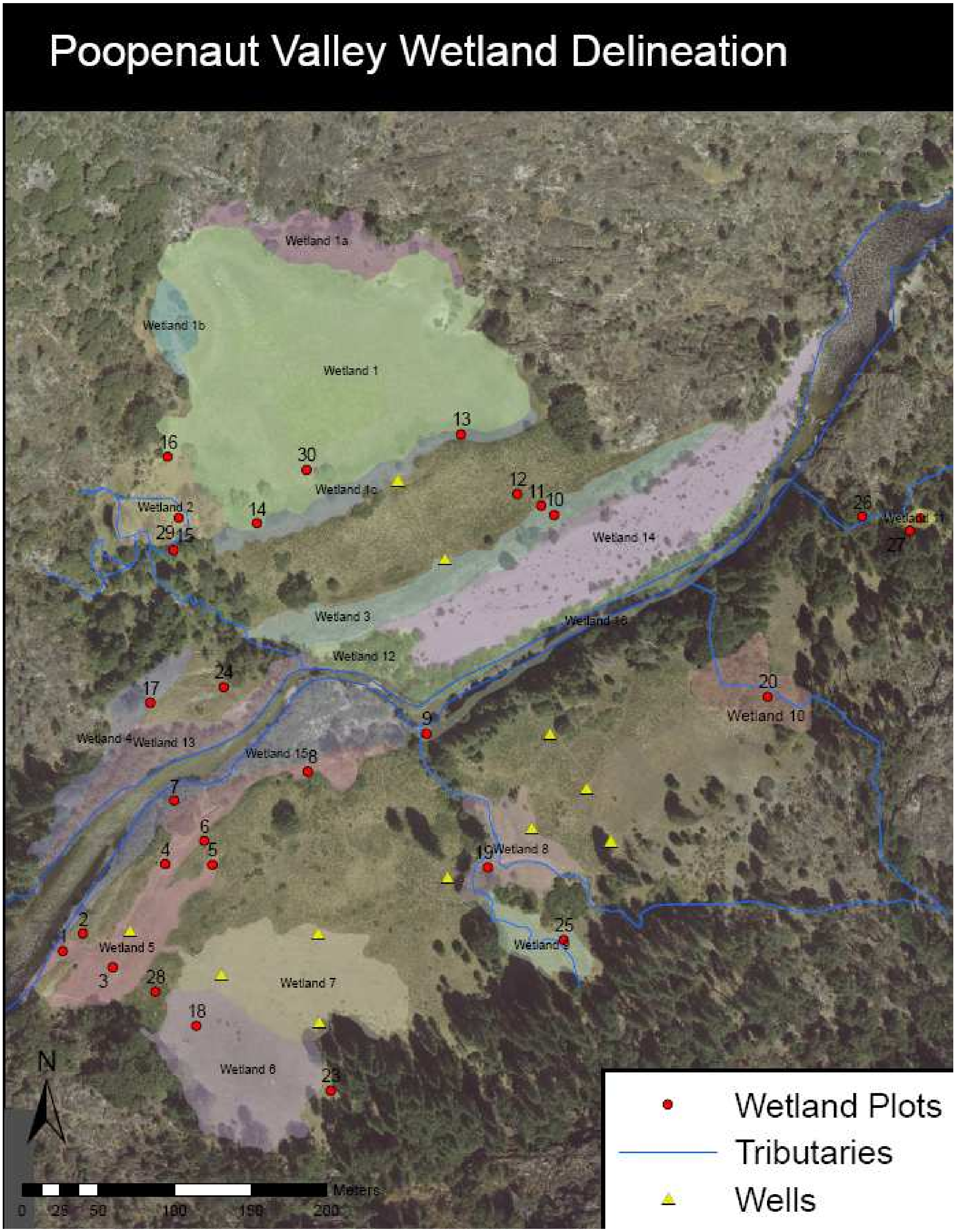


**Figure 3-2. Delineated Wetlands in Poopenaut Valley.**

### 3.4 Vegetation community descriptions

### 3.4.1 Wetland plant communities

Poopenaut Valley contains wetland areas, which are closely linked to river levels and are important indicators of the potential impacts of altered hydrologic regimes. These wetland areas perform many functions to help sustain the integrity of the hydrologic and biotic resources in the area. These functions, some of which are common to most wetlands in general, include storm water run-off abatement, sediment retention (especially with regard to habitats on the banks of rivers/streams), aquifer recharge, prevention of erosion through stream bank stabilization, and stream/river temperature moderation (Mitsch and Gosselink 2000). Forested wetlands in particular are substantial contributors of large woody debris (LWD) to riverine systems, an important component in wetland and riparian ecosystems. These wetlands also provide important habitat for an abundance of birds, amphibians, reptiles, mammals, fish and invertebrates.

Seven vegetation types represent the delineated wetlands in Poopenaut Valley (Table 3-3). Of these, three vegetation types are of particular interest. Tule *(Scirpus acutus var. occidentalis)* dominates the vegetation of the seasonal pond area (Figure 3-3), except the very center of the pond, where inflated sedge (*Carex vesicaria)* dominates (Figure 3-4). Tule is uncommon in Yosemite National Park and occurs only in areas of standing water at elevations between 1100-1200 meters.

**Figure 3-3. Tule in seasonal pond.**

**Figure 3-4. Inflated sedge in seasonal pond.**

One vegetation type, not ascribable to the Yosemite floristic classification system, dominates most of the delineated wetlands (Figure 3-5). The species dominating these stands, beardless wildrye (*Leymus triticoides)*, mugwort (*Artemisia douglasiana*), and western goldenrod *(Euthamia occidentalis)*, occur in other low-elevation meadows in Yosemite Valley (also with altered hydrologic conditions), but more commonly in low percentages in wetlands dominated by sedges *(Carex spp.)*. A nationally recognized Wooly Sedge [*Carex pellita (C. lanuginosa)*] herbaceous alliance is comprised of similar species and it is noted that when degraded (from grazing or altered hydrologic regimes), non-native forage species such as Kentucky bluegrass *(Poa pratensis)* and red top *(Agrostis stolonifera/gigantea)* dominate (NatureServe 2007). Sedges are present in all of the observed wetlands in Poopenaut Valley but at relatively low cover (15-40%). This vegetation type could represent a plant community formerly dominated by sedges transitioning to one dominated by grasses and forbs, in response to the altered hydrologic regime.

Kentucky bluegrass *(Poa pratensis)* is prevalent to some degree in most herbaceous plant communities in Poopenaut Valley, excluding very wet areas. It typically establishes in the transitional zone between wet and dry meadows and is most likely present due to the historic introduction of seed to improve forage for sheep and cattle (NatureServe 2007). There is a history of grazing of sheep and cattle in Poopenaut Valley but the extent, duration and intensity is unknown. One area, dominated by Kentucky bluegrass and mapped as that vegetation type, exhibited hydric soils and some hydrophytic vegetation (slightly more than 50%) but had very weak hydrologic indicators and a higher percentage of upland plant species than the adjacent wetlands (Figure 3-6). Based on the three wetland indicators, this area did display wetland characteristics but appears to be transitioning to more upland vegetation, possibly due to the current hydrologic regime.

**Figure 3-5. Kentucky bluegrass-dominated area. Figure 3-6. Kentucky bluegrass-dominated area.**

**Table 3-3: Vegetation Types and associated hydrologic features of wetlands identified in Poopenaut Valley (all wetlands are Palustrine)**

| Wetland | Wetland Type | Vegetation Type | Hydro Feature | Area (ha) |
|---|---|---|---|---|
| **1** | Emergent | Tule Herbaceous Alliance and Inflated Sedge Association | Pond | 3.0 |
| **1a** | Shrub/Scrub | Arroyo Willow Shrubland Alliance | Pond | 0.37 |
| **1b** | Shrub/Scrub | Arroyo Willow Shrubland Alliance | Pond | 0.13 |
| **1c** | Emergent | Beardless Wildrye- Mugwort - Western Goldenrod | Pond | 0.24 |
| **2** | Broad-leaf Forested | Black Cottonwood Forest | Tributary 1 | 0.13 |
| **3** | Emergent | Beardless Wildrye- Mugwort - Western Goldenrod | Tuolumne River | 0.59 |
| **4** | Emergent | Inflated Sedge Association | Tuolumne River | 0.21 |
| **5** | Emergent | Beardless Wildrye- Mugwort - Western Goldenrod and Inflated Sedge Association | Tuolumne River | 0.67 |
| **6** | Emergent | Beardless Wildrye- Mugwort - Western Goldenrod | Tuolumne River | 0.76 |
| **7** | Emergent | Kentucky Bluegrass Alliance | Tuolumne River | 0.75 |
| **8** | Emergent | Beardless Wildrye- Mugwort - Western Goldenrod | Tributary 2 | 0.3 |
| **9** | Emergent | Beardless Wildrye- Mugwort - Western Goldenrod | Tributary 2 | 0.19 |
| **10** | Shrub/Scrub | Arroyo Willow Shrubland Alliance | Tributary 3 | 0.28 |
| **11** | Shrub/scrub | Beardless Wildrye- Mugwort - Western Goldenrod | Tributary 4 | 0.03 |
| **12** | Shrub/scrub | Arroyo Willow Shrubland Alliance | Tuolumne River | 0.45 |
| **13** | Shrub/scrub | Arroyo Willow Shrubland Alliance | Tuolumne River | 0.38 |
| **14** | Emergent | Sparsely Vegetated | Tuolumne River | 1.34 |
| **15** | Shrub/scrub | Arroyo Willow Shrubland Alliance | Tuolumne River | 0.57 |
| **16** | Shrub/scrub | Arroyo Willow Shrubland Alliance | Tuolumne River | 0.16 |

### 3.4.2 Riparian plant communities

Riparian vegetation plays an important role in maintaining riparian ecosystem function by promoting stream bank stability and maintaining water quality, reducing the potential for erosion, increasing the storage of nutrients and water, and providing critical forage and habitat for wildlife, particularly birds (Knopf et al. 1988, Rood et al. 1995).

Willow shrubland and black cottonwood forest, described in the Yosemite floristic classification system (NatureServe 2007), represent the riparian plant communities in Poopenaut Valley. The willow shrublands are comprised of five willow species, arroyo willow *(Salix lasiolepis)*, shiny willow *(S. lucida ssp. lasiandra)*, red willow *(S. laegivata)*, dusky willow *(S. melanopsis)* and narrow-leafed willow *(S. exigua),* and make up two distinct willow-dominated communities.

Adjacent to the Tuolumne River, shiny willow typically comprises the overstory in tree form with dusky willow, arroyo willow and narrow-leafed willow comprising the understory (Figure 3-7). In some areas, there is little understory herbaceous vegetation and shiny willow stands appear even aged (Figure 3-8). Adjacent to the tributaries and the pond, arroyo willow (in shrub form) dominates, with a smaller component of red willow (in tree form), and exhibits a high herbaceous cover in the understory (> 80%). Some regeneration (vegetative) is present adjacent to the Tuolumne River but stands adjacent to tributaries and the seasonal pond appear to be even aged. Detailed maps of species dominance are available but not presented in this report.

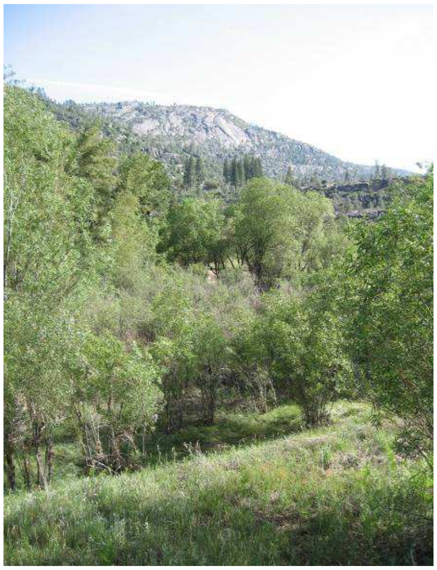

**Figure 3-7. Willow adjacent to Tuolumne River. Figure 3-8. Shiny willow with sparse understory.**

Most of the black cottonwood *(Populus balsamifera)* forests in Poopenaut Valley are associated with tributaries rather than with the Tuolumne River. Most stands are associated with Tributaries 1 and 3, besides a few single trees approximately fifty meters north of the Tuolumne River (Figure 3-9). Most stands are even aged with significant (> 80%) herbaceous cover and some cottonwood saplings in the understory, indicating that some active regeneration is occurring under the current hydrologic regime (Figure 3-10). Only one small portion of black cottonwood forest exhibits wetland characteristics, as the majority of the black cottonwood forests do not exhibit wetland characteristics, have significant upland plant cover and have no indicators of wetland hydrology.

**Figure 3-9. Black cottonwoods.**

**Figure 3-10. Cottonwood saplings.**

There is an extensive sandbar on the north side of the Tuolumne River that is sparsely vegetated with dusky willow, narrow-leafed willow and some invasive species, such as wooly mullein *(Verbascum thapsis)* and Himalayan blackberry *(Rubus discolor)*. A distinct belt of willow and alder establishment associated with low base flow levels characterizes this sandbar [Figure 3-11 at 3 cms (100 cfs) and Figure 3-12 at 56 cms (2000 cfs)].

**Figure 3-11. Riparian vegetation at low discharge.**

**Figure 3-12. Riparian vegetation at higher discharge**

### 3.4.3 Upland plant communities

Upland (i.e., non-wetland) plant communities characterize over half of Poopenaut Valley, although some degree of hydrophytic vegetation is present in all uplands. Upland areas bordering wetlands, specifically forests, provide important habitat for wildlife and are an integral part of the wetland and riparian systems. Upland forests contribute nutrient pulses, coarse woody debris, temperature moderation through shading, and habitat for emergent aquatic invertebrates.

Four upland plant communities (two herbaceous and two forested) are described according to the Yosemite floristic classification system (NatureServe 2007). The first upland plant association, Bracken Fern - Soap plant *(Pteridium aquilinum - Chlorogalum pomeridianum),* is not supported by the Yosemite floristic classification and has not been observed elsewhere in Yosemite National Park, particularly with the high abundance of soap plant observed in Poopenaut Valley (Figure 3-13). Bracken fern is often associated with and observed on wetland borders and under the shade of ponderosa pine and California black oak, but typically comprises small areas and does not represent a separate vegetation type. In Poopenaut Valley, this association borders nearly all of the identified wetlands and hydrologic features on slightly higher terraces and benches (Figure 3-14). Soils in these areas are very dark and could be hydric, suggesting that these areas formerly had wetland-type hydrology. The other upland herbaceous plant community observed in Poopenaut Valley is annual grassland dominated by non-native plants and is discussed in the non-native plant section below.

**Figure 3-13. Bracken Fern-Soap Plant community.**

**Figure 3-14. Bracken fern on terrace.**

Forests, dominated by ponderosa pine *(Pinus ponderosa),* incense-cedar *(Calocedrus decurrens)* and California black oak *(Quercus kelloggii)* occupy some terraces within the valley and at higher elevations above the valley (Figure 3-15). These stands typically exhibit older California black oak shaded by taller and younger ponderosa pine with incense-cedar comprising the middle and understory. Most of the ground surface is comprised of a thick litter and duff layer.

**Figure 3-15. Mixed ponderosa pine/incense-cedar/ California black oak forest.**

**Figure 3-16. Stand of incense-cedar.**

South of and adjacent to the Tuolumne River there is a belt of incense-cedar on a bench approximately 3 m (10 ft) above the base flow level (Figure 3-16). Conifer (ponderosa pine and incense-cedar) encroachment into existing wetlands, as observed in other meadow systems in Yosemite National Park (also with altered hydrologic regimes), is occurring here to some degree. Additional conifer encroachment on the sourthernmost edge of Poopenaut Valley is comprised of two distinct age groups of ponderosa pine and covers 0.26 ha.

### 3.5 Non-native plants

Of the nearly 1500 plant species identified in Yosemite National Park, 127 are non-native or invasive (Botti 2001). Non-native plants, specifically those considered to be invasive, incur both economic and ecological costs. They displace native plants, alter nutrient cycling and reduce habitat and food sources for native insects, birds and wildlife. They can also affect changes on natural processes such as hydrologic and fire regimes. In some cases, dam operations and water diversions such as those at O'Shaughnessy Dam can promote the spread of non-native plants by altering the timing, frequency, duration, and magnitude of floods that would otherwise discourage growth of non-native plants.

Through targeted surveys for non-native plants, with emphasis on invasive plants, we detected twenty-seven non-native plant species, five of which are considered invasive, in Poopenaut Valley in 2007 (Table 3-1). We mapped population locations (Figure 3-17) and recorded the approximate number of plants and physical characteristics of the site. Although eradication efforts did not occur due to time constraints, maps of invasive plant abundance and distribution will direct future eradication efforts.

Three invasive species, wooly mullein (*Verbascum thapsis*), Himalayan blackberry (*Rubus discolor*) and bull thistle (*Cirsium vulgare*) are present in nearly all wetlands, uplands, riparian areas and forests. All populations are relatively small, but are widely distributed throughout the valley and could easily expand. One small population of Klamath weed *(Hypericum perfoliatum),* observed on the north side of the Tuolumne River, needs verification.

There is a high abundance of perennial, non-native grasses typically planted for grazing. Cattle and sheep were grazed in Poopenaut Valley in the late 1800's but the intensity and duration is unknown (Greene 1987). Based on historic records and assessments of Yosemite Valley and other Sierra Nevada meadows, it is likely that perennial forage grasses such as red top grass (*Agrostis gigantea),* Kentucky bluegrass (*Poa pratensis)* and timothy grass (*Phleum pratense)* were sown in Poopenaut Valley (NatureServe 2007). These species are present in high densities and now persist in both wetland and upland areas.

An annual, non-native plant dominated community covers a substantial area in Poopenaut Valley. These areas exhibit low plant cover, a high percentage of bare ground (30-60%) and a high level of small mammal activity. Soils are extremely dry and loose and annual grasses, mostly cheatgrass *(Bromus tectorum)* and annual forbs (non-native sheep sorrel and native Sierra lessingia) dominate. This plant community occupies fluvial terraces adjacent to and above the Tuolumne River (Figure 3-18) as well as a large flat area between Tributary 2 and Tributary 3 (Figure 3-19). This community type, typically associated with disturbance (human and livestock), is uncommon in relatively undisturbed areas in Yosemite National Park (NatureServe 2007).

Error! Objects cannot be created from editing field codes.

**Figure 3-17. Map of invasive plants in Poopenaut Valley.**

**Figure 3-18. Cheatgrass dominated area.**

**Figure 3-19. Cheatgrass dominated area.**

### 3.6 Rare plants

Of the nearly 1500 plant species identified in Yosemite National Park, 150 are on the parks special status plant list. A special status plant species may be federally or state listed as rare, threatened or endangered. In Yosemite National Park, sensitive plant species also include those listed by the California Native Plant Society, those on the U.S. Forest Service Watch List, those endemic to the Sierra Nevada, and some with limited distributions in the park

The National Park Service completed a survey of rare plants within a quarter mile of the Tuolumne River in 2006, as part of the Tuolumne Wild and Scenic River Management planning efforts. Below the O'Shaughnessy Dam, the surveys identified fourteen plant species considered rare, five of which occur in Poopenaut Valley. Surveys documented populations of one federally listed species of concern, slender-stemmed monkeyflower (*Mimulus filicaulis*), and four Yosemite National Park Sensitive species, including California sunflower (*Helianthus californica*), false pimpernel (*Lindernia dubia var. anagallidea)*, Yosemite tarweed (*Madia yosemitana*) and giant trillium (*Trillium angustapetalum*). We observed two individual California broom-rape *(Orobanche californica ssp. grayana)*, also a Yosemite National Park Sensitive species, in Poopenaut Valley in the summer of 2007, and will survey for it again in 2008. Poopenaut Valley provides habitat for these sensitive and rare plant species, and these species require continued monitoring for any response to an altered hydrologic regime.

### 3.7 Fire history

According to the Yosemite National Park recorded fire history (1930 - present) the entire Poopenaut Valley area burned only once in the last 88 years in the 1996 Ackerson Fire (Figure 3-20). The northern (north of the Tuolumne River) portion of Poopenaut Valley burned in 1956. Twelve ignitions were recorded in the vicinity of Poopenaut Valley but were either suppressed or did not burn into the valley. Based on fire history assessments of the surrounding vegetation types, prior to suppression policy, Poopenaut Valley likely burned every 2-39 years (median approximately 15 years) from natural ignitions and/or anthropogenic (possible American Indian) burning (USDOI 2004). This study does not substantiate any effects of the altered fire regime on vegetation communities in Poopenaut Valley.

Error! Objects cannot be created from editing field codes.

**Figure 3-20. Fire history map of Poopenaut Valley.**

### 3.8 Discussion

Determinations of the effects of the altered hydrologic regime on groundwater and surface water connectivity and the effects on vegetation communities require further investigations. Because plant biodiversity and abundance can change annually in response to variations in precipitation, conclusions on plant diversity, historic and modern wetland extent and changes in plant communities cannot be determined after a single year of data collection. In 2007, runoff in the Merced River basin was the eighth lowest annual average since 1916 and the April snowpack in the Tuolumne River Basin above Hetch Hetchy was the tenth lowest since 1948. These dry conditions may have influenced plant abundance and composition in Poopenaut Valley. In addition, understanding of the relationship between water levels and surface and groundwater movement was limited to only one small peak release. Assessments completed in 2007 provide a baseline of the existing wetland, upland, riparian and forested plant communities and non-native and rare plant occurrence and abundance but need augmentation through continued observations of the defined wetlands and plant communities. Further assessment of these communities are necessary to capture the current range of variability prior to designing a monitoring program for determining the short-term and long-term effects of altering the hydrologic regime on vegetation communities.

Despite the altered hydrologic regime, there is a diverse mix of wetland, upland, riparian and forested plant communities providing essential habitat for wildlife in Poopenaut Valley. However, several areas in Poopenaut Valley exhibit an unusual assemblage of plants in wetland areas. El Capitan Meadow and Ahwahnee Meadow in Yosemite Valley, areas with altered hydrologic regimes, exhibit similar assemblages of plant communities, but to a lesser degree.

These areas in Poopenaut Valley exhibit hydric soils, a proportion (slightly less than 50%) of hydrophytic vegetation, but have no hydrologic indicators. These areas, not classified as wetlands, may be evidence of a transition to an upland plant dominated community in response to an altered hydrologic regime; these areas need additional study.

Seasonal flooding, duration of inundation, and levels of shallow groundwater all influence the composition and distribution of riparian plant communities (Dwire et al. 2004). From 1923-1967, summer base flows downstream of O'Shaughnessy Dam were typically elevated at 17- 20 cms (600 to 700 cfs) to deliver water to the Hetch Hetchy Aqueduct and to the diversion tunnel at Early Intake. With the completion of the Canyon Power Tunnel, the summer base flows were reduced to between 2 and 3.5 cms (75 and 135 cfs). Two distinct areas of riparian establishment are evident in Poopenaut Valley: 1) a row of white alder and willow rooted just above the current low flow water edge and 2) a second band of willows at the current low flow water edge (Figures 3-12 and 3-13), (McBain and Trush 2007). Riparian vegetation appears to be well established and comprises a significant proportion of the vegetation in Poopenaut Valley. However, there appears to be minimal regeneration (by seed or vegetative) of certain willow species and very little herbaceous cover under these stands. More investigations to establish the timing (season) and dispersal rates of seeds (through seed traps) and the relationship to stage level will improve understanding of this complex relationship.

## Chapter 4: Wildlife Habitat Relationship Models

### 4.1 Introduction

An inventory of the existing fauna downstream of O'Shaughnessy Dam is necessary for fully characterizing the present ecosystem. For this report, we were unable to conduct a comprehensive field survey of the full range of animal taxa, so we chose instead to prioritize field surveys for two taxa likely to be sensitive to altered hydrologic regimes: 1) passerine bird species, which are sensitive to changes to riparian habitat (Chapter 5) and 2) aquatic invertebrates, which are sensitive to changes to river discharge, water temperature, and water quality (Chapter 6). However, we did generate species lists of predicted occurrence for amphibians, reptiles, birds, and mammals in the Tuolumne River corridor in the Hetch Hetchy/Poopenaut Valley area using Wildlife Habitat Relationship (WHR) models.

