The Tuolumne River Runner's Natural History Accompaniment

This natural history field guide for the reach of the Tuolumne River from Lumsden to Ward's Ferry is intended as an appendix to the watershed-scale natural history book also written by UC Davis students this year. While the rest of the book discusses the natural and cultural significance of the entire Tuolumne watershed by dividing chapters into traditional disciplines of study, this appendix follows the river down the 18 miles of California's premier backcountry whitewater river trip, integrating the themes from the book. Specifically, this appendix explores the relationships between the physical and ecological components of the Tuolumne and two of its significant tributaries, or branches, which enter along this reach—the Clavey and the North Fork Tuolumne Rivers.

While this guide uses specific examples and locations to illustrate these concepts, and it is designed to be brought on the river, the authors hope that it is just as readable and informative to any casual reader.

Whitewater rafting and kayaking has been a recreational pastime in California for the past 40 years or so. As the state's population increases, equipment improves, and awareness spreads, so does the popularity of these and other river-related activities. This section of river, which offers an overnight wilderness trip with consistent and challenging whitewater within a few hours of the Bay Area, has been well-loved since paddlers first ran it (Cassady 1995). Commercial rafting companies with permits offer one, two, and three day trips down 'the T', and some offer seasonal day-trips on the Cherry Creek run, which is possibly the country's most difficult commercial run. The Forest Service issues permits for private trips, encouraging good river etiquette and contribution to the pristine environment and solitude to be found.

This reach of the river is roughly halfway between the Tuolumne's headwaters, in the peaks of Northern Yosemite, and the river's confluence with the San Joaquin, in the town of Modesto (Figure 1.1). Mountain rivers tend to reduce in slope but increase in volume as they flow downhill, and this stretch happens to be where these two principles converge to create suitable conditions for challenging yet relatively safe river running. Along this stretch, the upstream drainage area of the watershed covers about 1000 square miles, and the average gradient is 40 vertical feet per mile.

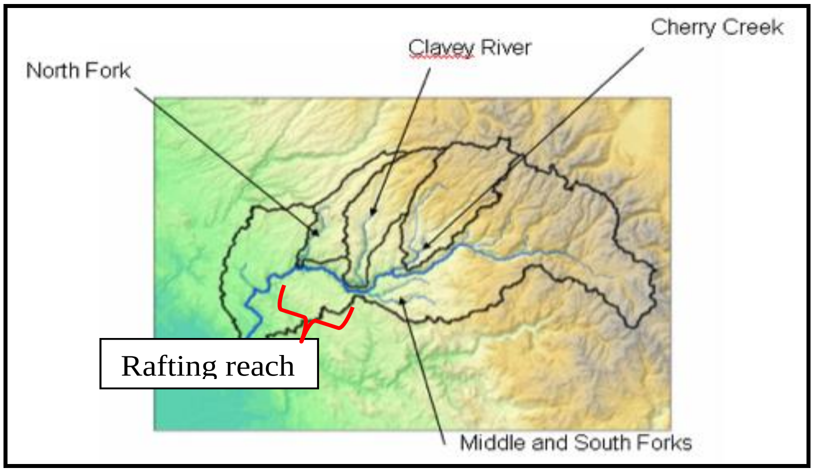

Figure 1.1 The Tuolumne Watershed above New Don Pedro

In 1984, the Tuolumne was California's first river awarded 'Wild and Scenic' status by the U.S. Congress. The NationalWild and Scenic River Act of 1968 was passed so that rivers with *"outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural or other similar values, shall be preserved in free-flowing condition, and that they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations."*

This reach of the Tuolumne is located in the middle of two major reservoir systems, something that you wouldn't necessarily know from looking at Meral's Pool or the ridge on the bumpy ride down. Other than the Tuolumne's relatively small South and Middle Forks, which enter just upstream of Meral's Pool, almost every drop of water that flows here is controlled by a system of dams and diversions operated by the city of San Francisco. In fact, most of the water in this part the Tuolumne River comes from Cherry and Eleanor Creeks, because water from Hetch Hetchy and Tuolumne Meadows goes to the Bay Area for drinking water. The interesting history and management of these dams are discussed in more detail in chapter 6 of the accompanying book and in Figure 1.2 below.

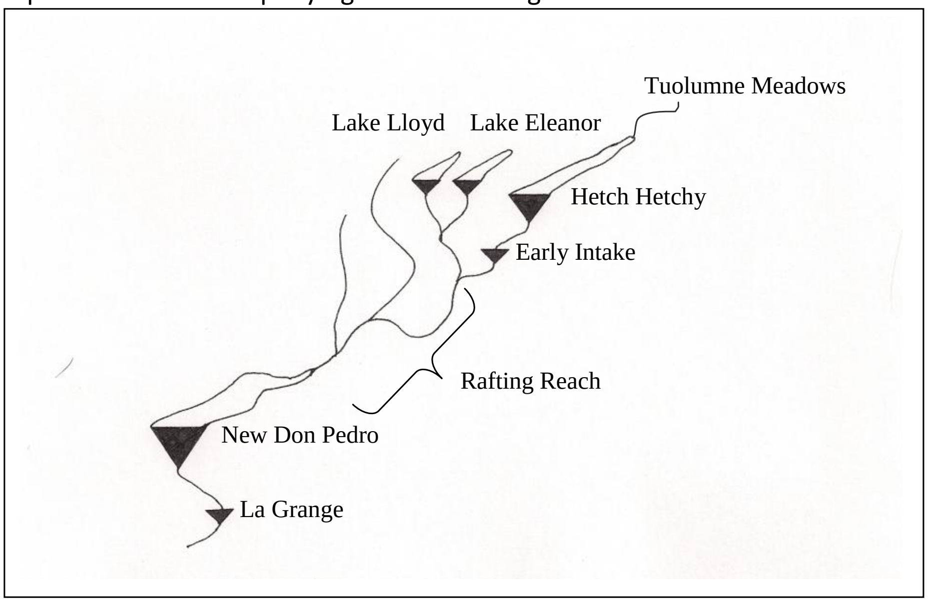

Figure 1.2 - Schematic of reservoirs on the Tuolumne River
(Adapted from McGurk SFPUC)