We used a three-step process to generate the species lists for the Tuolumne River corridor and Poopenaut Valley: (1) We determined habitat types using the park's Geographic Information System (GIS) vegetation map (Aerial Information Systems 1997) (Figure 4-1). (2) We used the California Department of Fish and Game's California Wildlife Habitat Relationships (CWHR) System Software (2006) to run Wildlife Habitat Relationships models. We performed two community-level matrix models associating wildlife species to a standardized habitat classification scheme. Using a "single-condition summary", we selected the location as Tuolumne County, indicated the relevant habitat types (see below), selected the lowest (most conservative) suitability level for all habitat groups and stage selections, included all available elements, and included all seasons. We generated two species lists (1) comprehensive list that includes all 12 habitat types (Douglas-fir, barren, blue oak- gray pine, lacustrine, montane chaparral, montane hardwood, montane hardwood-conifer, montane riparian, perennial grassland, ponderosa pine, urban, and wet meadow) in the six mile river corridor (includes ¼ mile buffer on either side of the river's edge) (APPENDIX 3) and (2) targeted list that includes wet meadow and montane riparian habitats in Poopenaut Valley (APPENDIX 4). Each species was assigned suitability, status, and, if relevant, source. Suitability refers to "predicted density and frequency of occurrence", indicated as low, medium, or high. Status identifies species as threatened, endangered, or special status. Source indicates that the species has been observed and documented by a research study or anecdotal sighting in the Tuolumne River corridor in the Hetch Hetchy/Poopenaut Valley area. (3) We used professional judgment to edit the species lists, drawing on knowledge of the natural history of the species, the habitat downstream of O'Shaughnessy Dam, observations made as part of the current Looking Downstream research project, past observations noted in Gaines (1992) and the Yosemite Wildlife Observation Database (2008), and previous park research (Wilkerson and Siegel 2002, Knapp 2003, Museum of Vertebrate Zoology Collections Database 2008) (APPENDIX 4). This multi-step process for generating species lists by habitat type is a conservative approach for determining species presence.

### 4.2 CWHR Species List Results

The first unedited species list generated from the CWHR model that included all 12 habitat types in the river corridor between O'Shaughnessy Dam and the park boundary predicted 357 vertebrate species. Using professional judgment, we edited the list to include a total of 260 species (12 amphibians, 23 reptiles, 168 birds, and 56 mammals). For the wet meadow and montane riparian habitats in Poopenaut Valley, we edited the raw predicted species list from 308 vertebrate species to 244 species, including 12 amphibians, 19 reptiles, 157 birds, and 56 mammals. From the species lists, there were 41 special status species (APPENDIX 5), all of which were predicted to occur in the riparian habitats found in Poopenaut Valley except coast horned lizard (*Phrynosoma coronatum*). The lists identified nine non-native species (APPENDIX 5), all of which are predicted to occur in Poopenaut Valley except the black rat (*Rattus rattus)*.

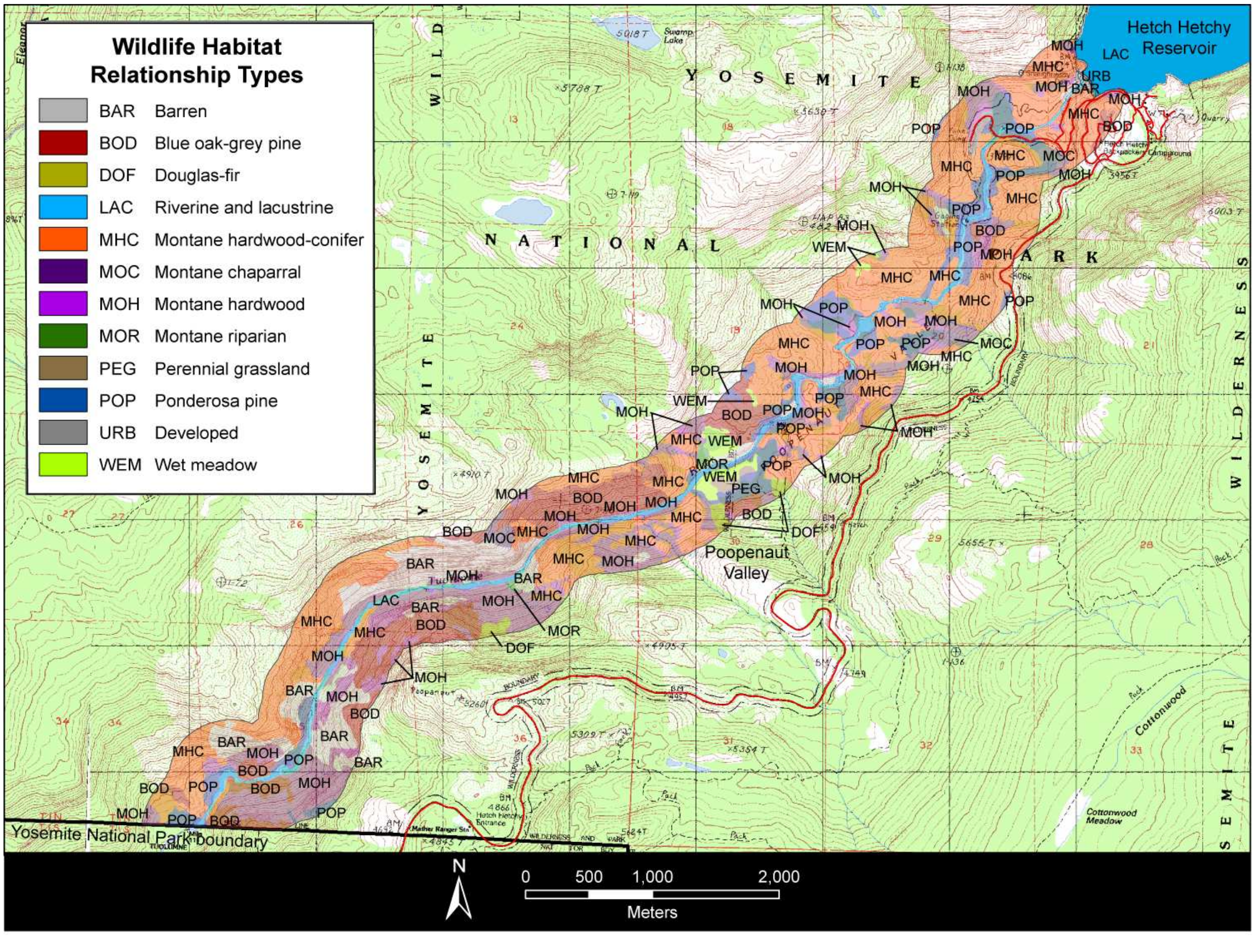


**Figure 4-1. Wildlife Habitat Relationship Types for the Tuolumne River corridor between O'Shaughnessy Dam and the Yosemite National Park boundary.**

## 4.3 CWHR Discussion

Results from the California Wildlife Habitat Relationships models predict that the Tuolumne River Corridor between O'Shaughnessy Dam and the Yosemite National Park boundary may support a high diversity and density of animals. Whereas the models consider habitat types and physiographic location, they do not take into consideration any hydrological effects incurred from the dam. The models present a list of species against which future field surveys may be compared. Bird surveys were prioritized in 2007 in Poopenaut Valley because bird population dynamics can be used to effectively evaluate ecosystem condition (RHJV 2004), which may help guide management decisions relating to water releases from O'Shaughnessy Dam.

## Chapter 5. Passerine Bird Surveys

### 5.1 Introduction

A considerable proportion of Sierra Nevada bird species depend on riparian meadow-associated habitat for breeding and overwintering, migration stopover, molting and pre-migration staging areas, corridors for dispersal, and supplemental habitat for birds that breed in nearby habitats (Cogswell 1962, Gaines 1977, DeSante 1995, Ralph 1998, Humple and Geupel 2002, and Flannery et al. 2004). Many riparian-dependent species, whose populations are declining, such as Yellow Warbler, Yellow-breasted Chat, and Common Yellowthroat, nest in early successional riparian habitat, particularly habitats with a dominant willow (*Salix* spp) component with dense understory cover (RHJV 2004). As cottonwoods and willows colonize bare stream banks and bars, they trap sediment and provide habitat for later successional species, which lead to a mosaic of vegetation types of various ages and species. To establish and flourish, early successional habitat depends on natural hydrology, including flooding, soil deposition, point bar formation (Sacramento River Advisory Council 1998), seed dispersal, and natural tree regeneration and growth (Smith et al. 1991, Stromberg and Patten 1992).

Interruptions to natural hydrology, including dams and water diversion, have compromised the viability of meadow habitat throughout much of the Sierra Nevada and have contributed to the decline in songbird populations (Small et al. 2000, RHJV 2004) (Figure 5-1). Two of California's endangered bird species, Willow Flycatcher and Great Gray Owl, inhabit montane meadows, and analyses of North American Breeding Bird Survey (BBS) data indicate that several additional meadow-affiliated species, including Belted Kingfisher, American Robin, Orange-crowned Warbler, Yellow Warbler, Wilson's Warbler, and Chipping Sparrow, also exhibit long-term population declines in the Sierra Nevada (Wilkerson and Siegel 2002).

Potential constraints on the reproductive success of riparian birds include: habitat availability and suitability, ability to find a suitable mate and nest site, nest predation, nest parasitism by the Brown-headed Cowbird, predation of adult and fledgling birds, and food availability. These factors may be tied to disrupted hydrologic patterns which in turn, may relate to the degradation of riparian plant communities and predator population dynamics (Small et al. 2000). Figure 5-1 proposes a conceptual model of how altered hydrology and land conversion may affect riparian bird populations (Small et al. 2000).

The sensitivity of bird populations to changes in the ecosystem makes them an important indicator of overall habitat quality (Marzluff and Sallabanks 1998). Long-term monitoring of birds, particularly during the breeding season, can be used to effectively assess habitat health (Ralph et al. 1993). Bird population dynamics have been used as scientifically viable surrogates for evaluation of ecosystem condition because (1) birds are conspicuous, easily observable, and monitoring and analysis are cost effective; (2) as secondary consumers (i.e. insectivores), birds are sensitive indicators of environmental change; and (3) knowledge of the natural history of many bird species has a rich basis in literature. In human-altered riparian areas, bird monitoring can be a valuable tool for gauging changes in habitat quality incurred from activities such as restoration efforts, river diversion and channelization projects, water impoundment, and flooding events.

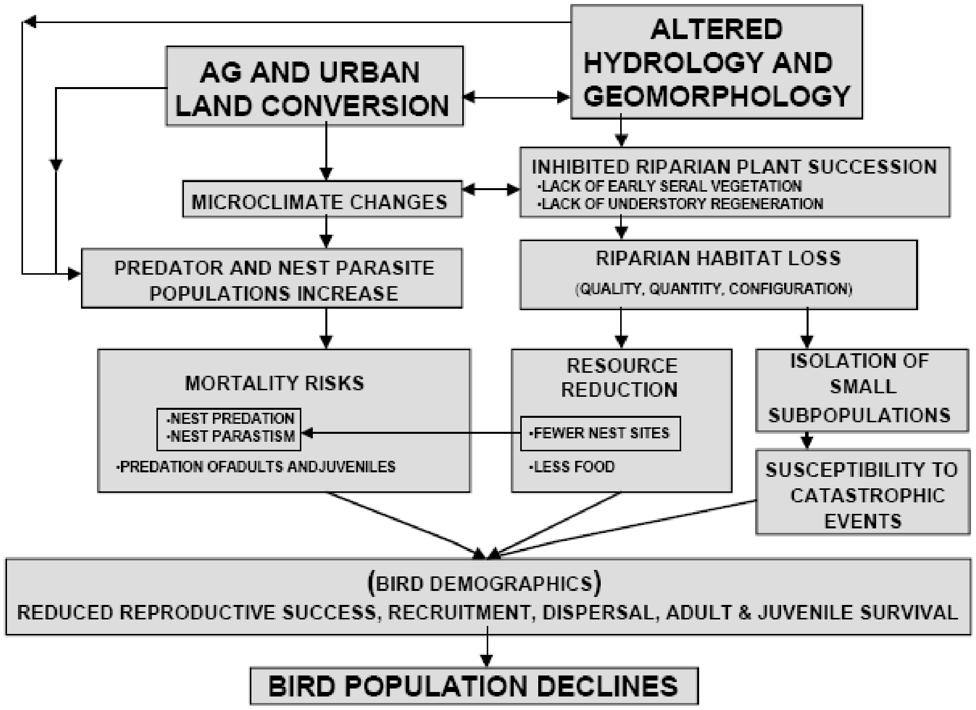


**Figure 5-1. Potential effects of altered hydrologic and geomorphic regimes on bird populations (from Small et al. 2000).**

The ability to restore the integrity of ecosystems downstream of O’Shaughnessy Dam requires that conservation and management actions be firmly grounded in scientific understanding. Currently, little information exists on wildlife communities and their habitat relations in Poopenaut Valley. Prior to this study, knowledge of this area was limited to anecdotal observations (Yosemite Wildlife Observation Database 2008) and three Yosemite-wide inventory projects (Wilkerson and Siegel 2002, Knapp 2003, and Museum of Vertebrate Zoology Collections Database 2008). The objectives of this study were to (1) model predicted occurrence of vertebrate species between O’Shaughnessy Dam and the park boundary and in Poopenaut Valley using California Wildlife Habitat Relationships (CWHR) system models and validation tools, (2) characterize the bird community in Poopenaut Valley, (3) and assess the Poopenaut Valley riparian habitat in relation to bird riparian focal species breeding in Poopenaut Valley.

### 5.2 Bird Area Search Surveys

We selected bird survey study areas in Poopenaut Valley based on their riparian habitat attributes and their dependence on river stage and inundation levels. We conducted area searches in each of five distinct “Search Areas”, shown in Figure 5-2. Search Areas 1 – 4 are designated wet meadow habitat and Search Area 5 is designated montane riparian habitat by the park’s 1997 Wildlife Habitat Relationship habitat-layer map (Aerial Information Systems 1997). However, the recently completed map of Yosemite floristic vegetation classification (NatureServe 2007) shows that Search Areas 3 and 4 comprise substantially more plant communities associated with upland dry meadow than wet meadow. The general study area is bordered by riparian plant communities, dominated by willows, white alder (*Alnus rhombifolia*), and black cottonwood (*Populus balsamifera trichocarpa*) along the edges of the Tuolumne River and its tributaries; and forested areas extending upslope and beyond the edges of the valley bottom, dominated by ponderosa pine (*Pinus ponderosa*), California black oak (*Quercus kelloggii*), and incense cedar (*Calocedrus decurrens*). See Chapter 3 for a full discussion of Poopenaut Valley's vegetation characteristics.

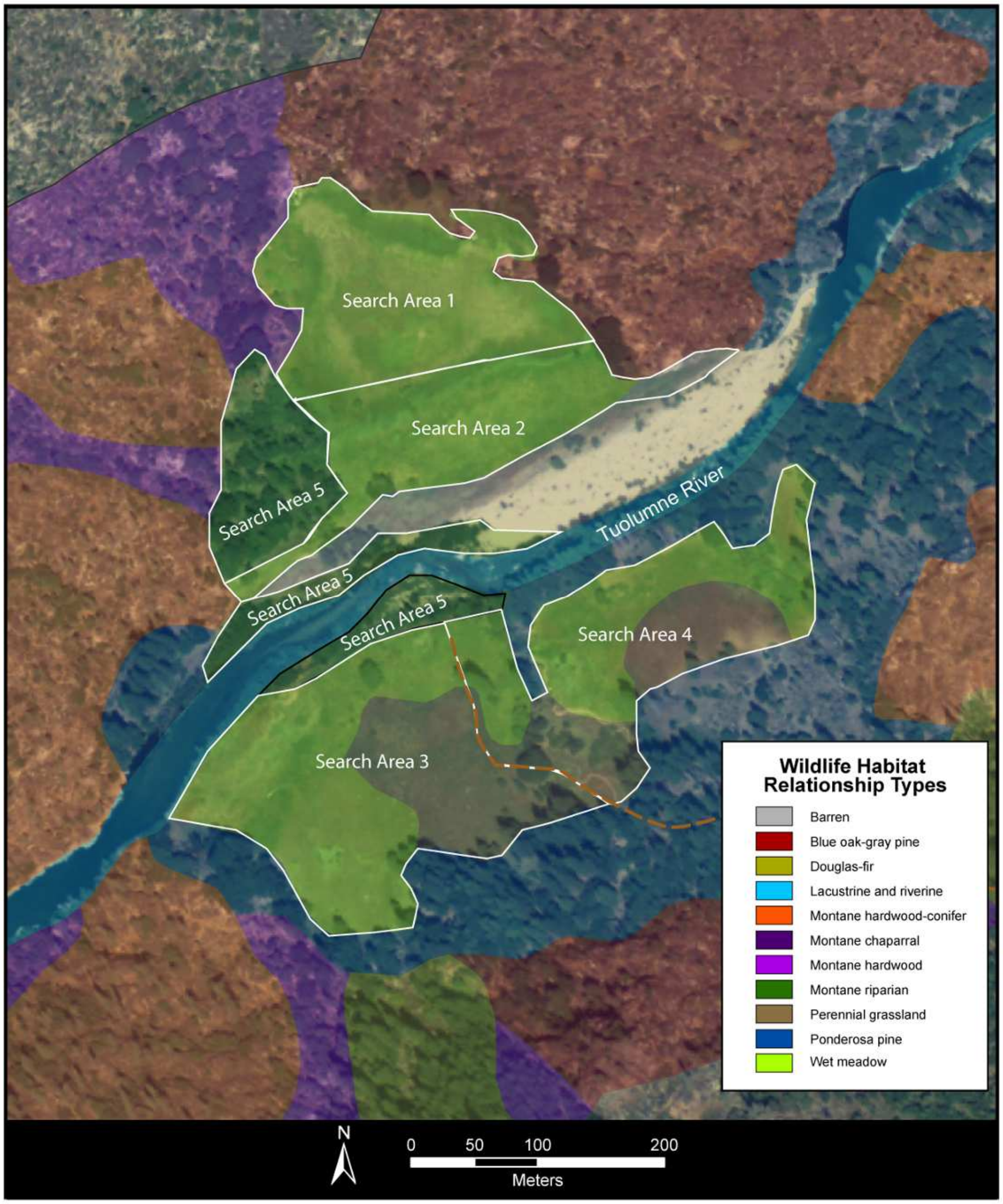


**Figure 5-2 Wildlife Habitat Relationship types and bird search areas in Poopenaut Valley.**

For each of the five bird search areas, vegetation descriptions and location maps follow. Search Area descriptions include percentage of area covered by *herbs* or plants less than 1.5 m tall; percentage of area covered by *shrubs* or plants between 1.5 and 5 m tall; *trees* or plants over 5 m tall; and bare ground, litter, sand, etc. Dominant plant species are listed for each strata (ground cover, shrubs, and trees) in order of relative dominance.

**Search Area 1** (Figure 5-3) spans approximately 36,650 $m^2$ (3.7 hectares) of which 70% is covered by ground cover comprised of the following dominant species: tule (*Scirpus acutus var. occidentalis*), Indian hemp (*Apocynum cannabinurm*), and inflated sedge (*Carex vesicaria*). Shrubs cover about 15% of the area and include willows and interior live oak (*Quercus chrysolepis)*. Trees cover approximately 5% of the area and include willow, black cottonwood, ponderosa pine, and interior live oak. Approximately 10% of the area is covered by bare ground, leaf litter, sand, etc. Area 1 is unique because it includes the majority of the seasonal pond.

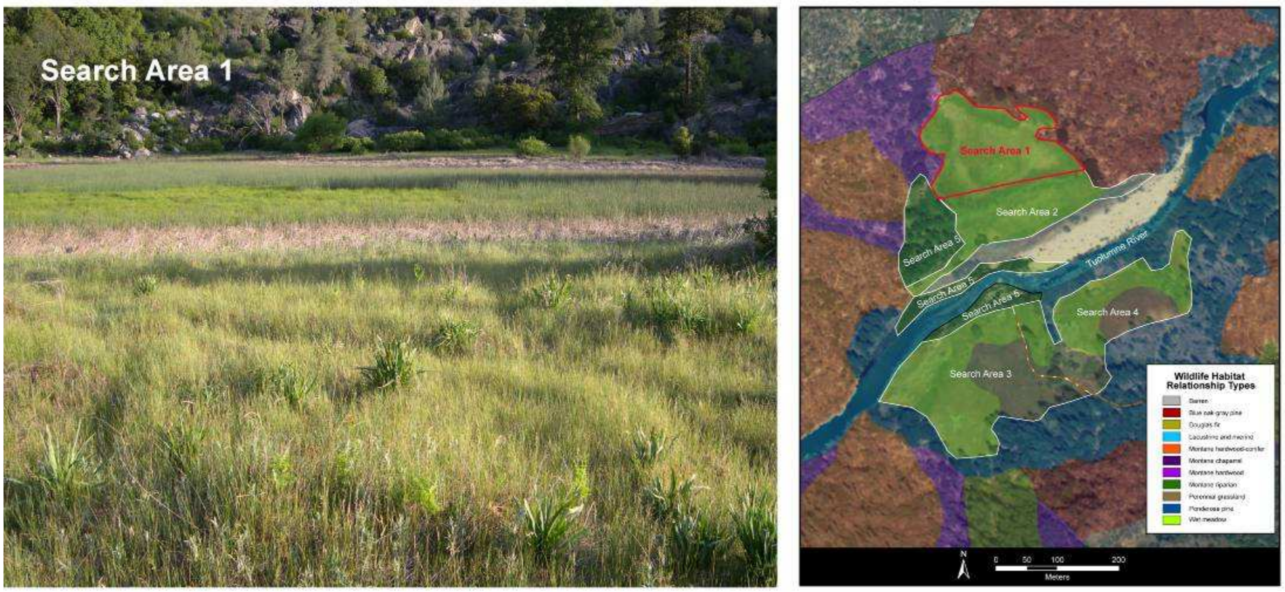


**Figure 5-3. Bird Search Area 1 in Poopenaut Valley, surveyed for birds May – June 2007. Map insert indicates Search Area 1 (in red) relative to the other survey areas.**

**Search Area 2** (Figure 5-4) spans approximately 36,650 $m^2$ (3.7 hectares) of which 60% is covered by ground cover comprised of the following dominant species: bracken fern (*Pteridium aquilinum*), soap plant (*Chloragalum pomeridianum),* Kentucky bluegrass (*Poa pratensis*), and sedges (*Carex ssp.)*. Shrubs cover about 20% of the area and include willows (*Salix* spp) and western chokecherry (*Prunus virginiana*). Trees cover approximately 10% of the area and include black cottonwood, California black oak, incense cedar, willow, and ponderosa pine. Approximately 10% of the area is covered by bare ground, leaf litter, sand, etc.

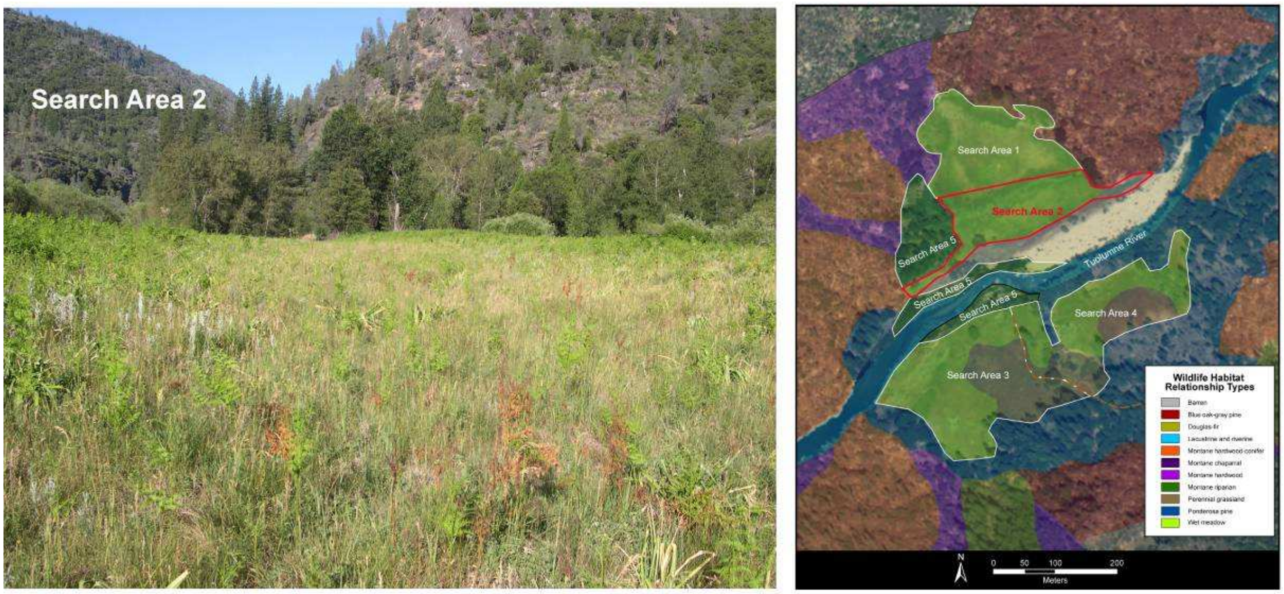


Figure 5-4. Bird Search Area 2 in Poopenaut Valley, surveyed for birds May – June 2007. Map insert indicates Search Area 2 (in red) relative to the other survey areas.

**Search Area 3** (Figure 5-5) spans approximately 43,250 $m^2$ (4.3 hectares) of which 79% is covered by ground cover comprised of the following dominant species: Kentucky bluegrass, bracken fern, and beardless wildrye (*Leymus triticoides*). Shrubs cover about 15% of the area and include western chokecherry and willows. Trees cover approximately 5% of the area and include ponderosa pine, black cottonwood, and California black oak. Approximately 1% of the area is covered by bare ground, leaf litter, sand, etc.

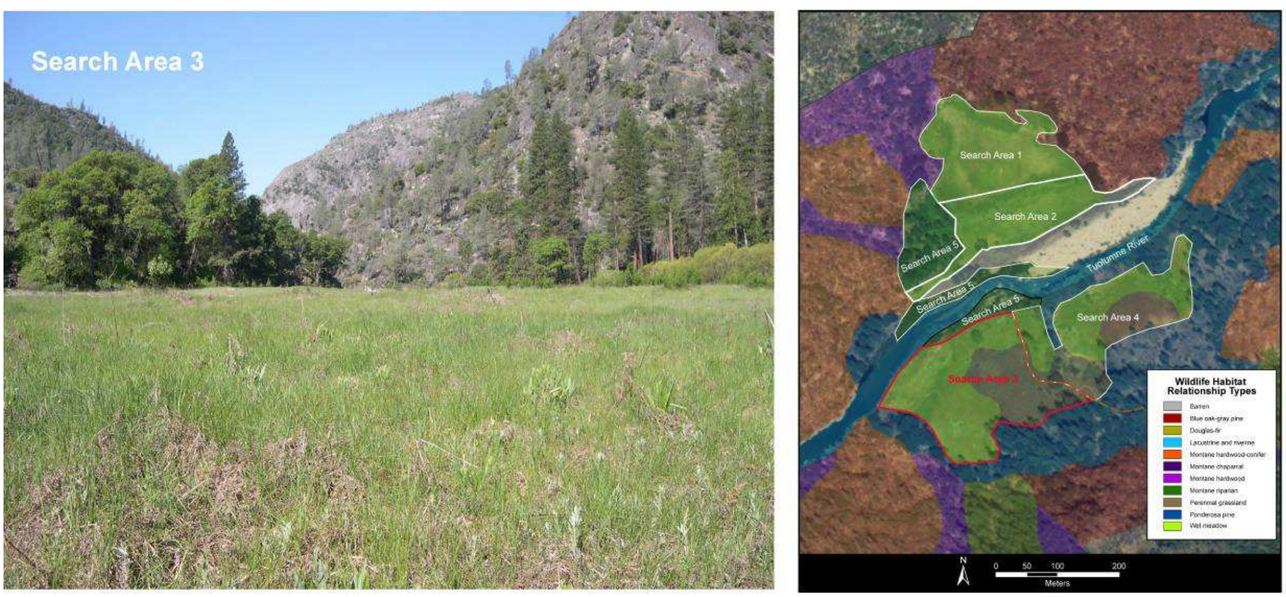


**Figure 5-5. Bird Search Area 3 in Poopenaut Valley, surveyed for birds May – June 2007. Map insert indicates Search Area 3 (in red) relative to the other survey areas.**

**Search Area 4** (Figure 5-6) spans approximately 33,800 $m^2$ (3.4 hectares) of which 60% is covered by ground cover comprised of the following dominant species: Kentucky bluegrass, bracken fern, and cheatgrass (*Bromus tectorum*). Shrubs cover about 20% of the area and include western chokecherry, willow, and black cottonwood. Trees cover approximately 10% of the area and include black cottonwood, ponderosa pine, incense cedar, willow, and interior live oak. Approximately 10% of the area is covered by bare ground, leaf litter, sand, etc.

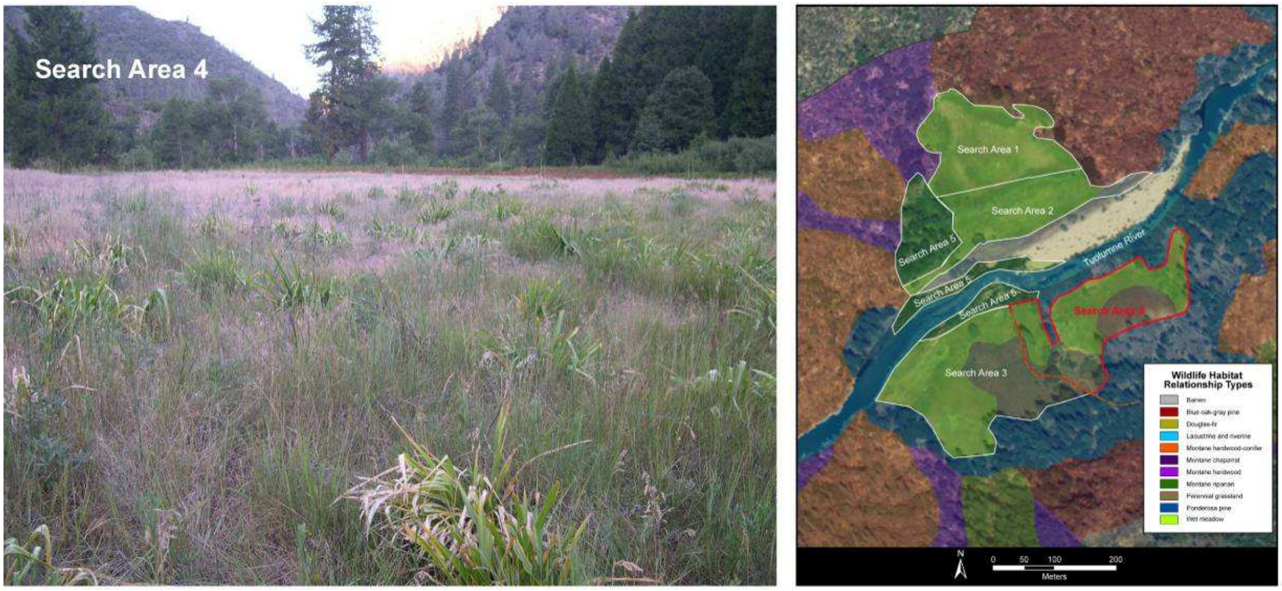


**Figure 5-6. Bird Search Area 4 in Poopenaut Valley, surveyed for birds May – June 2007. Map insert indicates Search Area 4 (in red) relative to the other survey areas.**

**Search Area 5** (Figure 5-7) spans approximately 21,070 $m^2$ (2.1 hectares) of which 10% is covered by ground cover comprised of the following dominant species: bracken fern, western goldenrod (*Euthamia occidentalis*), and mugwort (*Artemisia douglasiana*). Shrubs cover about 5% of the area and include willow, black cottonwood, red osier dogwood (*Cornus sericea*), and California black oak. Trees cover approximately 80% of the area and include black cottonwood, willow, California black oak, incense cedar, and ponderosa pine. Approximately 5% of the area is covered by bare ground, leaf litter, sand, etc.

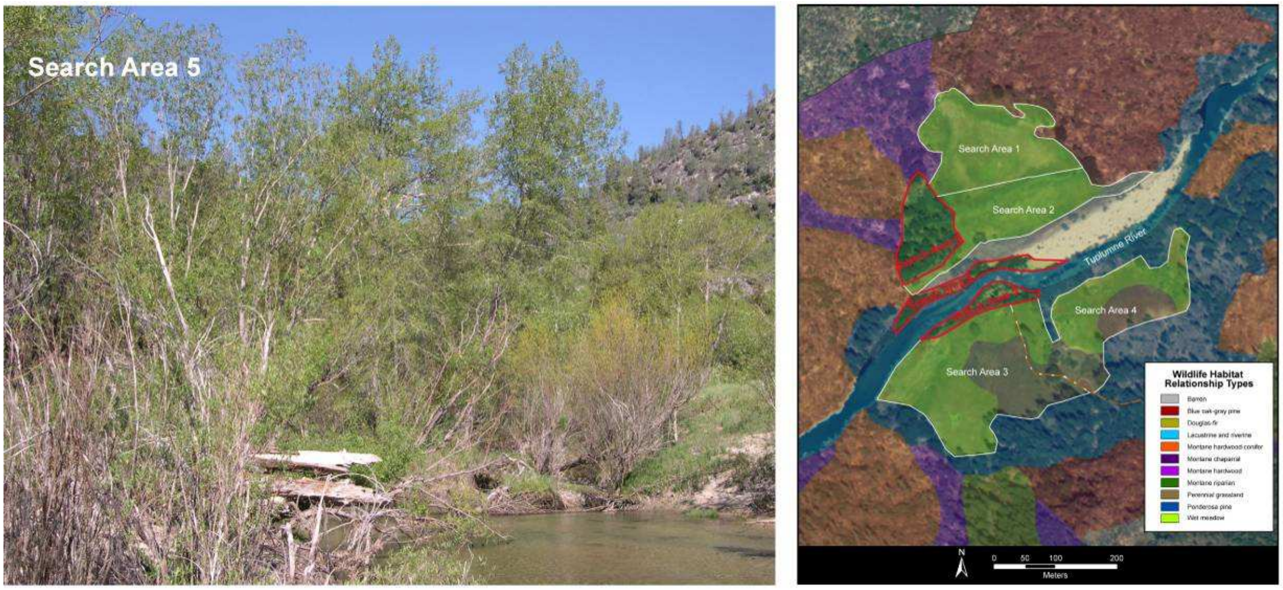


**Figure 5-7. Bird Search Area 5 in Poopenaut Valley, surveyed for birds May – June 2007. Map insert indicates Search Area 5 (in red) relative to the other survey areas.**

### 5.2.1 Area Search Method

We initially considered a study design that included point counts along each side of a 2 km section of the river corridor upstream of and including Poopenaut Valley. Following field reconnaissance, examination of vegetation maps below O'Shaughnessy Dam, and discussions with other researchers working in Poopenaut Valley, we decided to narrow the focus to censusing birds in the riparian habitat of Poopenaut Valley proper. Thus, the area search method was the preferred census method. The area search method measures the same variables as the point count method (abundance estimates and habitat relations) but is used when focusing on a smaller defined area (Ralph et al. 1993). Using this method, we characterized the bird community in the wet and upland meadow and montane riparian areas within Poopenaut Valley, which is also where the bulk of the vegetation and hydrology field work was conducted and where the vegetation and associated biota is most directly affected by different flow regimes.

We conducted standardized area search surveys to estimate bird community species abundance, composition, and habitat use in Poopenaut Valley wet meadow and montane riparian habitats. The area search method consists of a series of three 20-minute point counts in which the observer moves through a restricted area (Loyn 1986, Slater 1994). As shown in Figure 4-3, the Poopenaut Valley sampling area was delineated to provide five separate search areas, ranging from approximately 0.02 $km^2$ (2 hectares) in the montane riparian habitat to 0.04 $km^2$ (4 hectares) in the more open wet meadow habitat.

During the 2007 breeding season from May 1 to June 30 we censused each of five areas on three mornings, at least 10 days apart. Area searches were conducted after local sunrise time and were completed within four hours thereafter, during peak foraging and singing hours. We rotated the sampling sequence of search areas each visit to avoid bias due to temporal changes in bird activity. The observer counted all individual birds seen or heard over a 20 minute period. For each individual bird observed, the observer recorded species, method of detection (visual, song, or call), and indications of breeding status, such as copulation, courtship or territorial display, food carrying, and any observed fledglings on a standardized datasheet (APPENDIX 6). Birds observed outside of the search area were recorded separately, including those flying over the study area, unless they were foraging in the confined survey area (e.g., raptor hunting low to the ground or swifts foraging for insects). Area searches were not conducted during adverse weather, such as high winds or rain, when probability of detection would be reduced.

### 5.2.2 Bird Data Analysis

We estimated bird abundance and calculated bird species diversity per study area for the season. We estimated abundance as the number of birds detected per 20-minute survey. Relative abundance is a bird count estimate that should be proportional to the true population of birds in the area. To control for independent sampling among the three site visits, for each species in a given area we selected the repeat visit with the highest score (# detections) and omitted individuals detected in other visits to reduce bias (Nur et al. 1999). We were vigilant to avoid counting an individual more than once during each survey; however independence could not be controlled among areas, thus introducing bias into such analyses. The species diversity index is derived from the Shannon Wiener index and contains two separate components, species richness and species evenness (Krebs 1989, Brower et al. 1998). Species richness is defined as the total number of species detected in an area per unit time, and species evenness is how the number of birds is distributed through space (in this study, among areas). The diversity index rises as the number of species and equability in number of individuals among species increases. The index varies from 0, for an area in which all individuals belong to the same species, to a number greater than 0 for an area in which there are many species represented by an even distribution of individuals across species. In general, greater species diversity implies greater heterogeneity in the sample (Nur et al. 1999). During each 20-minute survey, we avoided counting an individual more than once by taking into consideration birds' breeding territories.

We calculated diversity indices and evenness values using Multivariate Statistical Package (MVSP 1985-2002). We performed Bray-Curtis Dissimilarity calculations using SYSTAT (SYSTAT 2006). For the purposes of this report, common names of vertebrate species, including birds, are used in the text; scientific names are given in the WHR species lists (see APPENDICES 3.1 and 3.2).

### 5.2.3 Breeding Birds

We used behavioral information collected from area search surveys to produce a list of confirmed, probable, and possible breeding bird species for each area according to Breeding Bird Survey criteria (Sauer et al. 2005). 'Possible breeders' are birds that are seen or heard at the site during the breeding season. 'Probable breeders' are indicated by one or more of the following: more than one singing male in the study area; a male singing during three visits within a month during the breeding season; a pair (male and female) observed together; territorial behavior; courtship behavior; copulation; or visiting a probable nest site during the breeding season. A 'confirmed breeder' is indicated by one or more of the following: carrying nesting material, building a nest; downy or recently fledged young present; adult carrying food for young or a fecal sac from the nest; a nest with the adults incubating; or a nest with eggs or young.

### 5.2.4 Results

Whereas we accounted for independent sampling among survey visits by reporting only the highest number of individuals detected per species, we were unable to account for independent sampling among survey areas, as some birds' breeding territories may span across more than one survey area. Thus, results are presented separately for each area in order to report abundance estimates that best represent numbers of individuals per area close to the true value, but are not easily extrapolated to the entire study area (areas 1-5).

A total of 42 species were detected during area search surveys at five areas (four wet meadow and one montane riparian) (Table 5-1). Per areas 1-5, relative abundance was 30, 29, 36, 41, and 69 individuals, respectively (Table 5-2). Three complete bird surveys were conducted on: May 9, 2007, May 21, 2007 and May 25, 2007 (split survey due to inability to access north side of river), and June 16, 2007. Access to all study areas on May 21, 2007 was disrupted due to an unexpected and abrupt flooding of the river. At all areas combined, the most frequently encountered species included Bullock's Oriole (17 individuals), American Robin (13 individuals), Lesser Goldfinch (13 individuals), and Yellow Warbler (12 individuals) (Table 5-1). We observed two special status species (Yellow Warbler and Yellow-breasted Chat); and six riparian focal species (Black-headed Grosbeak, Song Sparrow, Yellow-breasted Chat, Wilson's Warbler, Yellow Warbler, and Warbling Vireo). Seven raptor species, including Bald Eagle, Golden Eagle, Cooper's Hawk, Red-tailed Hawk, Northern Pygmy-Owl, Northern Saw-whet Owl, and Great Horned Owl were noted during surveys or site visits in 2007. The brown-headed cowbird was the only non-native bird species observed.

**Table 5-1. Bird species detected from area search surveys and their relative abundance in Poopenaut Valley, Yosemite National Park, in May – June 2007.**

| Common Name | Status | Areas 1 | 2 | 3 | 4 | 5 | Total |
|---|---|---|---|---|---|---|---|
| Acorn Woodpecker | | | | 3 | | 5 | 8 |
| American Robin | | 1 | 1 | | 7 | 4 | 13 |
| Anna's Hummingbird | | | 1 | 1 | 1 | 1 | 4 |
| Ash-throated Flycatcher | | 1 | | | | | 1 |
| Belted Kingfisher | | | | | 1 | 1 | 2 |
| Brown-headed Cowbird | | | | 1 | 2 | 3 | 6 |
| Black-headed Grosbeak | RFS | | 1 | 3 | 4 | 3 | 11 |
| Black Phoebe | | | 1 | | | 1 | 2 |
| Brown Creeper | | | | | 1 | | 1 |
| Black-throated Gray Warbler | | | 1 | | 1 | | 2 |
| Bullock's Oriole | | 1 | 3 | 6 | 2 | 5 | 17 |
| Bushtit | | 4 | | | | 6 | 10 |
| Calliope Hummingbird | | | | 2 | | | 2 |
| Cassin's Vireo | | | 1 | 2 | 2 | | 5 |
| Chipping Sparrow | | | | 1 | | | 1 |
| Downy Woodpecker | | | | | 1 | | 1 |
| Dusky Flycatcher | | 2 | | | 1 | 1 | 4 |
| Evening Grosbeak | | | | 2 | | | 2 |
| House Wren | | | 1 | | | | 1 |
| Hutton's Vireo | | | | | | 1 | 1 |
| Lazuli Bunting | | | | | 1 | 2 | 3 |
| Lesser Goldfinch | | 4 | | 2 | 3 | 4 | 13 |
| Mallard | | 3 | | | | | 3 |
| MacGillivray's Warbler | | | | | | 1 | 1 |
| Mourning Dove | | | | | | 1 | 1 |
| Northern Flicker | | | | 1 | | 1 | 2 |
| Northern Rough-winged Swallow | | 2 | 1 | 1 | | 2 | 6 |
| Pacific-slope Flycatcher | | | | | 1 | | 1 |
| Red-winged Blackbird | | 7 | 1 | 1 | | 2 | 11 |
| Savannah Sparrow | | | 1 | | | | 1 |
| Song Sparrow | RFS | 1 | 1 | | 1 | 2 | 5 |
| Spotted Towhee | | 1 | 1 | 2 | 3 | 1 | 8 |
| Steller's Jay | | | 1 | 1 | 1 | 1 | 4 |
| Violet-green Swallow | | | | 6 | | | 6 |
| Warbling Vireo | RFS | | 2 | | 1 | 6 | 9 |
| Western Tanager | | | | | 2 | 5 | 7 |
| Western Wood-Pewee | | 1 | 1 | 1 | 3 | 2 | 8 |
| Wilson's Warbler | RFS | 1 | 1 | | | 1 | 3 |
| White-throated Swift | | | 3 | | | | 3 |
| Yellow-breasted Chat | CSC, SSC, RFS | | | | 1 | | 1 |
| Yellow-rumped Warbler | | | | | | 3 | 3 |
| Yellow Warbler | CSC, SSC, RFS | 1 | 6 | | 1 | 4 | 12 |
| **Total** | | **30** | **29** | **36** | **41** | **69** | **205** |

CSC = California species of special concern; SSC = CDFG Bird Species of Special Concern; RFS = California Partners in Flight Riparian Focal Species

As predicted, Search Area 5 differed most dramatically from the other areas, both in habitat characteristics and in bird metrics. The montane riparian habitat had the highest number of area search detections (69 individuals), the highest species richness (27 species), the highest diversity index ($H$ = 1.34) and evenness ($J$ = 0.94), whereas the wet meadow areas averaged 34 individual detections of 18 species (Table 5-2). Search Area 1 stood out as having among the lowest values for all variables measured (Table 5-2).

**Table 5-2. Species richness (number of species), abundance, bird diversity, and evenness from area searches, by study area in Poopenaut Valley, May – June 2007.**

| Search Area | Species Richness | Abundance Estimate[a] | Species Diversity Index* | Evenness* |
|---|---|---|---|---|
| Search Area 1 Wet Meadow | 14 | 30 | 1.03 | 0.90 |
| Search Area 2 Wet Meadow | 19 | 29 | 1.18 | 0.92 |
| Search Area 3 Wet Meadow | 17 | 36 | 1.13 | 0.92 |
| Search Area 4 Wet Meadow | 22 | 41 | 1.25 | 0.93 |
| Search Area 5 Montane Riparian | 27 | 69 | 1.34 | 0.94 |

*For each species in a given area, the highest number of individuals detected in the three visits is reported.

Analysis of area search survey data using the Bray-Curtis Dissimilarity Measure revealed that the montane riparian habitat (Search Area 5) had the most unique bird assemblage, especially compared to Search Area 3 ($I_{BC}$ = 0.176, Table 5-3). On the other hand, Search Areas 3 and 1 shared the highest degree of community similarity ($I_{BC}$ = 0.500, Table 5-3).

**Table 5-3. Bray-Curtis Dissimilarity Matrix for bird assemblages by study area in Poopenaut Valley, May – June 2007. Numbers in bold type indicate the least and most similar sites.**

| | Area 1 | Area 2 | Area 3 | Area 4 | Area 5 |
|---|---|---|---|---|---|
| **Area 1** | 0.000 | | | | |
| **Area 2** | 0.250 | 0.000 | | | |
| **Area 3** | **0.500** | 0.286 | 0.000 | | |
| **Area 4** | 0.455 | 0.385 | 0.412 | 0.000 | |
| **Area 5** | 0.455 | 0.231 | **0.176** | 0.375 | 0.000 |

## 5.3 Breeding Birds

Out of 42 species identified during area searches, we identified three confirmed breeding species, 16 probable breeding species, and 23 possible breeding species in all study areas combined (Table 5-4). Confirmed breeding species included Black-headed Grosbeak, Bullock's Oriole, and Western Wood-Pewee.

**Table 5-4. List of bird species detected and their breeding status from area search surveys in Poopenaut Valley, Yosemite National Park, in May – June 2007.**

| Species | Possible | Probable | Confirmed |
|---|---|---|---|
| Acorn Woodpecker | X | | |
| American Robin | | S | |
| Anna's Hummingbird | | T, P | |
| Ash-throated Flycatcher | X | | |
| Belted Kingfisher | | S | |
| Brown-headed Cowbird | | S | |
| **Black-headed Grosbeak** | | **S** | **CN** |
| Black Phoebe | | S | |
| Brown Creeper | X | | |
| Black-throated Gray Warbler | X | | |
| Bullock's Oriole | | S, P | F |
| Bushtit | X | | |
| Calliope Hummingbird | | T, P | |
| Cassin's Vireo | | S, P | |
| Chipping Sparrow | X | | |
| Downy Woodpecker | X | | |
| Dusky Flycatcher | | P | |
| Evening Grosbeak | X | | |
| House Wren | X | | |
| Hutton's Vireo | X | | |
| Lazuli Bunting | X | | |
| Lesser Goldfinch | X | | |
| Mallard | X | | |
| MacGillivray's Warbler | X | | |
| Mourning Dove | X | | |
| Northern Flicker | X | | |
| Northern Rough-winged Swallow | | S, P | |
| Pacific-slope Flycatcher | X | | |
| Red-winged Blackbird | | T | |
| Savannah Sparrow | X | | |
| **Song Sparrow** | | **S** | |
| Spotted Towhee | | S | |
| Steller's Jay | X | | |
| Violet-green Swallow | X | | |
| **Warbling Vireo** | | **S** | |
| Western Tanager | | S, P | |
| Western Wood-Pewee | | S, T | ON |
| **Wilson's Warbler** | **X** | | |
| White-throated Swift | | C | |
| **Yellow-breasted Chat** | **X** | | |
| Yellow-rumped Warbler | X | | |
| **Yellow Warbler** | | **S, T** | |

Breeding status for each species is reported as possible, probable, and confirmed breeders (see text for description) at Poopenaut Valley, summer 2007. Codes indicating breeding status are: X = detected in study area during the breeding season; P = pair observed during the breeding season; S = more than one singing male in study area or male bird singing during at least 3 visits; D = drumming woodpecker heard; C = courtship behavior or copulation observed; T = Territorial behavior; CN = bird observed carrying nest material or nest building; CF = bird observed carrying food for young; F = recently fledged or downy young observed; ON = occupied nest observed. Partners in Flight riparian focal species are indicated by **bold** print.

### 5.4 Riparian Focal Species

Of the sixteen species listed in the 2004 Riparian Habitat Joint Venture (RHJV) focal species list for riparian-associated birds in California, six species (Black-headed Grosbeak, Song Sparrow, Warbling Vireo, Wilson's Warbler, Yellow-breasted Chat, and Yellow Warbler) were observed in Poopenaut Valley during 2007 area search surveys. A seventh riparian focal species, Willow Flycatcher, was not observed in 2007 but was captured in a mist-net in Poopenaut Valley on 17 August 1999 during the park-wide bird inventory (Wilkerson and Siegel 2002). The focal species list is not all-inclusive of riparian-associated birds in California, but it does include species that meet most or all of the following five criteria (RHJV 2004):

1. Use riparian vegetation as their primary breeding habitat in most bioregions of California;
2. Warrant special management status-endangered, threatened, or species of special concern on either the federal or state level;
3. Have experienced a reduction from their historical breeding range;
4. Commonly breeds throughout California's riparian areas; and
5. Have breeding requirements that represent the full range of successional stages of riparian ecosystems.

The following species accounts are based on species breeding habitat characteristics in the physiographic area of the Sierra Nevada:

The Black-headed Grosbeak (*Pheucticus melanocephalus*) (Figure 5-8A) is frequently found during the breeding season throughout California's riparian areas. Its *breeding grounds* generally include the presence of broad-leaved trees, such as willows, cottonwoods, oaks, riparian alders; and often nests in early to mid-successional vegetation. They also nest commonly in coniferous forests below the red fir zone, provided a few broad-leaved trees are present. They prefer semi-open canopy with moderate shrub cover and vertical stratification of vegetation layers. Their *nest site* is located in the midstory of primarily willow, alder, and ash with fairly high canopy cover.

The Song Sparrow (*Melospiza melodia*) (Figure 5-8B) has experienced a reduction in breeding range, yet is an abundant breeder in many riparian areas. Its *breeding grounds* consist of early successional riparian and wetland habitats, where they prefer dense shrubby vegetation consisting primarily of willow thickets. The *nest site* is located in the understory, in willow and native herbs, including goldenrod (*Solidago spectabilis*), California mugwort (*Artemisia douglasiana*), and milkweed (*Asclepias fascicularis*) (Siegel and DeSante 1999, Larison et al. 2001, RHJV 2004).

The Warbling Vireo (*Vireo gilvus*) (Figure 5-8C) has experienced a reduction in breeding range, yet is an abundant breeder throughout California's riparian areas. Its *breeding grounds* generally occur in moist areas with moderate to dense cover and a semi-open canopy. They prefer large deciduous trees, particularly aspens, cottonwoods, and alders, associated with streams. The species' *nest site* is located high in the canopy of deciduous trees (Siegel and DeSante 1999, RHJV 2004).

The Willow Flycatcher (*Empidonax traillii*) (Figure 5-8D) is a California endangered species which has decreased dramatically over the last half a century and is currently on the brink of extinction in the Sierra Nevada (Siegel et al. *In Press*). The *breeding grounds* typically include early successional riparian areas with clumps of willow. The species' *nest site* is located in the understory of primarily willows, and less often alders, cottonwoods, or other riparian deciduous vegetation. Willow Flycatchers tend to place their nests in a vertical fork of a riparian deciduous shrub (Harris 1991). The species generally requires large shrubby willows that line slow moving streams in open meadow situations or that scatter about seeps in moist meadows (Siegel and DeSante 1999, RHJV 2004).

The Wilson's Warbler (*Wilsonia pusilla*) (Figure 5-8E) is an abundant breeder throughout California's riparian areas. Its *breeding grounds* are generally restricted to moist montane riparian habitat and moist deciduous trees and thickets on the edges of montane meadows, characterized by willows, alders, and/or shrub thickets. The species' *nest site* is typically concealed at the base of horizontal willow branches (Stewart et al. 1978). Nests are located in the understory (0.3-3 m, but mostly below 0.9 m) in riparian deciduous plants, including, but not limited to, grass, nettles, and ferns (Siegel and DeSante 1999, RHJV 2004).

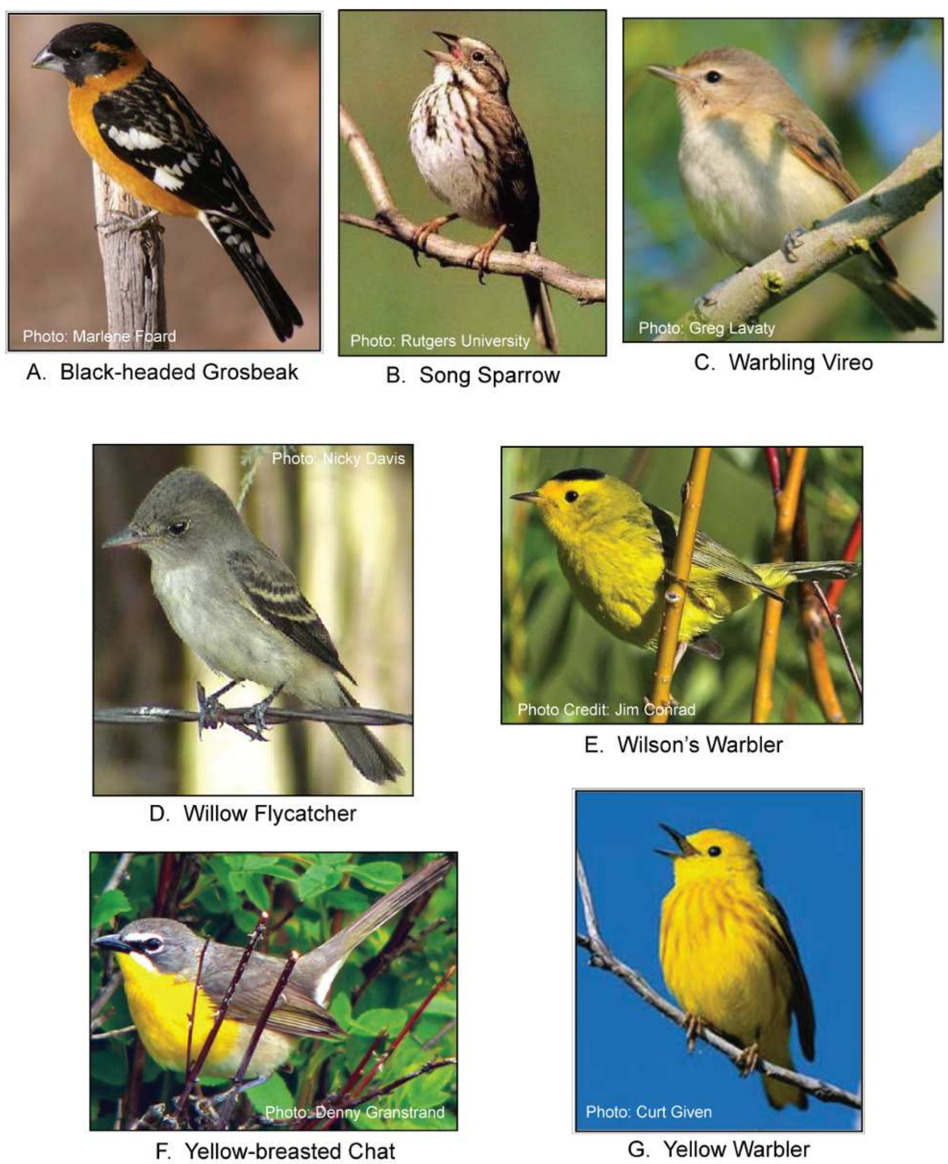


**Figure 5-8. California Riparian Focal Species identified in Poopenaut Valley.**

The Yellow-breasted Chat (*Icteria virens*) (Figure 5-8F) is a California species of special concern that has experienced a reduction in breeding range. Over the last 50 years, this species has decreased drastically along rivers and streams in the lower foothills of the west slope (Siegel and DeSante 1999), primarily due to dams, water diversions, and logging of riparian forests. The species' *breeding grounds* is in early successional riparian habitat, primarily willow thickets and tangles of blackberries and tall weeds. The *nest site* is located in the understory, in low, dense shrubs 0.3-2.4 meters high (Siegel and DeSante 1999, RHJV 2004).

The Yellow Warbler (*Dendroica petechia*) (Figure 5-8G) is a California species of special concern that has experienced a reduction in breeding range, yet is an abundant breeder throughout California's riparian areas. The *breeding grounds* are typified by wet areas with early successional riparian communities, or in remnant or regenerating canopy species stands. Their *nest site* is located in the mid-story of deciduous riparian plant species, such as willow and cottonwood (Siegel and DeSante 1999, RHJV 2004).

## 5.5 Discussion

Results from bird surveys indicate that Poopenaut Valley provides important breeding areas for a diverse group of birds representing a variety of breeding niches and differing seasonal strategies (resident species, short-distance, and long-distance migrants). Birds observed in riparian-associated habitats occupy breeding niches of differing heights in the vertical strata, including understory, mid-story, and canopy. This finding suggests that the available habitat in Poopenaut Valley provides structural integrity beneficial to a wide diversity of birds (MacArthur and MacArthur 1961, Karr and Roth 1971).

Of the seven riparian focal species detected in Poopenaut Valley, six species, Willow Flycatcher, Song Sparrow, Yellow-breasted Chat, Wilson's Warbler, Black-headed Grosbeak, and Yellow Warbler, depend on early successional habitat. Understory nesting species, Willow Flycatcher, Song Sparrow, Yellow-breasted Chat, and Wilson's Warbler, need dense, shrubby understory and herbaceous groundcover for successful nesting. Black-headed Grosbeak, a mid-story nester, favors territories having vegetation diversity and vertical complexity (Hill 1988). Gaines (1977) described such favorable habitat as having cottonwood-willow associations with primary and secondary canopy, a variety of shrubs of differing heights, and patches of forbs, grasses, and sedges. Warbling Vireo, a canopy nesting species, shows a strong association with mature mixed deciduous woodlands especially along riparian corridors (Gardali 2003).

Early successional growth of willows and young cottonwoods, vegetation diversity and vertical complexity, and herbaceous groundcover provide essential breeding habitat for many riparian-associated birds in Poopenaut Valley. In general, the establishment and succession of riparian vegetation rely upon a natural hydrology in the river system. Across California, dams and water diversion have significantly contributed to a decrease in riparian habitat, an increase in non-native plant species, and have been linked to a consequent decline in songbird populations (RHJV 2004). However, the riparian ecosystem in Poopenaut Valley may be more intact than observed in other systems impacted by altered hydrological regimes. The bird community in Poopenaut Valley appears to be utilizing various strata related to early and mid-successional riparian vegetation, generally not associated with artificial flow regulation.

Future research is needed to gain a greater understanding of ecosystem health in Poopenaut Valley and potential downstream effects of O'Shaugnessy Dam. Future long-term bird monitoring will indicate if localized declines are occurring in riparian associated birds; and focused demographic monitoring (nest-searching or mist-netting) will indicate if productivity is limiting those populations. In the short-run, results from this study indicate that a diverse bird community is using and depending on the riparian habitat in Poopenaut Valley during the breeding season. Given the scarcity of quality riparian habitat in the Sierra Nevada, and the biological wealth these critical ecosystems represent, protection of and management for these bird species and their habitat is warranted. We recommend restoring natural riparian processes to the extent possible to maintain and enhance the early successional growth of riparian vegetation, in particular willows and young cottonwoods, vertical complexity, and herbaceous groundcover. In particular, periodic floods would allow for seed dispersal and natural tree regeneration and growth which would promote understory and groundcover quality beneficial for many riparian-associated birds.

## Chapter 6: Characterizing Assemblages of Benthic Macroinvertebrates

### 6.1 Introduction

Macroinvertebrates are excellent integrators of physical, chemical, and biological processes and are highly valued as ecological indicators (e.g., Plafkin et al. 1989, Barbour et al. 1999). Invertebrates are also valuable as indicators because these animals include primary, secondary, tertiary, and higher-level consumers (e.g., Wallace and Hutchens 2000) and in turn are a critical food resource for a variety of vertebrate taxa (Allan 1995).

There can be a reduction of macroinvertebrate species richness, and an increase in abundance, below dams (Stanford and Ward 1989, Allan 1995), although this relationship can be altered if migratory fauna make up a large proportion of the assemblage (Holmquist et al. 1998). Lowest species richness is typically found in the waters just downstream of an impoundment (Stanford and Ward 1989, Armitage and Blackburn 1990). Replacement of certain taxa by others is common; for instance, low flows often result in a reduction of more lotic mayfly taxa and an increase in more lentic taxa (Brittain and Saltveit 1989).

This chapter provides baseline data on the benthic macroinvertebrate (BMI) assemblage in the Tuolumne River corridor between O'Shaughnessy Dam and the downstream end of Poopenaut Valley. For this initial one-year study, our primary need was to develop an understanding of current riffle BMI assemblage structure in the Tuolumne River between O'Shaughnessy dam and the upstream end of Poopenaut Valley. To this end, we planned spatially and temporally extensive sampling designed to capture year-round variability and to include as many taxa as possible.

### 6.2 Methods

We sampled the Tuolumne River at approximately six-week intervals from spring of 2007 through winter of 2008, sampling at a different randomly-chosen location on each trip (Table 6-1, Figure 6-1). Sample sites were located between O'Shaughnessy Dam and the upstream end of Poopenaut Valley. We sampled benthic macroinvertebrates, collected a variety of physical measurements, and made habitat assessments at each of these stations.

**Table 6-1. BMI sampling sites, dates, and UTM coordinates (WGS84, Zone 11).**

| | | | |
|---|---|---|---|
| 1 | 21 March 2007 | 11S 253212mE | 4201688mN |
| 2 | 3 May 2007 | 11S 254007mE | 4202441mN |
| 3 | 15 June 2007 | 11S 254023mE | 4202150mN |
| 4 | 27 July 2007 | 11S 254112mE | 4202602mN |
| 5 | 10 September 2007 | 11S 254200mE | 4202804mN |
| 6 | 22 October 2007 | 11S 252931mE | 4201265mN |
| 7 | 3 December 2007 | 11S 254322mE | 4203257mN |
| 8 | 1 February 2008 | 11S 254451mE | 4203285mN |

In an effort to ensure comparability with other ongoing sampling in the Tuolumne River, we used the US Environmental Protection Agency rapid bioassessment protocols (Barbour et al. 1999). These protocols emphasize kick netting in riffle habitats (Plafkin et al. 1989, Barbour et al. 1999) and call for a large 2 $m^2$ sample that is a composite of smaller samples. The net (with

0.5mm mesh) was held perpendicular to the current, and the upstream substrate was disturbed by vigorously kicking, scraping, overturning, and rubbing large cobbles, and small cobbles, gravel, and silt were dislodged and/or suspended, all while the "kicker" was moving upstream. The composite sample was then rinsed and transferred to a vessel and preserved in 70% non-denatured ethanol, cleaning and removing large pieces of gravel, leaves, and twigs in the process. Each sample consisted of four randomly selected 0.5 $m^2$ subsamples. Although the EPA protocols call for combining these subsamples, partway through the study it became clear that this approach is guilty of sacrificial pseudoreplication (*sensu* Hurlbert 1984) and that the immediate compositing of subsamples represents a needless loss of information that precludes generation of variance estimates for each sample. We therefore began preserving, sorting, and performing taxonomy on each subsample separately. The data from the four subsamples were then combined upon data entry. The result is that the composite data are produced exactly as per the EPA protocols, but error estimates for each sample are also acquired via the separate processing of the subsamples. The only significant additional effort involves careful recording of species accumulation for each complete composite sample, because species of course accumulate asymptotically, rather than linearly, i.e., the species richnesses for each of the four subsamples cannot simply be added to derive the species richness for the large composite sample.

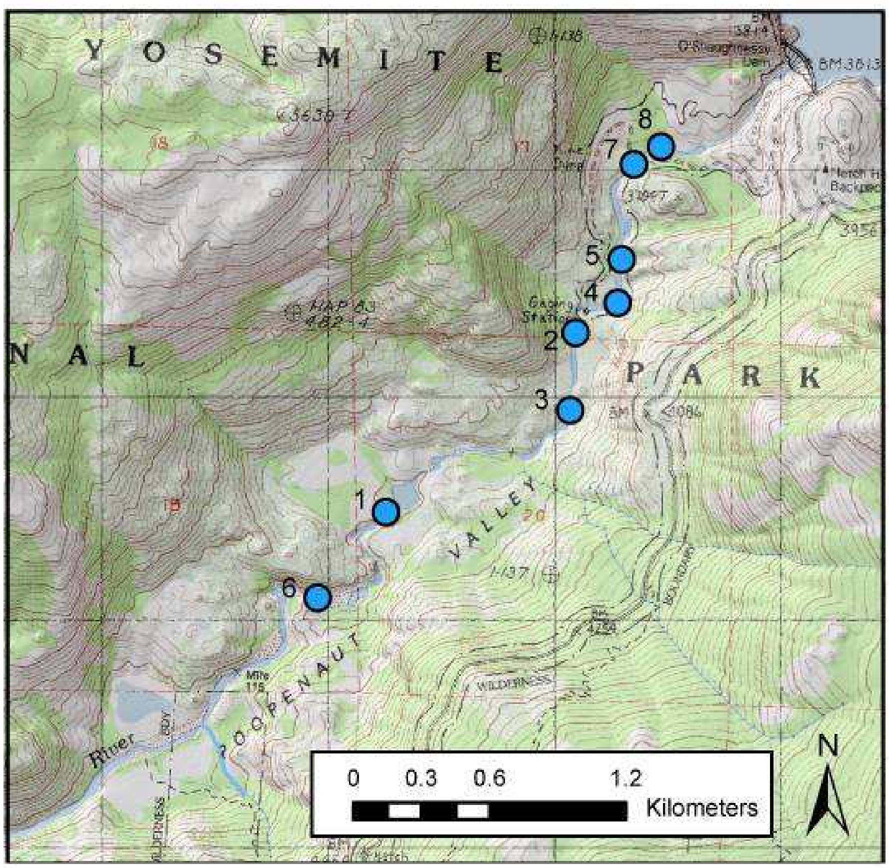


**Figure 6-1. Location of benthic macroinvertebrate (BMI) sampling sites.**

Figure 6-2.  BMI sampling site 1.

Figure 6-3.  BMI sampling site 2.

Figure 6-4.  BMI sampling site 3.

Figure 6-5.  BMI sampling site 4.

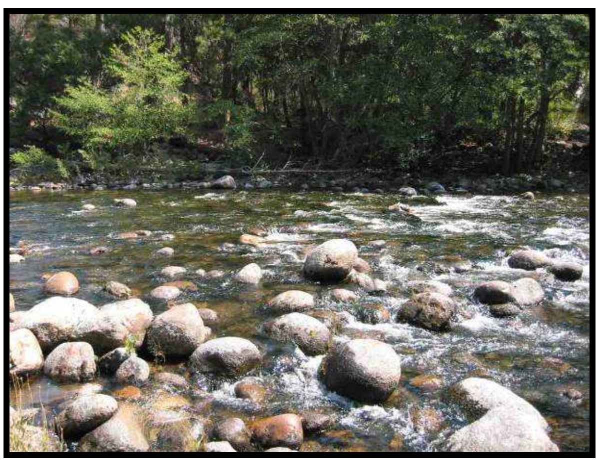

Figure 6-6.  BMI sampling site 5.

Figure 6-7.  BMI sampling site 6.

Figure 6-8. BMI sampling site 7.

Figure 6-9. BMI sampling site 8.

Although not part of the EPA protocols, we also collected some limited rock scraping samples on large rock substrata (boulders and submerged slabs). Samples were collected in a $0.25 m^2$ Surber sampler.

Samples were sorted completely in the lab, rather than subsampled, because complete sorting reduces the variance of metrics and increases taxon richness (Courtemanch 1996, Doberstein et al. 2000). Sorting was particularly laborious due to the large amounts of filamentous green algae that were present (Figures 6-2 through 6-4). Taxa were identified to the lowest possible level and entered on EPA Benthic Macroinvertebrate Laboratory Bench Sheets. Kerans and Karr (1994) found that richness, dominance, and trophic metrics were consistently the most useful, and our selected metrics reflect these findings. Calculated metrics include individual family and genus/species densities, total individuals/$m^2$, species and family richness, species and family richness following Margalef's correction for differential abundance ($D_{Mg}$ = (S - 1)/ln N, where S = number of species or families and N = number of individuals; Clifford and Stephenson, 1975, Magurran 1988), percent species and family dominance (single taxon), relative contributions of all functional feeding groups (singly and in various combinations and ratios), and the Hilsenhoff biotic index (Hilsenhoff 1987, Barbour et al. 1992, Kerans and Karr 1994). The Hilsenhoff index (HBI) is $\Sigma(n_i a_i/N)$, where $n_i$ = number of individuals in the $i^{th}$ taxon, $a_i$ = tolerance value (1-10) assigned to that taxon, and N = total number of individuals in sample with known tolerance values. This index provides an indication of the relative importance of "tolerant' and "intolerant" taxa in an assemblage (those that can and cannot live, respectively, in degraded habitats; in healthier systems, tolerant fauna tend to be outcompeted and intolerant taxa predominate). Functional feeding groups are broadly analogous to guilds (Root 1973, Hawkins and MacMahon 1989, Merritt and Cummins 1996). We used Merritt et al. (2008), Aquatic Bioassessment Laboratory (2003), Smith (2001), and Thorp and Covich (2001), among others, as our sources of functional feeding group assignments and Aquatic Bioassessment Laboratory (2003) and Merritt et al. (2008) as our sources for tolerance values. We were able to assign a functional feeding group and a tolerance value for each taxon. The assemblage structure was compared with that found in two other studies using Sorensen's similarity coefficient (Sorensen 1948, Krebs 1989).

Physical measurements at each sampling site included river discharge, water depth, water temperature, channel width, high water mark, percent shade, and coarse estimates of percentages of cobble, gravel, sand, and fines. Flow, depth, temperature, and stream width measurements were made at each of the kick net subsample locations after each subsample was collected, whereas the remainder of the measurements were estimates for the entire site. We measured flow with a General Oceanics rotary flow meter (with high-speed rotor) on a telescoping wading rod. We took photos and recorded UTM coordinates (WGS84, Zone 11) at each location.

We also completed EPA Habitat Assessment Field Data Sheets (Barbour et al. 1999) at each site at "habitat unit"/reach scales (10-1000 m; Fausch et al. 2002). The form includes visual estimates of habitat quality in terms of 1) epifaunal substrate, 2) substrate embeddedness, 3) velocity/depth regime, 4) sediment deposition, 5) channel flow status, 6) channel alteration, 7) frequency of riffles, 8) bank stability, 9) vegetative protection, and 10) width of riparian vegetation zone.

Most metrics demonstrated normality via Lilliefors tests (Lilliefors 1967, Wilkinson et al. 1992), although two metrics required removal of an outlier to meet this assumption. Some initial data exploration was done via multiple regressions. Because of potential co linearity in the multiple regression models, p for entry into, or removal from, the models was set at <0.05 and tolerance was set at 0.1.

Although the study was not designed to test seasonal differences, some trends were apparent, and we wished to examine some unplanned contrasts. Some response variables demonstrated heteroscedasticity ($F_{max}$ and Cochran's tests; Cochran 1941, Kirk 1982) which for a few variables was not removed by various transformations. We therefore used two-tailed Mann-Whitney U tests for all contrasts. We performed tests for most response variables, so the potential for multiple comparison error should be kept in mind when interpreting these results based on per-contrast error rate. All statistical tests were done in SYSTAT (Wilkinson et al. 1992).

### 6.3 Results

We sampled over a wide range of physical conditions; even the most consistent physical parameters varied by about a factor of two over the course of the sampling year. Water depths varied from 24.8 to 59.0cm (mean= 38.0cm, Table 6-2), water temperatures ranged from 4.5 to 10.5$^{o}$C (mean= 7.20 $^{o}$C), and river discharge ranged from 30.7 to 66.8cms. Other metrics were somewhat more variable (Table 6-2).

Habitat condition had mean scores that fell in the Optimal range for eight of the ten parameters (Table 6-3). Velocity/Depth Regime fell in the Marginal range because of the frequent lack of diverse flow regimes, and Frequency of Riffles was Suboptimal due to low occurrence of riffles. Although Epifaunal Substrate/Available Cover and Sediment Deposition fell in the Optimal range, these two parameters were close to Suboptimal because of lack of woody debris and sediment deposition, the latter primarily in pools. The overall habitat condition score was Optimal (mean = 155; SE = 5.13).

**Table 6-2. Means and standard errors for physical parameters.**

| Metric | Mean | SE |
|---|---|---|
| Water depth (cm) | 38.0 | 4.01 |
| Water temperature ($^oC$) | 7.20 | 0.671 |
| Flow (cm/sec) | 50.7 | 5.16 |
| Stream width (m) | 22.7 | 4.54 |
| Width (m): Depth (m) ratio | 61.5 | 10.3 |
| High water mark (m) | 2.40 | 0.600 |
| Percent shade | 27.0 | 15.0 |
| Percent cobble | 58.0 | 11.9 |
| Percent gravel | 21.0 | 6.40 |
| Percent sand | 13.0 | 3.74 |
| Percent fines | 8.00 | 5.83 |

**Table 6-3. Habitat characteristics from EPA Habitat Assessment Field Data Sheets with EPA condition categories. Each parameter is scored from 1-20; parameters 8-10 are scored from 1-10 for each bank and combined for the total score for the parameter in question. The overall score for a site is the sum of all ten parameters, with a maximum score of 200. SE = standard error.**

| Habitat Parameter | Mean | SE | Condition Category |
|---|---|---|---|
| 1. Epifaunal Substrate/ Available Cover | 15.4 | 0.571 | **Optimal** Greater than 70% of substrate favorable for epifaunal colonization and fish cover. |
| 2. Embeddedness | 16.3 | 0.808 | **Optimal** Gravel, cobble, and boulder particles are 0-25% surrounded by fine sediment. Layering of cobble provides diversity of niche space. |
| 3. Velocity/ Depth Regime | 7.14 | 0.459 | **Marginal** Only 2 of the 4 habitat regimes present. |
| 4. Sediment Deposition | 15.6 | 1.49 | **Optimal** Little or no enlargement of islands or point bars and less than 5% (<20% for low-gradient streams) of the bottom affected by sediment deposition. |
| 5. Channel Flow Status | 18.7 | 0.522 | **Optimal** Water reaches base of both lower banks, and minimal amount of channel substrate is exposed |
| 6. Channel Alteration | 18.4 | 0.481 | **Optimal** Channelization or dredging absent or minimal; stream with |

| | | | |
|---|---|---|---|
| | | | normal pattern. |
| 7. Frequency of Riffles | 10.1 | 1.62 | **Suboptimal**<br>Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7 and 15. |
| Habitat characteristics. | | | |
| 8. Bank Stability (Left)<br>(Right) | 8.71<br>9.14 | 0.360<br>0.404 | **Optimal**<br>Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected. |
| 9. Vegetative Protection<br>(Left)<br>(Right) | <br>8.43<br>8.71 | <br>0.429<br>0.421 | **Optimal**<br>More than 90% of the stream bank surfaces and immediate riparian zone covered by native vegetation, including trees, understory shrubs, or non-woody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally. |
| 10. Riparian Vegetative<br>Zone Width (Left)<br>(Right) | <br>9.00<br>9.14 | <br>0.309<br>0.340 | **Optimal**<br>Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone. |
| **Overall** | **155** | **5.13** | **Optimal** |

We collected 69 taxa representing 25 families and eight orders. There was a moderate level of evenness at the order level, although Ephemeroptera and Diptera made up the majority of the assemblage (Figures 6-10, 6-11). There was more evenness at the family level (Figures 6-12, 6-13) than at the order level, and the distribution lies between the log normal and MacArthur's broken stick models. Mean family richness was 16.3/2 $m^2$, which was reduced to $D_{Mg}$ = 2.70 after applying Margalef's correction for abundance, and family level dominance was 39.7% (Table 6-4). Species level rank-abundance showed a similar distribution (Figures 6-14, 6-15) to family rank-abundance. There was an average of 41.7 species per 2 $m^2$, which converted to 7.04 after Margalef's correction, and species dominance was 21.4% (Table 6-4).

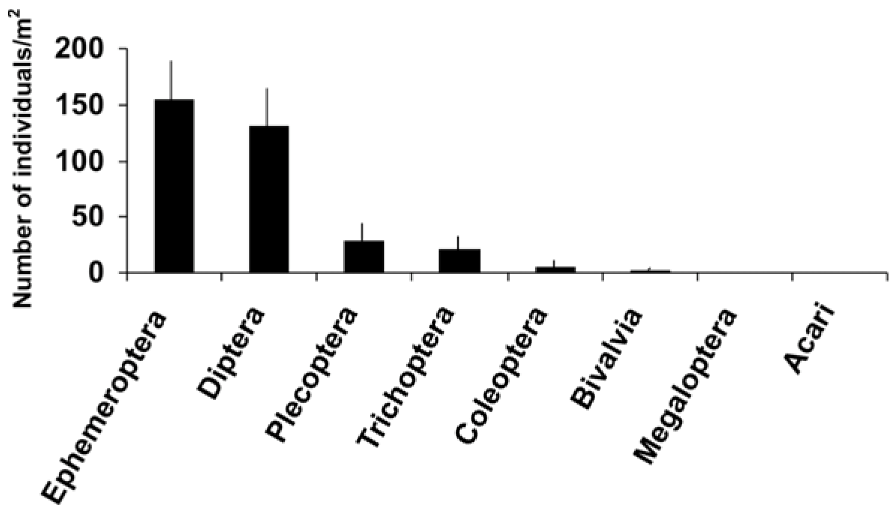


**Figure 6-10. Rank-abundance by order, plus Class Bivalvia (linear scale).**

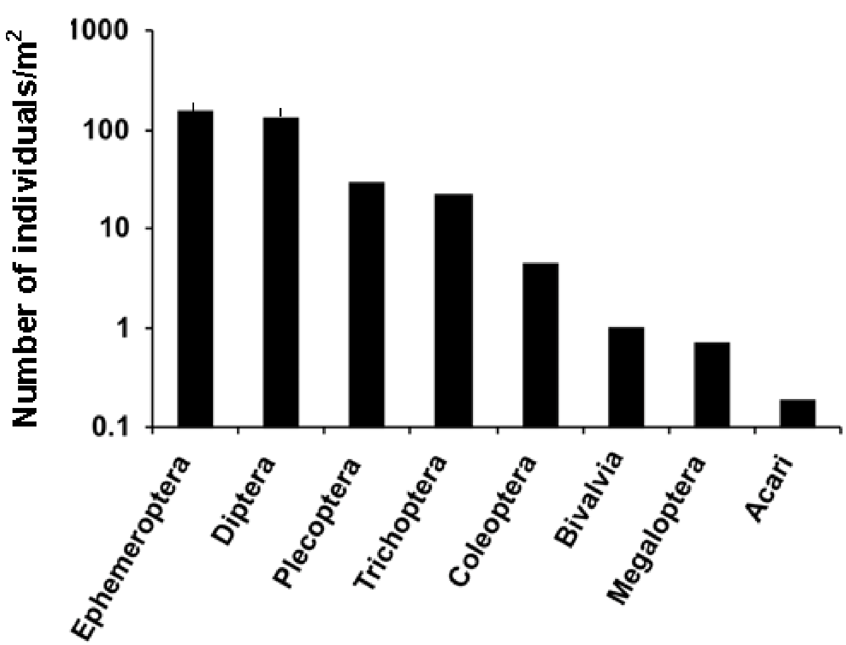


**Figure 6-11. Rank-abundance by order, plus Class Bivalvia (log scale).**

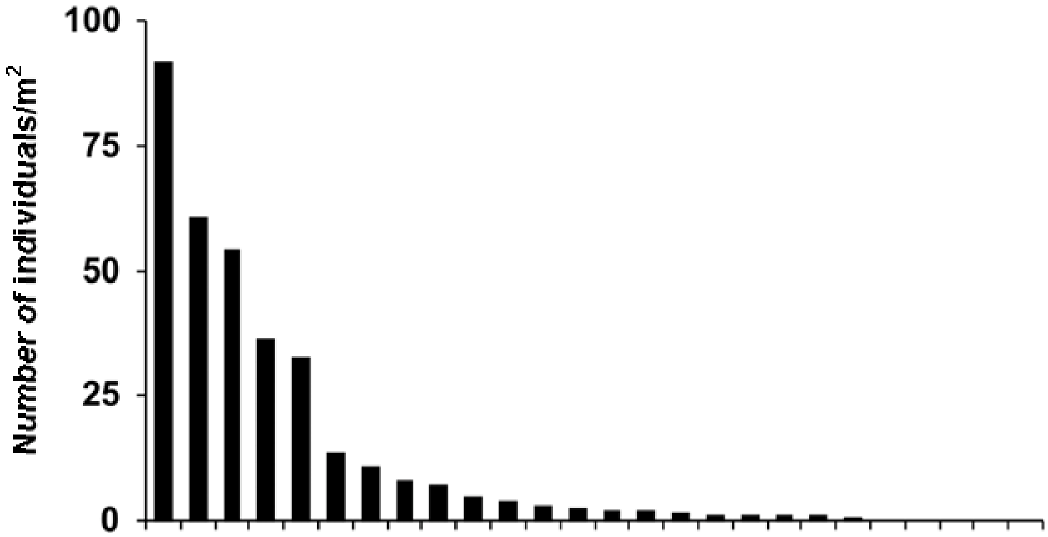


**Figure 6-12. Rank-abundance by family (linear scale).**

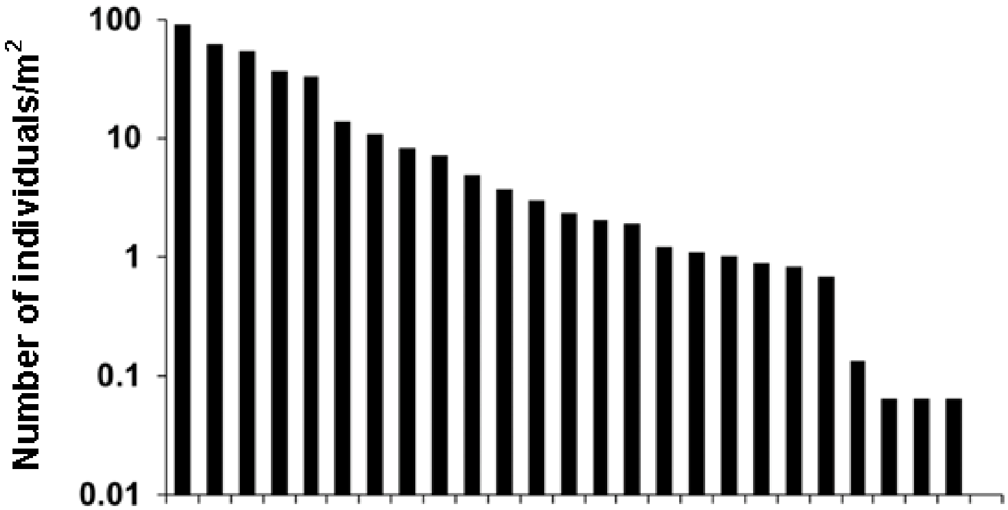


**Figure 6-13. Rank-abundance by family (log scale).**

**Table 6-4. Means and standard errors for diversity metrics.**

| | Mean | SE |
|---|---|---|
| Family Richness | 16.3 | 0.365 |
| Margalef's Corrected Family Richness | 2.70 | 0.178 |
| Percent Family Dominance | 39.7% | 4.11 |
| Species Richness | 41.7 | 3.40 |
| Margalef's Corrected Species Richness | 7.04 | 0.365 |
| Percent Species Dominance | 21.4% | 5.30 |

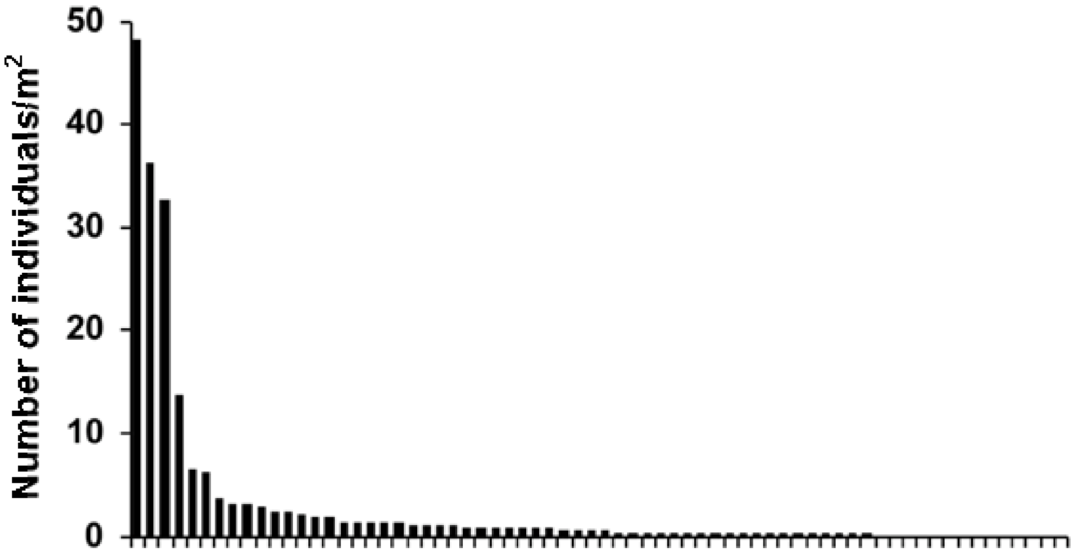


**Figure 6-14. Rank-abundance at the species level (linear scale).**

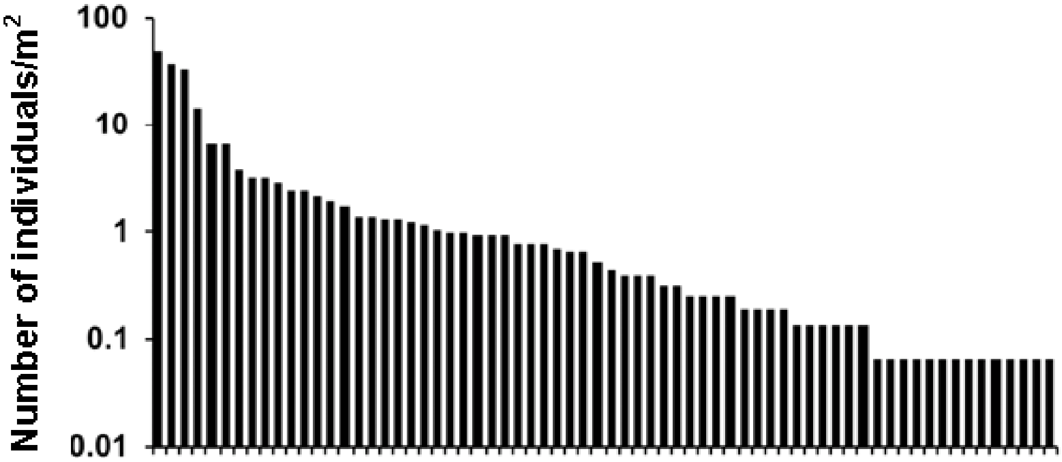


**Figure 6-15. Rank-abundance at the species level (log scale).**

Ephemeroptera were found in every sample, and this order was dominated by Baetidae, Ephemerellidae, and Leptophlebiidae (mean individuals/m$^2$= 60.3, 54.1, and 32.5, respectively; Table 6-5). The only family collected in the study with a higher abundance was Chironomidae. All families had a high frequency of occurrence; the three previously noted families occurred in each sample and the remaining two families, Ameletidae and Heptageniidae, had frequencies of 0.750 and 0.875. Ephemerellidae was particularly speciose with nine taxa represented. The most abundant mayflies at the genus/species level were *Baetis* spp., *Ephemerella excrucians*, and *Paraleptophlebia* sp. (60.3, 48.3, and 32.5 individuals/m$^2$; Table 6-5). *Baetis* and *Paraleptophlebia* were found in every sample.

Plecoptera were lower in abundance (individuals/m$^2$= 28.3) but were still found in every sample (Table 6-5). There was a relatively high level of evenness among the stonefly families: Nemouridae, Perlidae, Chloroperlidae, and Perlodidae had 10.8, 8.38, 7.31, and 1.88 individuals/m$^2$, respectively. Only Chloroperlidae was represented in every sample. The most abundant species were *Hesperoperla pacifica and Malenka* sp. (6.38 and 6.31 individuals/m$^2$, respectively), and *Hesperoperla pacifica, Claassenia sabulosa,* and *Suwallia* sp. A had the highest frequency of occurrence at 0.625 (Table 6-5).

Trichoptera were similar to Plecoptera in abundance, and the most common caddisfly families were Hydropsychidae, Hydroptilidae, and Philopotamidae (13.6, 4.50, and 1.19, respectively). Hydropsychidae and Hydroptilidae had the highest frequency of occurrence at 0.750. The most common taxa were *Hydropsyche* sp., *Hydroptila* sp. A, and *Dolophilodes* sp. (13.6. 3.88, 1.19 individuals/m$^2$, respectively; Table 6-5).

Coleoptera were relatively uncommon (4.38 individuals/$m^2$), and Elmidae (riffle beetles) and Hydrophilidae (water scavenger beetles) were the only families collected (4.31 and 0.0625 individuals/$m^2$, respectively; Table 6-5). Of the seven collected Coleoptera taxa, six were elmids, and both larval and adult elmids occurred in the samples. The elmids *Cleptelmis addenda* and *Optioservus quadrimaculatus* were the most abundant beetles (2.31 and 1.25 individuals/$m^2$, respectively); *Optioservus* had the highest frequency of occurrence (0.625). *Atractelmis wawona* (the Wawona riffle beetle), a federal species of concern, was not encountered.

Diptera was the most abundant order (132 individuals/$m^2$), and in turn Chironomidae (midges; 92.1 individuals/$m^2$) and Simuliidae (black flies; 36.2 individuals/$m^2$) were the most common dipterans (Table 6-5). Chironomidae was the only dipteran family found in each sample. Tipulidae (crane flies) and Empididae (dance flies) were also important both in terms of abundance and species richness (Table 6-5).

We also collected dobsonflies (Megaloptera), water mites, and clams, all in small numbers (Table 6-5). *Orohermes crepusculus*, the dobsonfly in our samples, was the largest animal that we collected; some specimens reached 4.5cm. No New Zealand mudsnails (*Potamopyrgus antipodarum*), or any other gastropods, were collected.

The sampled taxa represented a variety of feeding groups (Table 6-5). The majority of species were either predators (29) or collector-gatherers (20). There were fewer scrapers (6), shredders (6), collector-filterers (4), and piercer-herbivores (4), although scraping was frequently a secondary functional feeding mode. Important predator groups included stoneflies, crane flies, dance flies, and mites. Ephemerellid mayflies and riffle beetles were generally collector-gatherers. Most of the primary scrapers were heptageniid mayflies, most of the shredders were nemourid stoneflies, most of the piercer-herbivores were hydroptilid caddisflies, and the only collector-filterers were black flies and some of the caddisflies.

**Table 6-5. Densities (per m$^2$; SE = standard error) and frequency of occurrence of taxa, primary and secondary functional feeding groups (1$^o$ and 2$^o$ FFG), and California Tolerance Values (CTV). Ephemeroptera and Plecoptera were all nymphs; Megaloptera, Trichoptera, and Diptera were larvae except for occasional pupae (pu); Coleoptera were either larvae (l) or adults (a); and Acari and Bivalvia were adults. FFGs: p = predator, cg = collector-gatherer, cf = collector-filterer, ph = piercer-herbivore, sc = scraper, sh = shredder. Tolerance values represent a general spectrum of tolerance to poor water quality, scored from 0 (highly intolerant) to 10 (highly tolerant). Continued next page.**

| | Abundance | | Frequency | 1$^o$FFG | 2$^o$FFG | CTV |
|---|---|---|---|---|---|---|
| | Mean | SE | | | | |
| **Ephemeroptera** | 153 | 32.1 | 1.00 | | | |
| Ameletidae | 3.00 | 1.20 | 0.750 | | | |
| *Ameletus* sp. | 3.00 | 1.20 | 0.750 | sc | cg | 0 |
| Baetidae | 60.3 | 21.4 | 1.00 | | | |
| *Baetis* spp. | 59.0 | 21.3 | 1.00 | cg | sc | 4 |
| Unknown | 1.31 | 1.06 | 0.250 | cg | sc | 4 |
| Heptageniidae | 3.56 | 1.24 | 0.875 | | | |
| *Cinygmula* sp. | 0.625 | 0.246 | 0.625 | sc | cg | 4 |
| *Epeorus longimanus* | 0.625 | 0.498 | 0.250 | sc | cg | 4 |
| *Ironodes* sp. | 1.44 | 0.759 | 0.500 | sc | cg | 4 |
| *Rithrogena* sp. | 0.875 | 0.875 | 0.125 | sc | cg | 0 |
| Ephemerellidae | 54.1 | 23.4 | 1.00 | | | |
| *Caudatella heterocaudata* | 0.0625 | 0.0625 | 0.125 | cg | sc | 1 |
| *Caudatella hystrix* | 1.31 | 0.744 | 0.500 | cg | sc | 1 |
| *Drunella grandis ingens* | 0.0625 | 0.0625 | 0.125 | cg | sc | 0 |
| *Ephemerella excrucians* | 48.3 | 22.8 | 0.875 | cg | sc | 1 |
| *Ephemerella dorothea infrequens* | 1.13 | 0.760 | 0.250 | sh | cg | 1 |
| *Ephemerella* sp. A | 0.250 | 0.250 | 0.125 | cg | sc | 1 |
| *Ephemerella* sp. B | 0.0625 | 0.0625 | 0.125 | cg | sc | 1 |
| *Ephemerella* sp. C | 0.188 | 0.188 | 0.125 | cg | sc | 1 |
| *Serratella teresa* | 2.81 | 2.08 | 0.375 | cg | | 2 |
| Leptophlebiidae | 32.5 | 10.3 | 1.00 | | | |
| *Paraleptophlebia* sp. | 32.5 | 10.3 | 1.00 | cg | sh | 4 |
| **Plecoptera** 28.3 | 8.34 | 1.00 | | | | |
| Nemouridae | 10.8 | 4.72 | 0.625 | | | |
| *Malenka* sp. | 6.31 | 3.80 | 0.500 | sh | | 2 |
| *Podmosta delicatula* | 2.38 | 2.38 | 0.125 | sh | | 2 |
| *Zapada cinctipes* | 1.69 | 1.69 | 0.125 | sh | | 2 |
| Unknown | 0.375 | 0.375 | 0.125 | sh | cg | 2 |

**Table 6-5, cont. Densities (per $m^2$; SE = standard error) and frequency of occurrence of taxa, primary and secondary functional feeding groups ($1^o$, $2^o$ FFG), and California Tolerance Values (CTV). Continued next page.**

| | Abundance | | Frequency | $1^o$FFG | $2^o$FFG | CTV |
|---|---|---|---|---|---|---|
| | Mean | SE | | | | |
| **Plecoptera, cont.** | | | | | | |
| Perlidae | 8.38 | 3.74 | 0.875 | | | |
| *Claassenia sabulosa* | 1.81 | 0.647 | 0.625 | p | | 3 |
| *Hesperoperla pacifica* | 6.38 | 3.74 | 0.625 | p | | 2 |
| *Hesperoperla* sp. | 0.125 | 0.0818 | 0.250 | p | | 2 |
| Unknown | 0.0625 | 0.0625 | 0.125 | p | | 2 |
| Perlodidae | 1.88 | 0.976 | 0.500 | | | |
| *Cultus tostonus* | 0.0625 | 0.0625 | 0.125 | p | | 2 |
| *Cultus* sp. | 0.313 | 0.313 | 0.125 | p | | 2 |
| *Osobenus yakimae* | 0.938 | 0.938 | 0.125 | p | | 2 |
| *Skwalla americana* | 0.125 | 0.125 | 0.125 | p | | 2 |
| *Isoperla* sp. A | 0.250 | 0.250 | 0.125 | p | | 2 |
| *Isoperla* sp. B | 0.188 | 0.188 | 0.125 | p | | 2 |
| Chloroperlidae | 7.31 | 3.05 | 1.00 | | | |
| *Alloperla* sp. | 0.250 | 0.250 | 0.125 | p | | 1 |
| *Haploperla chilnualna* | 1.13 | 0.603 | 0.625 | p | cg | 1 |
| *Plumiperla* sp. | 0.938 | 0.868 | 0.250 | p | | 1 |
| *Suwallia* sp. A | 3.00 | 1.46 | 0.625 | p | | 1 |
| *Suwallia* sp. B | 1.94 | 1.45 | 0.250 | p | | 1 |
| Unknown | 0.0625 | 0.0625 | 0.125 | p | | 1 |
| **Megaloptera** | | | | | | |
| Corydalidae | 0.688 | 0.298 | 0.500 | | | |
| *Orohermes crepusculus* | 0.688 | 0.298 | 0.500 | p | | 0 |

**Table 6-5, cont. Densities (per m$^2$; SE = standard error) and frequency of occurrence of taxa, primary and secondary functional feeding groups (1$^o$, 2$^o$ FFG), and California Tolerance Values (CTV). Continued next page.**

| | Abundance Mean | SE | Frequency | 1$^o$FFG | 2$^o$FFG | CTV |
|---|---|---|---|---|---|---|
| **Trichoptera** | 21.3 | 8.13 | 0.875 | | | |
| Philopotamidae | 1.19 | 0.886 | 0.250 | | | |
| *Dolophilodes* sp. | 1.19 | 0.886 | 0.250 | cf | | 2 |
| Polycentropodidae | 0.875 | 0.337 | 0.500 | | | |
| *Polycentropus* sp. | 0.875 | 0.337 | 0.500 | p | cf | 6 |
| Hydropsychidae | 13.6 | 7.58 | 0.750 | | | |
| *Hydropsyche* sp. | 13.6 | 7.58 | 0.750 | cf | | 4 |
| Rhyacophilidae | 0.375 | 0.375 | 0.125 | | | |
| *Rhyacophila* sp. | 0.375 | 0.375 | 0.125 | p | | 0 |
| Hydroptilidae | 4.50 | 2.02 | 0.750 | | | |
| *Hydroptila* sp. A | 3.88 | 1.77 | 0.500 | ph | sc | 6 |
| *Hydroptila* sp. B | 0.438 | 0.371 | 0.250 | ph | sc | 6 |
| *Hydroptila* sp. (pu) | 0.188 | 0.132 | 0.250 | ph | sc | 6 |
| Lepidostomatidae | 0.750 | 0.423 | 0.500 | | | |
| *Lepidostoma* sp. | 0.750 | 0.423 | 0.500 | sh | | 1 |
| **Coleoptera** 4.38 | 2.27 | 0.625 | | | | |
| Hydrophilidae | 0.0625 | 0.0625 | 0.125 | | | |
| *Enochrus* sp. (a) | 0.0625 | 0.0625 | 0.125 | ph | | 5 |
| Elmidae | 4.31 | 2.28 | 0.625 | | | |
| *Cleptelmis addenda* (l) | 2.25 | 1.97 | 0.375 | cg | sc | 4 |
| *Cleptelmis addenda* (a) | 0.0625 | 0.0625 | 0.125 | cg | sc | 4 |
| *Heterlimnius* sp. (l) | 0.250 | 0.250 | 0.125 | cg | sc | 4 |
| *Optioservus quadrimaculatus* (a) | 1.25 | 0.366 | 0.625 | cg | | 4 |
| *Rhizelmis nigra* (l) | 0.375 | 0.375 | 0.125 | sc | cg | 2 |
| *Zaitzevia* sp. (a) | 0.0625 | 0.0625 | 0.125 | cg | | 4 |
| Unknown (l) | 0.0625 | 0.0625 | 0.125 | cg | | 4 |
| **Diptera** | 132 | 29.0 | 1.00 | | | |
| Chironomidae* | 92.1 | 19.0 | 1.00 | cg | p | 6 |
| Psychodidae | 0.0625 | 0.0625 | 0.125 | | | |
| *Pericoma* sp. | 0.0625 | 0.0625 | 0.125 | cg | | 4 |
| Simuliidae | 36.2 | 14.6 | 0.750 | | | |
| *Simulium* spp. | 36.1 | 14.5 | 0.750 | cf | | 6 |
| *Simulium canadense* (pu) | 0.0625 | 0.0625 | 0.125 | cf | | 6 |

**Table 6-5, cont. Densities (per m$^2$; SE = standard error) and frequency of occurrence of taxa, primary and secondary functional feeding groups (1$^o$, 2$^o$ FFG), and California Tolerance Values (CTV).**

| | Abundance | | Frequency | 1$^o$FFG | 2$^o$FFG | CTV |
|---|---|---|---|---|---|---|
| | Mean | SE | | | | |
| **Diptera, cont.** | | | | | | |
| Tipulidae | 2.25 | 0.835 | 0.750 | | | |
| *Antocha* sp. | 0.125 | 0.0818 | 0.250 | cg | | 3 |
| *Dicranota* sp. | 1.25 | 0.866 | 0.250 | p | | 3 |
| *Hexatoma* sp. | 0.875 | 0.515 | 0.375 | p | | 2 |
| Empididae | 1.06 | 0.427 | 0.500 | | | |
| *Clinocera* sp. | 0.188 | 0.188 | 0.125 | p | | 6 |
| *Hemerodromia* sp. | 0.438 | 0.371 | 0.250 | p | | 6 |
| *Wiedemannia* sp. | 0.0625 | 0.0625 | 0.125 | p | | 6 |
| *Clinocera/Wiedemannia* (pu) | 0.188 | 0.188 | 0.125 | p | | 6 |
| Unknown Empididae A | 0.0625 | 0.0625 | 0.125 | p | | 6 |
| Unknown Empididae B | 0.125 | 0.125 | 0.125 | p | | 6 |
| **Acari** | | | | | | |
| Hydrachnidae | 0.125 | 0.125 | 0.125 | | | |
| *Hydrachna* sp. | 0.125 | 0.125 | 0.125 | p | | 5 |
| Hydryphantidae | 0.0625 | 0.0625 | 0.125 | | | |
| Thyadinae | 0.0625 | 0.0625 | 0.125 | p | | 5 |
| **Mollusca, Bivalvia** | | | | | | |
| **Veneroida** | 0.875 | 0.806 | 0.250 | | | |
| Sphaeriidae | 0.875 | 0.806 | 0.250 | | | |
| *Sphaerium* sp. | 0.875 | 0.806 | 0.250 | cg | | 8 |
| **Total Individuals** | **341** | **45.0** | | | | |

* Individual chironomid morphospecies were separated and counted but most were not identified.

The proportional importance of the various functional feeding groups shifted significantly when considered as proportion of individuals (Table 6-6) instead of relative to numbers of taxa. Collector-gatherers accounted for 70.9% of total individuals-- a function of several abundant mayfly species (Table 6-5). Although predators accounted for a majority of taxa, due in large part to the speciose stoneflies (Table 6-5), predators only represented 7.47% of individuals (Table 6-6). In contrast, the four collector filterer taxa represented 13.5% of total individuals (Table 6-6), a function of abundant black flies (Table 6-5). Percent scrapers was notably low at only 1.98% (Table 6-6).

Tolerance values ranged from 0 to 8, but there were far more intolerant taxa (tolerance from 0 to 3; 36 taxa) than intolerant taxa (tolerance from 8 to 10; one taxon, the clam *Sphaerium* at a value of 8; Table 6-5). This one tolerant taxon represented 1.4% of taxa and only 0.26% of individuals. Tolerance values for mayflies and stoneflies were low, ranging from 0 to 4 and 1 to 3, respectively. Our one megalopteran species had a tolerance of 0. The caddisflies, beetles, and flies ranged higher (0 to 6, 2 to 5, and 2 to 6, respectively; Table 6-5). The unweighted mean tolerance by taxon was 3.1. Hilsenhoff's biotic index, which effectively weights tolerance by abundance of individual taxa, was 4.01 (SE = 0.338). Another measure of river health, Percent Ephemeroptera-Plecoptera-Trichoptera (EPT), was relatively high at 78.8% of total individuals (SE = 5.04), and we collected 44 EPT taxa.

**Table 6-6. Mean percentage of fauna (by individuals) and standard errors for primary functional feeding groups.**

| | **Mean** | **SE** |
|---|---|---|
| Percent Scrapers | 1.98 | 0.532 |
| Percent Predators | 7.47 | 1.76 |
| Percent Collector-Gatherers | 70.9 | 5.35 |
| Percent Shredders | 4.30 | 01.61 |
| Percent Collector-Filterers | 13.5 | 4.94 |
| Percent Piercer-Herbivores | 1.80 | 0.796 |

Initial data exploration via multiple regression yielded few significant models. Positive predictors included flow for simuliids (black flies), vegetation in the riparian zone (Table 6-3) for chironomids (midges), and lack of sediment deposition (Table 6-3) for baetid mayflies.

Some seasonal trends were apparent, particularly when spring-summer and fall-winter months were compared (Table 6-7). Diptera increased three-fold during the fall and winter (from a mean of 66.9 to 196 individuals/$m^2$; Table 6-7). Much of this increase was driven by an increase in simuliid black flies from zero to a mean of 71.8 individuals/$m^2$ (Table 6-7, Figure 6-16). Chironomid midges, particularly Tanytarsini, also increased from a spring-summer mean of 63.0 to a fall-winter mean of 121 individuals/$m^2$ (27.4 and 19.3 SE, respectively), although these differences were not significant (Mann-Whitney U test, $p = 0.0814$). These increases in dipteran abundance were combined with a decrease in number of %Ephemeroptera-Plecoptera-Trichoptera from a mean of 228 to 177 individuals/$m^2$, e.g., *Serratella teresa* (Table 6-7). In turn, %EPT decreased (from over 80% to 30%; Table 6-7, Figure 6-17), and %Collector-Filterers, the simuliid functional feeding group, increased (from zero to above 20%; Table 6-7, Figure 6-18). The dominant functional feeding group, collector-gatherers, decreased from 91% to about 60% during this time (Figure 6-18), though this was not a significant change (Mann-Whitney U test, $p = 0.149$). Most dipterans collected in the study had higher tolerance values than the rest of the taxa (Table 6-5), and Hilsenhoff's Biotic Index increased steadily from 2.29 to ~5.0 from spring to winter (Figure 6-19, Table 6-7). Percent Species Dominance, however, decreased from 56% to ~15% during this time period (Figure 6-20, Table 6-7) whereas % Family Dominance did not show as steady a decline (Figure 6-20).

**Table 6-7. Mean values (SE = standard error) for selected metrics as a function of period during which sampling occurred: Spring-Summer (March through August) or Fall-Winter (September through February). Most response variables were tested for seasonal differences and the majority were non-significant; only significant results are presented here. P-values are the result of two-tailed Mann-Whitney U tests. *Simulium* is a black fly (Diptera: Simuliidae); *Serratella* is a mayfly (Ephemeroptera; Ephemerellidae); %CF = Percent Collector-Filterers; %EPT = Percent Ephemeroptera-Plecoptera-Trichoptera; %Dominance (Sp) = Percent dominance by the most common species in each sample; HBI = Hilsenhoff's Biotic Index (larger values indicate increased tolerance to poor water quality).**

| | **Spring-Summer** | | **Fall-Winter** | | |
|---|---|---|---|---|---|
| | **Mean** | **SE** | **Mean** | **SE** | **p** |
| Diptera | 66.9 | 27.9 | 196 | 18.6 | 0.0209 |
| *Simulium* sp. | 0.500 | 0.354 | 71.8 | 11.9 | 0.0202 |
| *Serratella teresa* | 5.63 | 3.86 | 0.00 | 0.00 | 0.0472 |
| %CF | 2.75 | 1.78 | 24.3 | 5.79 | 0.0209 |
| %EPT | 78.7 | 5.04 | 44.8 | 0.818 | 0.0209 |
| %Dominance (Sp) | 29.9 | 9.04 | 12.9 | 0.890 | 0.0209 |
| HBI | 3.28 | 0.350 | 4.75 | 0.226 | 0.0209 |

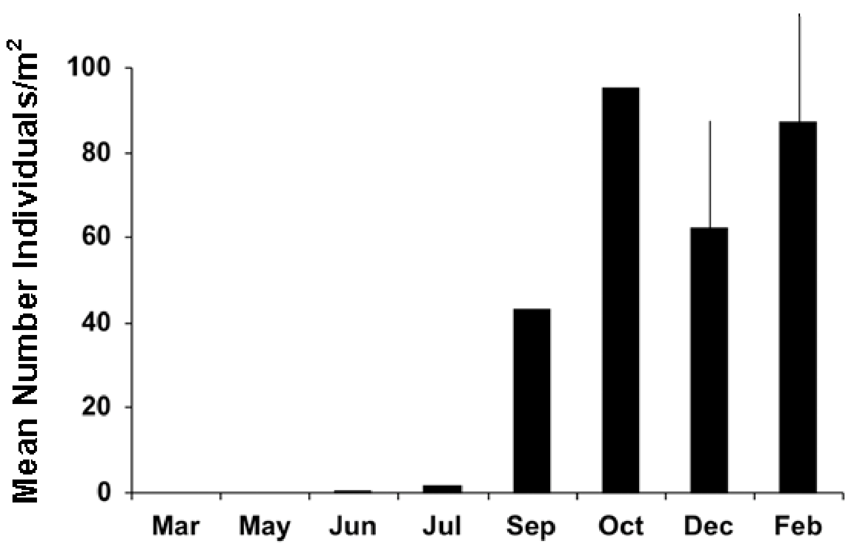


**Figure 6-16. Simulium (black flies; Diptera: Simuliidae) densities during 2007 study year.**

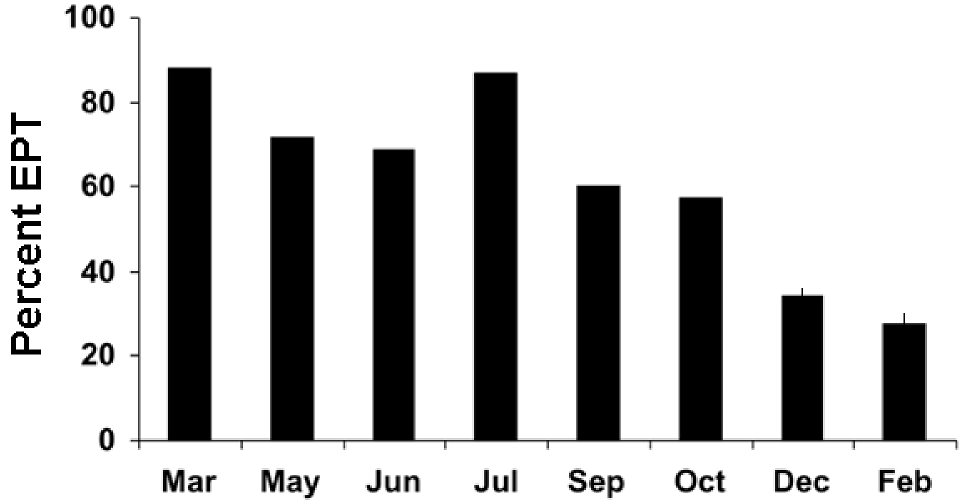


**Figure 6-17. Percent Ephemeroptera-Plecoptera-Trichoptera during 2007 study year.**

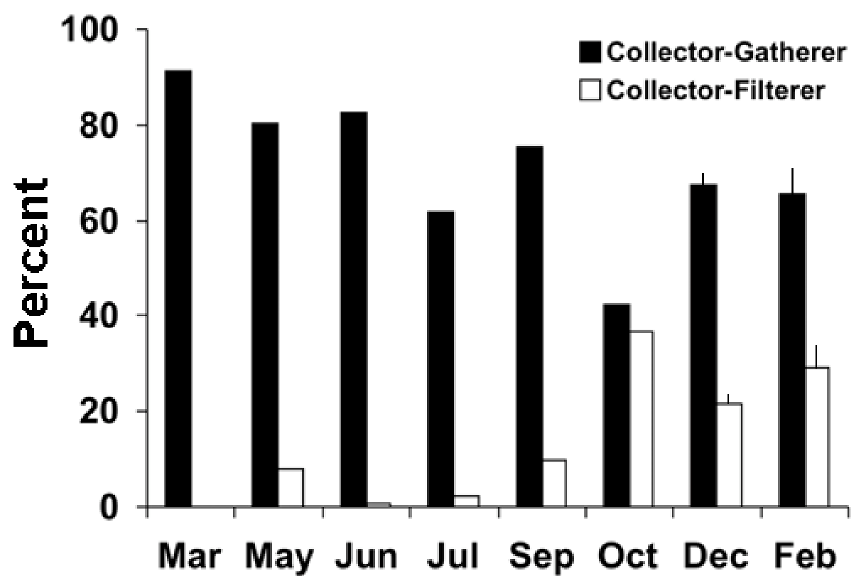


**Figure 6-18. Percent Collector-Gatherers and Collector-Filterers during 2007 study year.**

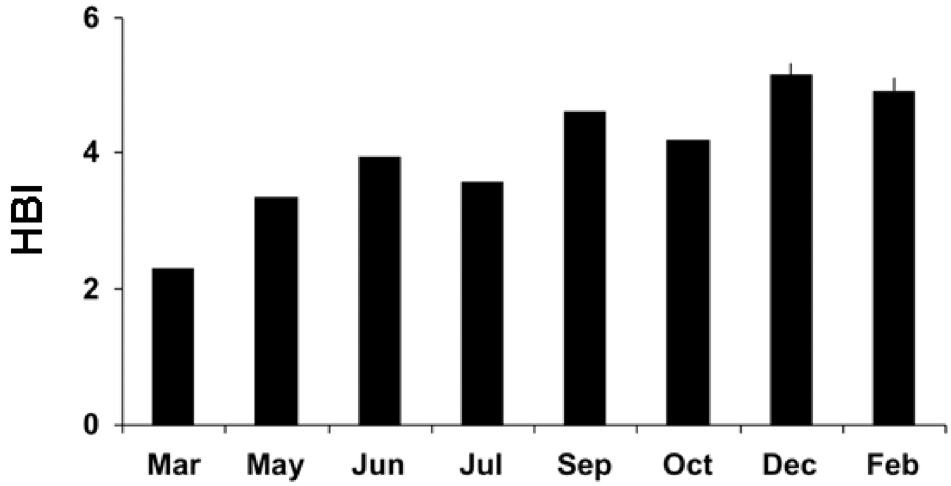


**Figure 6-19. Hilsenhoff Biotic Index during 2007 study year.**

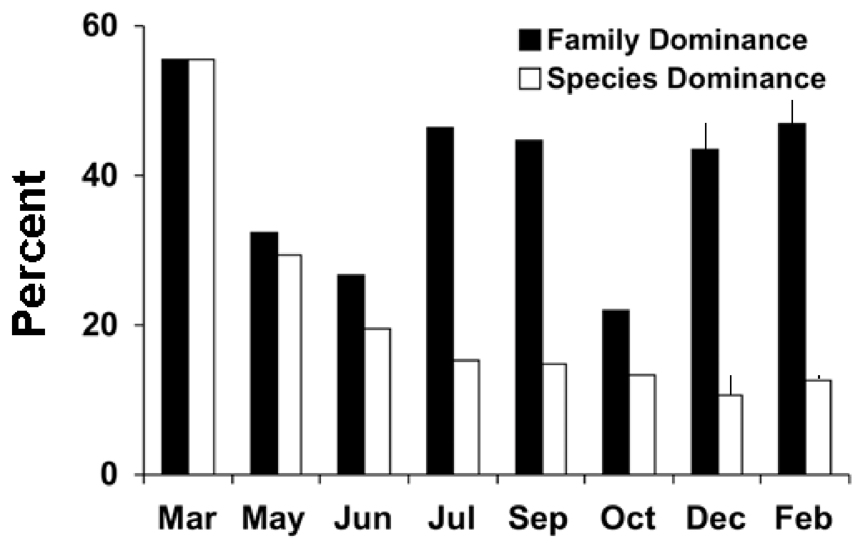


**Figure 6-20. Percent Family and Species Dominance during 2007 study year.**

Large rock substrata (boulders and submerged slabs) yielded higher means (mean = 767 individuals/m$^2$, SE = 719) than cobble substrata, but variability was very high, as some samples had almost no fauna present. Ephemeroptera were abundant in one sample but absent in the others (mean = 294 individuals/m$^2$, SE = 294). Adult and larval elmid (riffle) beetles were common in the same abundant sample and again absent in the other rock scrapings (mean = 276 individuals/m$^2$; SE = 276). Diptera were also present in large numbers (mean = 104 individuals/m$^2$, SE = 68.2). Trichoptera and Plecoptera were less abundant (~50 individuals/m$^2$ each).

### 6.4 Discussion

We collected a diverse assemblage of macroinvertebrates that was generally similar in character to the assemblage in the riffle habitats in the upper Merced River that were at approximately the same elevation and that had similar ecological characteristics (Stillwater Sciences 2007). Many of the families were common to both studies, including all mayfly families. Each stream had one beetle, one fly, and one stonefly that the other stream lacked. The Merced had four caddisfly families that were absent from the Tuolumne, and the Tuolumne had three caddisfly families that were absent from the Merced. The upper Merced comparison sites had four families of mites that we did not find in the upper Tuolumne, but the upper Tuolumne had one mite family that was absent from the Merced as well as bivalves. Sorensen's similarity coefficient was 0.68 for families and 0.59 for species. We did not collect any New Zealand mudsnails from the Tuolumne River.

By way of further comparison, the reach of the upper San Joaquin River in Devils Postpile National Monument is a nearby river at about twice the elevation of the Poopenaut Valley (2300 versus 1100 m) but with a fauna that was not much more different from the upper Tuolumne than the upper Merced, despite the difference in elevation (Holmquist and Schmidt-Gengenbach 2005). Most of the families collected were shared by both the upper San Joaquin and upper Tuolumne. Although both streams again had the same families of mayflies, there were four families of caddisflies that were found in the Poopenaut that were not found in the Postpile, and vice versa. There were three families of Plecoptera and one dipteran and one hemipteran family that were found in the Postpile but not in the Poopenaut, but dobsonflies, bivalves, and one family of beetle were found in the Poopenaut but not in the Postpile. Sorensen's similarity coefficient was 0.68 for families, i.e., exactly the same as for the Tuolumne-Merced comparison, and species similarity (0.53) was only slightly lower than the Tuolumne-Merced similarity (0.59).

Rank-abundance plots retain much more information than diversity indices that, used alone, distill complex communities into single numbers with accompanying information loss, and rank-abundance plots are therefore useful components of initial assemblage descriptions. The family and species rank abundance plots (log scale; Figures 6-13, 6-15) fall between the log normal distribution and MacArthur's broken stick model. These curves indicate relatively high richness and evenness, minimal niche preemption, and relatively uniform division of resources (Magurran 1988, Schowalter 2006).

Collector-gatherers dominated the functional feeding groups at 70.9% of individuals and 31.8% of taxa. Collector-gatherers in combination with collector-filterers accounted for 84.4% of individuals, which exceeds the high 70% found in the upper Merced (Stillwater Sciences 2007). Such a high proportion of collector-gatherers, or a low collector-filterer: collector-gatherer ratio (which also obtained in the Poopenaut reach at 0.19), can suggest a relatively low ratio of suspended fine particulate matter to deposited fine particulate matter (Merritt and Cummins 1996, Merritt et al. 2008), which in turn can be related to reduction in transported particulates below deep release dams (Allan 1995). Predatory taxa accounted for 44.6% of species, but only 7.5% of individuals. The ratio of predators to all other feeding groups (0.08) was somewhat lower than the frequently encountered range of 0.10-0.20 (Merritt and Cummins 1996, Merritt et al. 2008). Scrapers were less important in our upper Tuolumne samples (2%) than in the upper Merced (21%; Stillwater Sciences 2007).

It is encouraging that there were so few "tolerant" (see Section 6.2 Methods) fauna in the riffles below the dam. Our one tolerant taxon, the clam *Sphaerium*, accounted for only 1.4% of taxa and 0.26% of individuals. In contrast, tolerant taxa represented 14% of taxa in the riffles in the upper Merced. Hilsenhoff's Biotic index (HBI), which weights tolerance by abundance, was relatively low at 4.01 across our samples. Percent Ephemeroptera-Plecoptera-Trichoptera (EPT) was in turn high at 78.8%.

Although the detection of seasonal patterns was not a goal of this study, some patterns emerged, particularly when comparing spring-summer months with fall-winter months. There were significant increases in Diptera, collector-filterers, and HBI and a concomitant decrease in %EPT, in large part due to an increase in *Simulium* black flies. Somewhat surprisingly, there was also a decrease in Percent Species Dominance, which was largely a function of increased richness and abundance of Chironomidae (Diptera) during the fall and winter. Benthic invertebrate sampling is often done in the summer and/or fall, but clearly year-round sampling is desirable when possible because of the shifting nature of the assemblage.

The ancillary sampling of boulders and slabs indicated that these habitats have twice the faunal density of riffles in this reach, but also that this density is highly variable. In some cases these large rock substrata had a strikingly different assemblage structure than the riffles. For example, the mean of 276 elmid beetles/$m^2$ was 64 times greater than the mean for riffles.

Habitat assessments indicated that in general this river reach should provide good habitat for fauna (overall score of 155 was at the low end of the Optimal range; Table 6-3). The mean habitat quality score fell into the lower range of scores for the nearby upper Merced River (Stillwater Sciences 2007). McBain and Trush (2006) identify reduction of magnitude and duration of snowmelt flows and reduced winter peak flood magnitude as likely consequences of flow regulation below Hetch Hetchy with potential effects on geomorphology, riparian vegetation, and fauna (see also Chapter 2 of this report). Reduced flow variability can lead to reduced habitat heterogeneity and increased algal cover and sediment deposition (Allan 1995). Carter and Fend (2001) found several of these factors to be important in structuring the BMI assemblage in the upper Merced. There was a lack of woody debris at our sites, and there was generally a substantial cover of filamentous green algae (Figures 6-2 through 6-4). There were, however, plentiful green algae in the river above the reservoir as well (pers. obs.). There was clear evidence of sediment deposition at some sites, though the mean for this parameter fell just within the Optimal range, and this parameter was a significant predictor of baetid mayfly abundance at our sites.

Stream width, depth, and flow in the study reach of the Tuolumne River (Table 6-2) were generally similar in riffle habitats in the upper Merced River (Stillwater Sciences 2007). Temperatures from the Poopenaut reach of the Tuolumne River, however, appear to have been substantially lower than those from the upper Merced River: 7.81$^{o}$C (mean from our 2007 September and October samples) versus 13.3$^{o}$C (our calculated mean for the upper Merced River based on fall 2006 data in Stillwater Sciences 2007). The much more extensive data from temperature recorders above and below the reservoir and on the upper Merced River (discussed in Chapter 2) confirm this observation. Deep-release dams typically reduce daily and annual temperature fluctuations and lower mean annual temperatures (Ward and Stanford 1979). These changes often lead to negative impacts on BMI diversity because of disruption of thermal cues for reproduction and development, reduction of degree days for completion of life cycles, and slowing of metabolic rates (Hayden and Clifford 1974, Lemkuhl 1974, Allan 1995), and Hawkins et al. (1997) found temperature to be a key factor in structuring BMI. McBain and Trush (2006) note that fauna are likely to be similarly affected by disrupted thermal regimes below Hetch Hetchy. Although diversity is often reduced in response to increased temperatures, overall production can be increased (Wohl et al. 2007). Water temperatures below the dam are clearly lower than above-reservoir and Merced River temperatures (Chapter 2 of this report), but our first year of study did not include an above-reservoir comparison group, precluding conclusions about temperature regime and the influence of the dam and reservoir on downstream BMI along this isolated reach. We did not find increases in BMI diversity or decreases in tolerance with increasing distance downstream from the dam, suggesting that temperature effects *may* not be as pronounced as seen below some other cold-water dams (Ward and Stanford 1979, Allan 1995). The 5 km study reach, however, may have been insufficient in length to have allowed appreciable warming before the discharged water left the study area.

Year 1 was designed to be an initial characterization of the BMI assemblage in riffle habitats that could be used as baseline data. Year to year variability can be substantial (Leland et al. 1986, Holmquist and Schmidt-Gengenbach 2005), and we advocate continued monitoring of this reach, including additional habitats, in order to establish a longer-term baseline and to detect effects due to changes in dam operations, climate, and other factors. Because of the likely importance of hydrological factors in driving assemblage structure of BMI and other faunal groups, Yosemite National Park, the San Francisco Public Utilities Commission, and outside cooperators are developing plans to use experimental releases for an initial assessment of short term release pulses on fauna during the summer of 2008, and characterizing the response of BMI will be a part of this effort.

This first year of study yielded some results suggesting some level of impact due to dam operations, whereas other results provide an initial indication of little if any negative effect, but this study was not specifically designed to be an assessment of effects of an altered flow regime. Comparison of below-dam, above-reservoir, and unregulated reaches can be a powerful tool to discriminate potential effects of dam operations, with the caveat that these reaches can also differ as a function of geomorphological or other covariates (Holmquist et al. 1998, Greathouse et al. 2006a,b). Such comparisons would be an important complement to our ongoing Looking Downstream efforts.

## Chapter 7: Discussion and recommendations for future work

With only one year of data, and with those data characterizing an unusually dry year, we are unable in this interim report to reach any robust conclusions regarding the downstream impacts of O'Shaughnessy Dam and Hetch Hetchy Reservoir on the greater Poopenaut Valley area. However, our initial studies suggest that because of several factors unique to this setting (e.g., a low overall gradient, a downstream bedrock constriction that promotes floodplain inundation, upslope glacial moraines that contribute sediment to the river), Poopenaut Valley and its ecosystems have largely been spared the severe impacts seen downstream of other dams. Despite an altered hydrologic regime, riparian and meadow ecosystems in Poopenaut Valley continue to provide important habitat for a variety of plant and animal species, many of them sensitive indicators of habitat quality.

Figure 7-1 shows repeat photographs of Poopenaut Valley taken from the Hetch Hetchy Road over a 92-year interval (note that the photographs were not taken from the exact same location). Although there are some changes visible in the Poopenaut Valley landscape, namely conifer encroachment adjacent to the river and along the margins of the meadows, and a reduction in vegetation on the hillslopes (probably due to the Ackerson fire of 1996), there are also some striking similarities. Most of the areas functioning as meadows in 1915 appear relatively intact in 2007, and geomorphic features such as the prominent sand bar on the north side of the river appear relatively unchanged. Superficially at the landscape scale, Poopenaut Valley displays fewer changes than some areas in the Tuolumne River watershed upstream of Hetch Hetchy Reservoir (e.g., Vale and Vale 1994). Of course, important changes occur at sub-landscape scales. This study addresses how these changes have manifested in the present-day ecosystem.

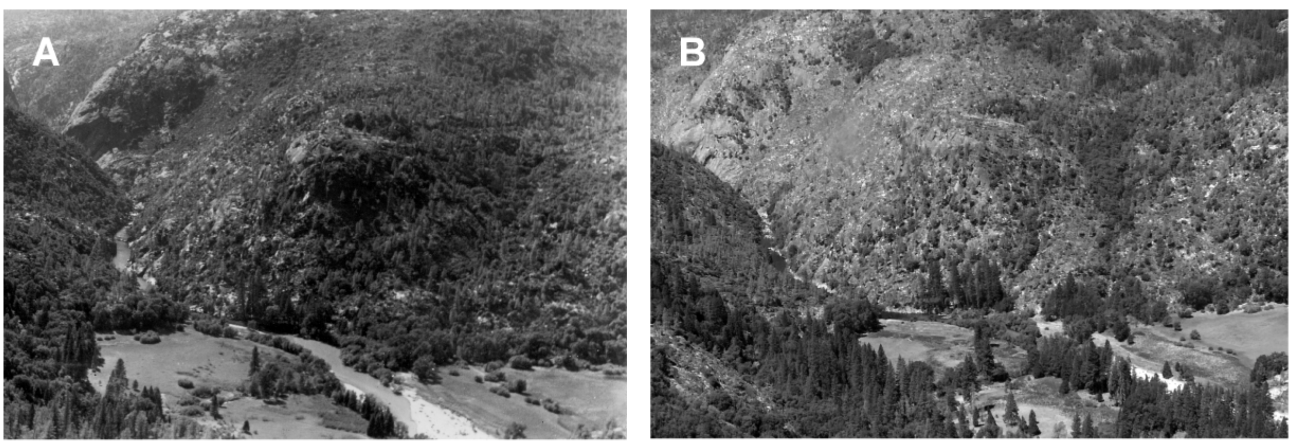


**Figure 7-1. Comparative photographs of Poopenaut Valley from (A) circa 1915 (photograph by F.E. Matthes) and (B) 2007 showing degree of geomorphic and vegetative change over 92-year time period.**

Our primary area of interest in Poopenaut Valley continues to be the inter-related connections between the surface and ground water hydrology, the health of riparian and wetland habitats, and the animal species that depend on them. We intend to conduct additional work in 2008 to further our understanding of streamflow effect on these connected systems. Riparian vegetation plays a critical role in maintaining riparian ecosystem function by promoting stream bank stability and water quality, reducing the potential for erosion, increasing the storage of nutrients and water, and providing forage and habitat for wildlife (Knopf et al. 1988, Rood et al. 1995, Castelli et al. 2000). The composition and distribution of riparian plant communities are influenced by seasonal flooding, duration of inundation and levels of shallow groundwater (Dwire et al. 2004); thus, riparian plant communities are vulnerable to altered hydrologic regimes downstream of dams. Riparian and wetland areas are among the most important habitats in the Sierra Nevada; they are also among the most impacted (SNEP, 1996). In Yosemite National Park, examples of impacts to wetland and riparian habitats over the past 150 years include ditching of wet meadows, removal of riparian vegetation and large in-channel wood that stabilize channel banks, and lowering of the El Capitan Moraine in Yosemite Valley in an attempt to reduce the amount and duration of standing water on adjacent meadows (Milestone 1978). As such, wetland and riparian ecosystems in Yosemite National Park receive high priority for both protection and restoration (e.g., Siegel and DeSante 1999). In all cases, the primary impact to these ecosystems is an altered hydrologic relationship between surface water and groundwater, resulting in less frequent overbank flooding and saturation of meadows soils. The situation in Poopenaut Valley is clearly analogous, and highlights our interest in, and concern for, wetland and riparian habitats in Poopenaut Valley.

An issue that we did not address in 2007 but expect to address in 2008 is that of the nature and timing of tributary incision into Poopenaut Valley floodplain surfaces. These tributaries are incised over 1 m along the perimeter of the floodplains, and up to 3 m where they enter the river (Figure 7-2). Tributary incision likely lowers the water table beneath the meadows, causing aridification of meadow soils (e.g., Loheide and Gorelick 2007). This reduction in water availability can cause a succession from native hydrophytic vegetation to mesic or xeric vegetation (Loheide and Gorelick 2007). It is not yet clear whether tributary incision results from dam operations (e.g., other meadows in the Sierra Nevada without regulated upstream flows show incised tributaries, perhaps due to grazing), but Figure 7-3 illustrates a possible mechanism by which alteration of the natural river hydrograph may have contributed to tributary incision. Under pre-dam conditions the peak discharge of the tributaries may have coincided with the peak discharge of the river (which was of longer duration), resulting in the tributaries entering Poopenaut Valley at times when the backwater effect created ponded water in the meadows (Figure 6-3). Under this scenario the tributaries would deliver their coarse sediment load to the perimeter of the meadow and no incision would occur. However, under modern conditions the peak discharge of the tributaries may occur much earlier than the peak discharge of the river, leading to incision into the floodplain surfaces (Figure 7-3). When the peak discharge occurs in the river channel, river water backs up into these incised channels.

**Figure 7-2. Tributary incision into Poopenaut Valley meadow surfaces.**

We plan to test the hypothesis shown in Figure 7-3 by analyzing data from stage recorders in the tributaries, which were provided by McBain and Trush, Inc., and installed in late 2007. Analysis of the hydrographs (timing and magnitude) from both the river and the tributaries should provide critical information needed to assess whether these incised channels result from dam operations.

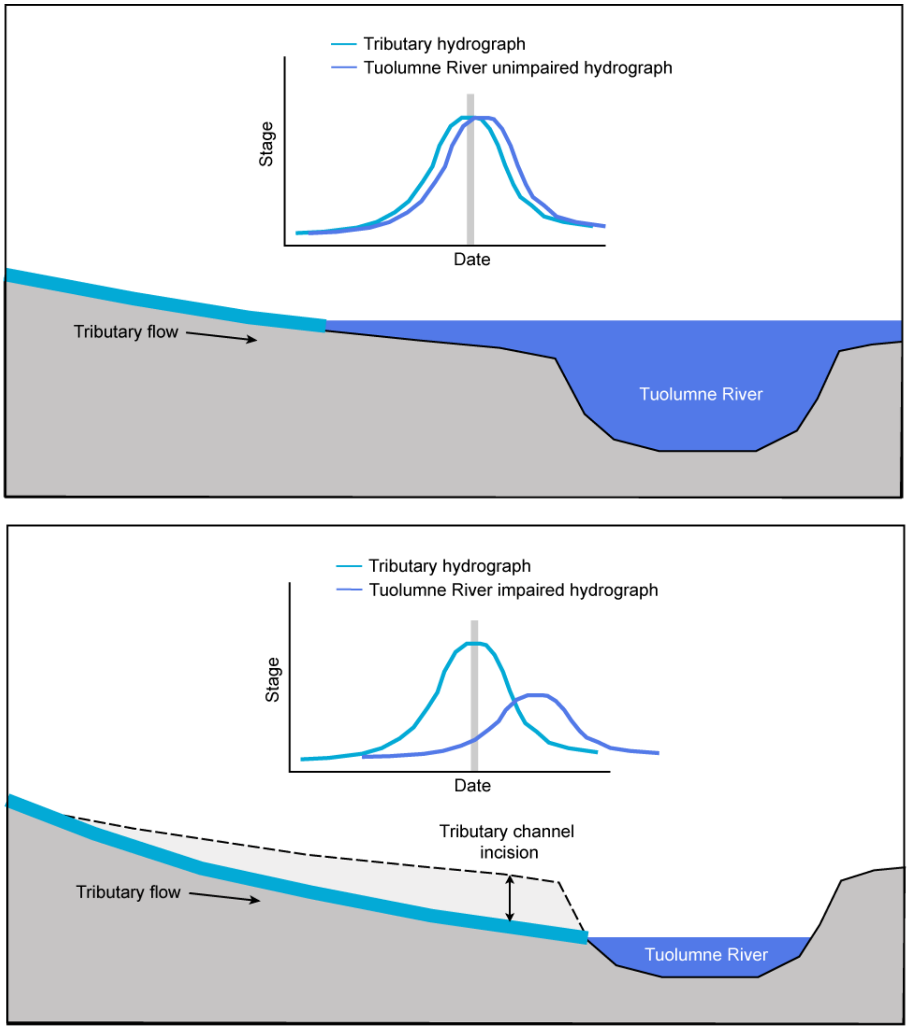


**Figure 7-3. Schematic diagram illustrating possible relation between alteration of natural river hydrographs and tributary incision into Poopenaut Valley meadow surfaces.**

Fundamentally, the existence and health of Poopenaut Valley meadows depends on adequate saturation of its soils during the growing season. Based on the assessment of the current extent of the wetlands and the associated plant communities (Chapter 3), it appears that water table levels are sufficient to sustain some wetlands and discourage extensive conifer encroachment. This probably relates to the unique stage-discharge relationship in Poopenaut Valley, and the relatively high transmissivity of meadow soils (Chapter 2). However, several lines of evidence suggest that wetland extent in Poopenaut Valley has decreased, possibly due to regulated river flows. We observed hydric soils within the forested edge of the southwestern-most wetlands, in areas of conifer encroachment, in areas now dominated by upland plants, and in wetlands with weak hydrologic indicators that exhibit nearly equal amounts of upland and wetland plant species. This indicates that wetland areas were more extensive in Poopenaut Valley in the past; these areas may be transitioning to drier upland habitats due to dam operations. There are several distinct cohorts of different aged conifer encroachment, and investigations into the timing of establishment of these trees (age trees by coring) could potentially be correlated with high or low discharge trends.

Water-table depth, soil-water content, and wetland riparian species are strongly connected (Loheide and Gorelick 2007, Allen-Diaz 1991, Merendino et al. 1990, Yabe and Onimaru 1997). The hydrologic analysis presented in Figure 2-8 is our first attempt to differentiate between the frequencies of different stage durations under regulated and unregulated conditions. Coupled with additional water table observations during a larger and/or longer duration dam release, and with a two-dimensional groundwater model, this analysis could determine the river discharge rates and durations necessary to maintain or improve wetland and meadow habitats. As an example, the necessary inundation or saturation of a wetland is 12.5% (26 consecutive days) of the growing season every 5 out of 10 years, as defined by the U.S. Army Corps of Engineers. In Poopenaut Valley, the growing season is generally March through September, about 210 days. Soil saturation must occur within a major portion of the root zone (usually within 30 cm (12 inches) of the surface) of the prevalent vegetation (Environmental Laboratory 1987). Based on studies in other Sierra Nevada meadows, hydrophytic vegetation (adapted to periods of inundation) occurs where the water table is 0–40 cm below the surface, and more mesic vegetation (not typically adapted to periods of inundation) exists where the water-table is 20–80 cm below the surface (Allen-Diaz 1991). Hydrologic regimes can effect soil properties (organic horizons, soils particle size, available nutrients, temperature) and determine plant species distribution (Castelli et al. 2000). With the collection of additional data to further field validate optimal river discharge rates and durations, it will be possible to determine the extent of wetland habitat that is maintained by current hydrologic conditions and the potential extent of wetlands under reconstructed unregulated conditions. This analysis will determine the minimum river discharges and durations necessary to achieve the reconstructed pre-dam condition. Depending on the operational constraints of managing Hetch Hetchy Reservoir, this information can be used to mimic a hydrograph that would potentially benefit Poopenaut Valley's hydrology, vegetation, and wildlife.

In order to complete the analysis proposed above, we recommend the following tasks for 2008:

- Complete a one-dimensional surface water hydraulic model of Poopenaut Valley, in cooperation with scientists from McBain and Trush, Inc. The results from this model, along with observed stage-discharge relationships, will form the basis of a refined stage-discharge relationship, as shown in Figure 2-7. This relationship will allow for a quantitative assessment of the river discharge needed to maintain and enhance meadow habitat in Poopenaut Valley.
- Construct and calibrate a two-dimensional groundwater model in order to project the level, extent and duration of inundation/saturation of the root zone at different river discharges and discharge durations.
- Conduct vegetation surveys to determine timing of wetland plant emergence, growth, and flowering in Poopenaut Valley as well as in wet meadows adjacent to unregulated rivers such as the Merced River in Yosemite Valley. This step is particularly important to determine the time of year that increased flows would be most effective.
- Monitor wetland plant diversity, abundance, and cover to determine temporal trends.
- Determine ages of cohorts of conifer encroachment in order to relate periods of encroachment to dam operations or climate.
- Establish rigorous photo-point documentation of meadow habitat and flooding.

Further investigation into the riparian plant communities is necessary to better establish age classes, seed production and dispersal, establishment, sediment transport and dynamics associated with altered flow regimes and the extent to which these processes can be changed to mimic a more natural riparian system. We recommend the following work to improve understanding of riparian plant communities in Poopenaut Valley:

- Establish seed traps: Assessment of willow and cottonwood seed abundance and dispersal (timing and distance) as related to the timing and duration of peak river discharge.

- Conduct belt transects along river cross-sections in order to assess plant species spatial distribution, composition, and cover.

Observations in Poopenaut Valley and in other montane meadows indicate that wetter areas exhibit less non-native plant dominance, both for perennial (e.g., Kentucky bluegrass) and annual (e.g., cheatgrass) species. Perennial grasses sown for forage during past grazing operations were not observed in wetlands dominated by sedges. If duration and magnitude of inundation or saturation of the root zone increases, these non-native perennial grasses may be able to out-compete more hydrophytic plants and, subsequently, decline in dominance. Based on historic stream gage data downstream of O'Shaughnessy Dam, rising and falling limbs of peak flow hydrographs are typically very short (compared to the much more gradual rising and falling limbs observed in free-flowing rivers such as the Merced during spring runoff) and could be maintaining soil disturbance in those areas that lack the anchoring roots of perennial plants, thereby perpetuating annual non-native plant communities.

In order to investigate factors potentially perpetuating the growth of non-native plants, we recommend the following work:

- Conduct vegetation transects in order to monitor plant diversity, abundance, and cover and associate these data with existing and potential hydrologic conditions as described in the wetlands investigations above.
- Eradicate existing invasive plant populations as feasible.

Our hydrological assessments completed in 2007, along with future monitoring and modeling of groundwater transport from established monitoring wells, will foster a better understanding of the dynamics affecting the wetland, riparian, upland and forested plant communities. These efforts will improve our ability to anticipate the potential effects of alterations in the magnitude, duration, timing, frequency and rate of change of peak river discharges on plant and wildlife communities. While it is clear that variability in the hydrologic regime is crucial for sustaining these communities, continued monitoring and modeling will provide information needed to develop future recommendations for maintaining and enhancing wetland and riparian plant communities and the wildlife species that depend on them.

Since riparian habitat harbors the most diverse bird communities in the arid and semi-arid regions of the western United States (Knopf et al. 1988), it is not surprising that the patches of riparian habitat in Poopenaut Valley support a relatively diverse bird assemblage. Search Area 5, characterized by montane riparian habitat, yielded higher species richness, relative abundance, species diversity, and evenness, compared to the meadow habitats. However, the three confirmed breeding species, Black-headed Grosbeak, Bullock's Oriole, and Western Wood-Pewee, were observed in all five Search Areas and 15 species were observed outside of Search Area 5, indicating the importance of a diverse mosaic of wet and upland meadow and montane riparian habitat types.

Despite the diverse bird assemblage observed in Poopenaut Valley, it remains unknown if Poopenaut Valley is acting as a population source in which young birds are being successfully recruited into the population; or, alternatively, if Poopenaut Valley is acting as a population sink in which birds are being produced elsewhere, colonizing Poopenaut Valley, and then experiencing reproductive failure. Investigating demographic parameters, such as nesting success of riparian focal species, would determine if productivity is a potential limiting factor. Identifying factors associated with low reproductive success may help identify which management and restoration actions may be necessary to improve Poopenaut Valley's riparian ecosystem (RHJV 2004).

In order to further investigate bird population dynamics that reflect the quality of the riparian habitat in Poopenaut Valley, we recommend the following work:

- Continue bird surveys to decipher bird population dynamics in Poopenaut Valley. Long-term data are vital to understanding the difference between true population decline and natural fluctuation in population size.
- Compare bird survey results from Poopenaut Valley with survey results associated with similar habitat types along the Merced River.
- Conduct a more extensive California Wildlife Habitat Relationship model analysis that is specific to the breeding season, and based on habitat features existing in Poopenaut Valley, in order to compare predicted breeding bird species with bird species observed during surveys.
- Conduct select monitoring to determine factors influencing nesting success of the Song Sparrow, Yellow Warbler, and Warbling Vireo. This is best accomplished using a nest searching and monitoring protocol.

The diversity of riparian obligate birds, including six riparian focal species, encountered in Poopenaut Valley is an indicator of avian population health. Thus, conservation efforts to protect and restore riparian habitat in Poopenaut Valley should be prioritized. Reproductive success is an important demographic parameter that provides a foundation around which to build a riparian conservation program. Preliminary results suggest that 16 probable breeding species inhabit Poopenaut Valley; further research will begin to confirm which species are reproducing successfully.

Bird and benthic macroinvertebrate survey results are based on only one year of data. Year to year variability in among these fauna can be substantial, and we advocate continued monitoring, including of additional habitats, in order to establish a longer-term baseline and to detect effects due to changes in dam operations, climate, and other factors. Our results would be more robust statistically, and our analyses more meaningful, if combined with data from additional years and compared with data from unregulated reaches such as the upper Merced River and the Tuolumne River upstream of Hetch Hetchy Reservoir. Certain habitats encountered in Poopenaut Valley are unique and could be difficult to find elsewhere; however, these sorts of comparisons are essential for accurately assessing the impacts from dam operations. Benthic macroinvertebrate sampling in 2008 will decrease the spatial variability in sampling and increase the temporal variability, across a range of river discharges, to more accurately assess aquatic flow-habitat relationships.

Habitats that have only been moderately impacted by human activity, as opposed to those that have been substantially impacted, are generally considered to be the best candidates for restoration efforts. In most respects, Poopenaut Valley appears to have sustained moderate impacts from an altered hydrologic regime, and thus is a prime candidate for careful, science-based management of flows from O'Shaughnessy Dam. Future work in Poopenaut Valley will help to inform the timing, duration, and magnitude of flows that will maximize benefits to downstream ecosystems.

## Acknowledgements

We appreciate valuable discussions with, field assistance from, and data sharing with scientists from McBain and Trush, Inc. Specifically we thank Scott McBain, Bill Trush, John Bair, and Geoff Hales, and we look forward to additional collaborations in 2008 and beyond. We also thank Bill Sears, Bruce McGurk, Tim Ramirez, Jim Salerno, Brian Sak, and Mike Horvath of the San Francisco Public Utilities Commission (SFPUC) and Hetch Hetchy Water and Power for discussions, data, and support of this project. We thank Joy Fisher, Maureen McGlintchy, and Heather Todd (all NPS) for assistance installing the groundwater monitoring wells. Dena Grossenbacher (NPS) took the photographs of Poopenaut Valley meadow inundation in June 2006. NPS GIS specialist, Bill Kuhn, created many of the figures in this report. We thank Peggy Moore for commenting on Chapter 3, Jeff Maurer, Les Chow, and Steve Thompson for editing the predicted species lists in Chapter 4 and commenting on Chapter 5. Observations presented in this report from Yosemite's Wildlife Observation Database were collected by several individuals, including park employees, visitors, and researchers. We thank Jason Love for macroinvertebrate field and lab assistance, Jean Dillingham, Derham Giuliani, and Peter Norquist for help sorting macroinvertebrate samples, and Eric Berlow (Sierra Nevada Research Institute) and Bruce McGurk and Deborah Tanko (SFPUC) for kindly arranging housing during macroinvertebrate sampling trips. This work was funded by the SFPUC.

## References


Aerial Information Systems. *Yose_1997veg_final_poly* [computer map, Arc coverage] 1997. Yosemite National Park: National Park Service, 1997.

Allan J.D. 1995. Stream ecology: structure and function of running waters Chapman and Hall, London, 388 pp

Allen-Diaz, B. 1991. Water-table and plant species relationships in Sierra Nevada Meadows. American Midland Naturalist, v. 126:30–43.

Andrews, E.D. 1986 Downstream effects of Flaming Gorge Reservoir on the Green River, Colorado and Utah. Geological Society of America Bulletin. v. 97: 1012-1023.

Armitage P.D., and J.H. Blackburn. 1990. Environmental stability and communities of Chironomidae (Diptera) in a regulated river. Regulated Rivers: Resource Management 5:319-3328

Aquatic Bioassessment Laboratory. 2003. List of Californian macroinvertebrate taxa and standard taxonomic effort. California Dept. of Fish and Game, Rancho Cordova, CA, 45 pp

Barbour M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates, and fish, 2nd edition. EPA 841-B-99-002

Barbour M.T., J.L. Plafkin, B.P. Bradley, C.G. Graves, and R.W. Wisseman. 1992. Evaluation of EPA's rapid bioassessment benthic metrics: metric redundancy and variability among reference stream sites. Environmental Toxicology and Chemistry 11(4):437-449

Brittain J.E., and S.J. Saltveit. 1989. A review of the effect of river regulation on mayflies (Ephemeroptera). Regulated Rivers: Resource Management 3:191-204

Brower, J.E., J.H. Zar, and C.N. von Elde. 1998. Field and Laboratory Methods for General Ecology, 4$^{th}$ ed. McGraw Hill, New York.

Boyer, E.W., G.M. Hornberger, K.E. Bencala, and D.M. Mcknight. 1997. Response characteristics of DOC flushing in an alpine catchment, *Hydrologic Processes*, v. 11, p. 1635-1647.

California Wildlife Habitat Relationships System (CWHR). 2006. System Software Version 8.1 California Department of Fish and Game, April 26, 2006. http://www.dfg.ca.gov/biogeodata/cwhr.

Carter J.L., and S.V. Fend. 2001. Inter-annual changes in the benthic community structure of riffles and pools in reaches of contrasting gradient. Hydrobiologia 459:187-200

Castelli, R.M. J.C. Chambers, and R.J. Tausch. 2000. Soil-plant relations along a soil-water gradient in Great Basin riparian meadows. Wetlands, Vol. 20 (2):251-266.

Chambers, J. C., K. Farleigh, R. J. Tausch, J. R. Miller, D. Germanoski, D. Martin, and C. Nowak. 1998. Understanding long-and short-term changes in vegetation and geomorphic processes: The key to riparian restoration, p. 101–110. *In:* D. F. Potts (ed.) Proceedings: Rangeland Management and Water Resources. American Water Resources Association and Society for Range Management, Reno, NV, USA

Chase, M.K., N. Nur, and G. Geupel. 1997. Survival, productivity, and abundance in a Wilson's Warbler population. Auk 114: 354-366.

Clarkson, R.W. and Childs, M.R. 2000. Temperature Effects of Hypolimnial-Release Dams on Early Life Stages of Colorado River Basin Big-River Fishes. *Copeia*, v. 2, p. 402-412

Clifford H.T., and W. Stephenson. 1975. An introduction to numerical classification. Academic Press, London

Cochran, W.G. 1941. The distribution of the largest of a set of estimated variances as a fraction of their total. Annals of Eugenics 11:47-52

Cogswell, H.L. 1962. Operation recovery begun in California's Central Valley. Western Bird Bander 37: 5254.

Collier, M., R.H. Webb, and J.C. Schmidt. 1996. Dams and Rivers: A Primer on the Downstream Effects of Dams, U.S. Geological Survey Circular 1126, 94 p.

Cooper, D. 2007. Plant Ecologist, University of Colorado, Boulder CO. Personal Communication.

Courtemanch, D.L. 1996. Commentary on the subsampling procedures used for rapid bioassessments. Journal of the North American Benthological Society 15:381-385

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U. S. Fish and Wildlife Service. FWS/OBS-79/31.

DeSante, D.F. 1995. The status, distribution, abundance, population trends, demographics, and risks of the landbird avifauna of the Sierra Nevada mountains. The Institute for Bird Populations.

Doberstein, C.P., J.R. Karr, and L.L Conquest. 2000. The effect of fixed-count subsampling on macroinvertebrate biomonitoring in small streams. Freshwater Biology 44:355-371

Dodge, F.C.W., and L.C. Calk. 1987. Geologic Map of the Lake Eleanor Quadrangle, Central Sierra Nevada, California. U.S. Geological Survey Geologic Quadrangle Map GQ-1639.

Dwire, K.A., B. Kauffman, E.N.J. Brookshire and J. E. Baham. 2004. Plant biomass and species composition along an environmental gradient in montane riparian meadows. Oecologia, Vol. 139:309-317.

Environmental Laboratory. 1987. Corps of Engineers wetlands delineation manual. Technical Report Y-87-1. Vicksburg, MS: U. S. Army Engineer Waterways Experiment Station.

Fausch, K.D., C.V. Torgersen, C.V. Baxter, and H.W. Li. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. BioScience 52:483-498

Flannery, M.E., S.L. Guers, T. Gardali, N. Nur, and G.R. Geupel. 2004. Landbird migration at the Salton Sea: the importance of desert riparian habitat. Studies in Avian Biology 27:106-115.

Gaines, D.A. 1977. The valley riparian forests of California: their importance to bird populations. In Ann Sands (editor) Riparian Forests in California: Their Ecology and Conservation. Institution of Ecology Publication 15, Univ. of California, Davis, 57-85.

Gaines, D.A. 1992. Birds of Yosemite and the East Slope, Revised ed. Artemisia Press, Lee Vining, California, 352 pp.

Gardali, T., G. Ballard, N. Nur, and A. King. 2000. Demography of a declining population of Warbling Vireo in coastal California. Condor 102: 601-609.

Gardali, T. 2003. Warbling Vireo (Vireo gilvus). In The Riparian Bird Conservation Plan: a strategy for reversing the decline of riparian-associated birds in California. California Partners in Flight. http://www.prbo.org/calpif/htmldocs/riparian_v-2.html.

Greathouse, E.A., C.M. Pringle, W.H. McDowell, and J.G. Holmquist. 2006a. Indirect upstream effects of dams: consequences of migratory consumer extirpation in Puerto Rico. Ecological Applications 16(1):339-352

Greathouse, E.A., C.M. Pringle, and J.G. Holmquist. 2006b. Conservation and management of migratory fauna: dams in tropical streams of Puerto Rico. Aquatic Conservation: Marine and Freshwater Ecosystems 16:695-712

Harris, J.H. 1991. Effects of brood parasitism by Brown-headed Cowbirds on Willow Flycatcher nesting success along the Kern River, California. Western Birds 22: 13-26.

Hawkins, C.P., J.N. Hogue, L.M. Decker, and J.W. Feminella. 1997. Channel morphology, water temperature, and assemblage structure of stream insects. Journal of the North American Benthological Society 16:728-749

Hawkins, C.P., and J.A. MacMahon. 1989. Guilds: the multiple meanings of a concept. Annual Review of Entomology 34:423-451

Hayden, W., and H.F. Clifford. 1974. Seasonal movement of the mayfly Leptophlebia cupida (Say) in a brown-water stream of Alberta, Canada. American Midland Naturalist 91:90-102

Hill, G.E. 1988. Age, plumage brightness, territory quality, and reproductive success in the Black-headed Grosbeak. Condor 90: 379-388.

Hilsenhoff, W. 1987. An improved biotic index of organic stream pollution. The Great Lakes Entomologist 20:31-39

Holmquist, J.H., J. Schmidt-Gengenbach, and B.B. Yoshioka. 1998. High dams and marine-freshwater linkages: effects on native and introduced fauna in the Caribbean. Conservation Biology 12(3):621-630

Holmquist, J.H., and Schmidt-Gengenbach, J. 2005. Inventory of invertebrate fauna in Devil's Postpile National Monument. Final report submitted in fulfillment of contract no. R8590030067, 71 pp

Humple, D.L., and G.R. Geupel. 2002. Autumn populations of birds in riparian habitat of California's central valley. Western Birds 33: 34-50.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54(2):187-211

Johnson, M., and G. Geupel. 1996. The importance of productivity to the dynamics of a Swainson's Thrush population. Condor 98: 133-141.

Karr, J.R., and R.R. Roth. 1971. Vegetation structure and avian diversity in several New World areas. American Naturalist 105: 435-435.

Kattelmann, R. and M. Embury. 1996. Riparian Areas and Wetlands. In *Sierra Nevada Ecosystem Project: Final Report to Congress, Volume III: Assessments, Commissioned Reports, and Background Information*. Wildland Resources Center Report No. 38, p. 201-274.

Kerans, B.L., and J.R. Karr JR. 1994. A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley. Ecological Applications 4:768-785

Kirk, R.E. 1982. Experimental design: procedures for the behavioral sciences, 2nd edition. Brooks/Cole Publishing Co., Monterey, CA, 911 pp

Knapp, R.A. 2003. Yosemite lakes survey: 2000-2002. Sierra Nevada Aquatic Research Laboratory, University of California. Final report prepared for Yosemite National Park, California.

Knopf, E.L., R.R. Johnston, T. Rich, E.B. Samson, and R.C. Szaro. 1988. Conservation of riparian ecosystems in the United States. Wilson Bulletin 100 (2): 272-284.

Knopf, E.L., and F.B. Samson. 1994. Scale perspective on avian diversity in western riparian ecosystems. Conservation Biology 8: 669-676.

Krebs, C.J. 1989. Ecological methodology. Harper/Collins, New York, 654 pp

Larison, B., S.A. Laymon, P.L. Williams, and T.B. Smith. 2001. Avian responses to restoration: nest site selection and reproductive success in Song Sparrows. Auk 118:432-442.

Lehmkuhl, D.M. 1974. Thermal regime alterations and vital environmental physiological signals in aquatic systems. In: Gibbons, J.W., and R.R. Sharitz (eds) AEC Symposium Series (CONF-730505), p 216-222

Leland, H.V., S.V. Fend, J.L. Carter, and A.D. Mahood. 1986. Composition and abundance of periphyton and aquatic insects in a Sierra Nevada, California, stream. Great Basin Naturalist 46(4):595-611

Ligon, F.K., W.E. Dietrich, and W.J. Trush. 1995. Downstream Ecological Effects of Dams: A geomorphic perspective. BioScience 45 (3):183-192.

Lilliefors, H.W. 1967. On the Kolmogorov-Smirnov test for normality with mean and variance unknown. Journal of the American Statistical Association 64:399-402

Loheide, S., and S.M. Gorelick. 2007. Riparian hydroecology: A coupled model of the observed interactions between groundwater flow and meadow vegetation patterning. Water Resources Research, Vol. 43 (7): W07414.

Loyn, R.H. 1986. The 20 minute search – a simple method for counting forest birds. Corella 10:58-60.

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

MacArthur, R.H., and J.W. MacArthur. 1961. On bird species diversity. Ecology 42:594-598.

Mack, R.N., and D.A. Pyke. 1984. The demography of Bromus tectorum: the role of microclimate, grazing and disease. The Journal of Ecology, Vol. 72 (3):731-748.

Magurran, A.E. 1988. Ecological diversity and its measurement. Princeton Univ. Press, Princeton, NJ, 179 pp

Martin, D. 1999. Species interactions and recovery potentials of Nebraska sedge/ Kentucky bluegrass meadows in central Nevada. Ph.D. Dissertation. University of Nevada, Reno, NV, USA.

Martin, D. and J. Chambers. 2002. Restoration of riparian meadows degraded by livestock grazing: Above- and belowground responses. Plant Ecology, Vol. 163 (1):77-91.

Marzluff, J., and R. Sallabanks. 1998. Avian Conservation: research and management. Island Press, Covelo, CA.

McBain and Trush, Inc. and RMC Water and Environment. 2006. Upper Tuolumne River: Available Data Sources, Field Work Plan, and Initial Hydrology Analysis. 49 p.

McBain and Trush, Inc. and RMC Water and Environment. 2007a. Upper Tuolumne River: Descriptions of River Ecosystem and Recommended Monitoring Actions. Final Report, April 2007.

McBain and Trush, Inc., and RMC Environmental. 2007b. Upper Tuolumne River sediment source and sediment transport capacity evaluation. Draft Report, November 2007.

Merendino, H.T., H.R. Smith, and R.I. Pederson. 1990. The response of wetland vegetation to seasonality of drawdown. Wildlife Society Bulletin, 1893:245–251.

Merritt, R.W., and K.W. Cummins. 1996 Trophic relations of macroinvertebrates. In: Hauer, F.R., and G.A. Lamberti (eds) Methods in stream ecology, Academic Press, San Diego, p 453-474

Merritt, R.W., K.W. Cummins, and M.B. Berg (eds). 2008. An introduction to the aquatic insects of North America, 4th edition. Kendall/Hunt Publishing Co., Dubuque, IA, 1158 pp

Milestone, J.F. 1978. The influence of Modern Man on the Stream System of Yosemite Valley. Masters Thesis, San Francisco State Unversity. 227 p.

Mitsch, W.J, and J.G. Gosselink. 2000. Wetlands, 3rd Edition. Wiley, New York, NY, USA.

Multivariate Statistical Package (MVSP). 1985-2002. version 3.0, Kovach Computing Services. On-line at: http://www.kovcomp.co.uk/mvsp/.

Museum of Vertebrate Zoology Collections Database. 2008. Museum of Vertebrate Zoology, University of California Berkeley, CA 94720. http://mvz.berkeley.edu

National Park Service, 2006a. Visitor Experience and Resource Protection Program 2006 Field Guide. Yosemite National Park, 151 pp.

National Park Service, 2006b. Visitor Experience and Resource Protection Program 2006 Annual Report. Yosemite National Park, 102 pp.

Natural Resources Conservation Service (NRCS). 2006. Wetland Indicator Status Plants Database. U. S. Department of Agriculture, Natural Resources Conservation Service, Fort Worth, TX.

NatureServe. 2007. Classification of the Vegetation of Yosemite National Park and Surrounding Environs in Tuolumne, Mariposa, Madera and Mono Counties, California. Unpublished final report submitted to the National Park Service. 409 p.

Noon, K. 2008. National Park Service Wetland Scientist, Water Resources Division, Fort Collins, CO. Personal communication.

Nur, N., S.L. Jones, and G.R. Geupel. 1999. Statistical guide to data analysis of avian monitoring programs. U.S. Department of the interior, Fish and Wildlife Service, BTP-R6001-1999, Washington, D.C.

Pierson, E.D., W.D. Rainey, and L.S. Chow. 2006. Bat use of the giant sequoia groves in Yosemite National Park, project report prepared for The Yosemite Fund, Yosemite, California.

Pierson, E.D., W.D. Rainey, and C.J. Corben. 2001. Seasonal patterns of bat distribution along an altitudinal gradient in the Sierra Nevada, Report prepared for California Department of Transportation, California State University at Sacramento Foundation, and Yosemite Fund.

Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross, and R.M. Hughes. 1989. Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish. U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Washington, D.C. EPA 440-4-89-001

Poff, N.L, J.D. Allan, M.B Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime. BioScience, Vol. 47 (11):769-784.

Ralph, C.J., G.R. Geupel, P. Pyle, T.E. Martin, and D.F. DeSante. 1993. A handbook of field methods for monitoring landbirds. Gen. Tech. Rep. PSW-GTR-144. Albany, CA: Pacific Southwest Research Station, USDA Forest Service.

Ralph, C.J. 1998. A comparison of timing, content, and monitoring methods of landbird migration in the Pacific States. Paper presented at the North American Ornithological Conference, April 1998. St. Louis, MO.

Riparian Habitat Joint Venture (RHJV). 2004. The Riparian Habitat Conservation Plan: a Strategy for Reversing the Decline of Riparian Associated Birds in California. Version 2.0 California Partners in Flight www.prbo.org/CPIF/Riparian/Riparian.html.

Rood, S.B., J.M. Mahoney. 1990. Collapse of riparian poplar forest downstream from dams in western prairies – probable causes and prospects for mitigation. Environmental Management, Vol. 14 (4):451-464.

Rood, S. B., J.M. Mahoney, D.E. Reid, L. Zilm. 1995. Instream flows and the decline of riparian cottonwoods along the St-Mary River, Alberta. Canadian journal of botany, Vol. 73 (8):1250-1260.

Root, R.B. 1973. Organization of a plant-arthropod association in simple and diverse habitats: the fauna of collards (Brassica oleracea). Ecological Monographs 43:95-124

Rummel, R.S. 1946. Some effects on competition from cheatgrass brome on crested wheatgrass and bluestem wheatgrass. *In*: Ecology, Vol. 27 (2): pgs 159-167.

Sacramento River Advisory Council. 1998. Draft Sacramento River Conservation Area Handbook. Red Bluff, CA.

Sauer, J.R., J.E. Hines, and J. Fallon. 2005. The North American Breeding Bird Survey, Results and Analysis 1966 – 2005. Version 6.2.2006. USGS Patuxent Wildlife Research Center, Laurel, MD.

Schowalter, T.D. 2006. Insect ecology: an ecosystem approach, 2nd edition. Academic Press (Elsevier), 572 pp

Shafroth, P.B., J.C. Stromberg, and D.T. Patten. 2002. Riparian vegetation response to altered disturbance and stress regimes. Ecological Applications, Vol. 12(1):107-123.

Sibson, R. 1981. A Brief Description of Natural Neighbor Interpolation. *Interpolating Multivariate Data*, John Wiley & Sons, New York, pp. 21-36.

Siegel, R.B. and D.F. DeSante. 2002. Avian inventory of Yosemite National Park (1998-2002) Final Report to the park from The Institute for Bird Populations, P.O. Box 1346, Point Reyes Station, CA 94956-1346.

Siegel, R.B., R.L. Wilkerson, and D.F. DeSante. In press. Extirpation of the Willow Flycatcher from Yosemite National Park. Western Birds.

Sierra Nevada Ecosystem Project. 1996. Final Report to Congress, v. III, Assessments, Comissioned Reports, and Background Information. University of California, Davis. 1101 pp.

Slater, P.J. 1994. Factors affecting the efficiency of the area search method of censusing birds in open forest and woodlands. Emu 94:9-16.

Small, S.L., N. Nur, A. Black, G.R. Geupel, D. Humple, and G. Ballard. 2000. Riparian bird populations of the Sacramento River system: Results from the 1993-1999 field seasons. Final Report to The Nature Conservancy and U.S. Fish & Wildlife Service from PRBO Conservation Science, 4990 Shoreline Highway, Stinson Beach, CA 94970.

Smith, D.G. 2001. Pennak's freshwater invertebrates of the United States, 4th edition, John Wiley and Sons, New York, 638 pp

Smith, D.S., A.B. Wellington, J.L. Nachlinger, and C.A. Fox. 1991. Mortality and age of black cottonwood stands along diverted and undiverted streams in the eastern Sierra Nevada, California. Ecological Applications (1):89-97.

Sorenson, T. 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content. Kong. Dan Vidensk. Selsk. Biol. Skr. 5(4):1-34

Stanford, J.A., and Ward, J.V. 1989. Serial discontinuities of a Rocky Mountain river. I. Distribution and abundance of Plecoptera. Regulated Rivers: Resource Management 3:169-175

Stewart, R.M., R.P. Henderson, and K. Darling. 1978. Breeding ecology of the Wilson's Warbler in the high Sierra Nevada, California. Living Bird 16:83-102.

Stillwater Sciences (2007) The Merced River Alliance Project: interim biological monitoring and assessment report. Stillwater Sciences, Berkeley, CA, 211 pp

Stromberg, J.C. and D.T. Patten. 1992. Mortality and age of black cottonwood stands along diverted and undiverted streams in the eastern Sierra Nevada, California. Modroño 39(3):205-223.

SYSTAT. 2006. version 11.0, Systat Software Inc. On-line at: www.systat.com

Thorp J.H., and A.P. Covich. 2001. Ecology and classification of North American freshwater invertebrates, 2nd edition. Academic Press, San Diego, 1056 pp

U.S. Geological Survey, variously dated. National Field Manual for the Collection of Water-Quality Data, U.S. Geological Survey Techniques of Water-Resources Investigations, Book 9, Chapters A1-A9.

Vale, T.R. and G.R. Vale. 1994. Time and the Tuolumne Landscape: Continuity and change in the Yosemite high country. University of Utah Press, Salt Lake City, UT. 212 pp.

Vanicek, C.D., and R.H. Kramer. 1969. Life history of the Colorado Squawfish and Colorado Chub in the Green River in Dinosaur National Monument, 1964-1966: Transactions of the American Fisheries Society, 98 (2): 193-208.

Vanicek, C.D., R.H. Kramer, and D.R. Franklin. 1970. Distribution of Green River fishes in Utah and Colorado following closure of Flaming Gorge Dam: Southwestern Naturalist, 14 (3): 297-315.

Wallace, J.B., J.J Hutchens, Jr. 2000. Effects of invertebrates in lotic ecosystem processes. In: Coleman, D.C., and P.F. Hendrix (eds) Invertebrates as webmasters in ecosystems, CABI Publishing, New York, p 73-96

Ward, J.V. 1984. Ecological perspectives in the management of aquatic insect habitat. In: Resh V.H., and D.M. Rosenberg (eds) The ecology of aquatic insects, Praeger Publishers, New York, p 558-577

Ward, J.V., and J.A. Stanford (eds). 1979. The ecology of regulated rivers. Plenum Publishing Corp., New York

Webb, R.H., J.C. Schmidt, G.R. Marzolf, and R.A. Valdez. 1999. The Controlled Flood in Grand Canyon. American Geophysical Union Geophysical Monograph 110, Washington, D.C., 367 p.

Whisenant, S.G. 2005. Directing vegetation change, Chapter 4, pgs 100-127. *In*: Repairing Damaged Wildlands. Fifth printing. Cambridge University Press, New York, NY.

Wilkerson, R.L. and R.B. Siegel. 2002. Establishing a Southern Sierra Meadows Important Bird Area: Results from meadow surveys at Stanislaus, Sierra, and Sequoia National Forests, and Yosemite and Sequoia/Kings Canyon National Parks**.** The Institute for Bird Populations, Point Reyes Station, CA.

Wilkinson, L., M.A. Hill, and E. Vang. 1992. SYSTAT: Statistics, Version 5.2 Edition, SYSTAT, Inc., Evanston, IL, 724 pp

Williams, G.P and M.G. Wolman. 1984. Downstream effects of dams on alluvial rivers: U.S. Geological Survey Professional Paper 1286, 48 p.

Wohl, E., D. Cooper, L. Poff, F. Rahel, D. Staley, and D. Winter. 2007. Assessment of stream ecosystem function and sensitivity in the Bighorn National Forest, Wyoming. Environmental Management 40:284-302

Yabe, K. and K. Ornimahu. 1997. Key variables controlling the vegetation of a cool-temperate mire in northern Japan. Journal of Vegetation Science, Vol. 8 (1):29-36.

Yosemite Wildlife Observation Database. 2008. Microsoft Office Access Application, last updated March 2008. Division of Resources Management and Science, Yosemite National Park, CA.