These reservoirs have a significant influence on physical and biological processes within the Tuolumne River. The water moving though a river channel, which we measure by magnitude, duration, timing, and frequency of flows, controls a complex web of ecosystem interactions. Some of these relationships are direct, such as the way in which more water provides more habitat for fish, but others are more indirect, such as with high flows that remove aquatic plants, yet deposit sediment elsewhere that is beneficial to new recruits. Ultimately, all of these relationships are highly complex, with positive and negative feedback loops and food web relationships that can be difficult to identify. In addition, as the Clavey and North Fork Tuolumne Rivers converge with the mainstem Tuolumne, they exert their own influences while providing similarities and differences from the Tuolumne to offer clues to what it would look like without upstream infrastructure. These biological and physical relationships are explored in the following pages.

Introduction to Tuolumne Hydrology

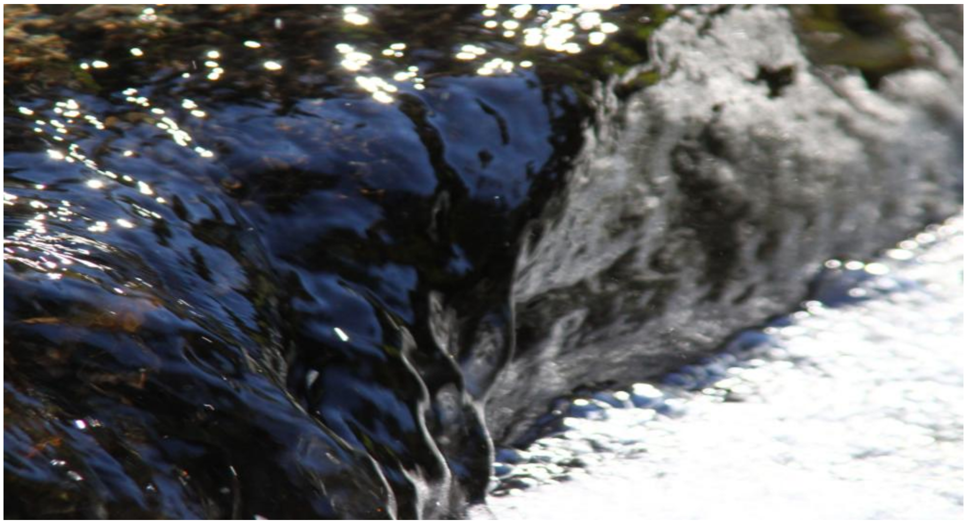

Photo: Patrick. Hilton

Hydrology is the study of the behavior and distribution of water on and below the surface of the Earth. The 'hydrology' of a river can also refer to its character, such as the daily changes in volume, amount, or kinetic energy its waters have as it flows along. As discussed in chapter 1 of the book, the Tuolumne's hydrology is a function of its climate, topography, vegetation, and reservoir management. California's Mediterranean climate varies annually, but natural patterns of high discharge from storms and snowmelt in the winter and spring, coupled with low flows during the dry summer, give the rivers dynamic character year-round.

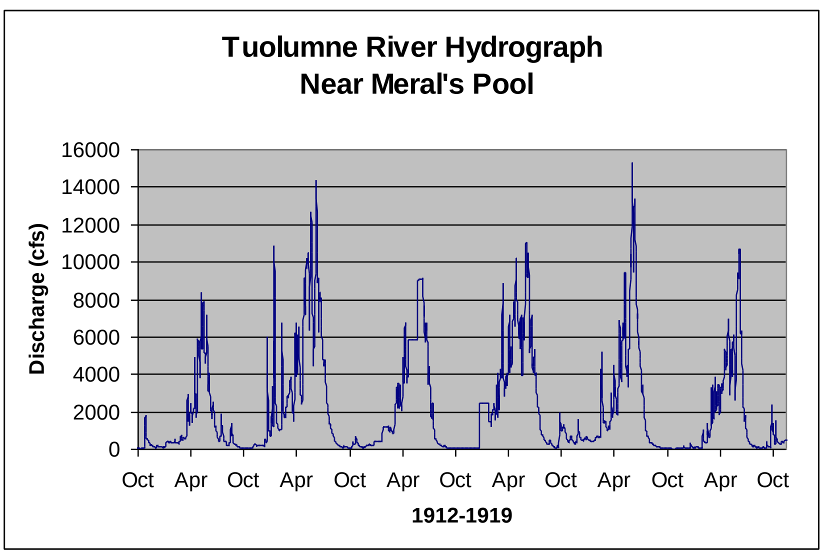

Figure 1.3 - A typical 5-year hydrograph of the Tuolumne River, before Hetch Hetchy

The hydrograph in Figure 1.3 describes discharge, or the volume of water that flows past a given point in a given amount of time. The horizontal axis represents time, in this case a period of six years, and the vertical axis is the amount of water, in cubic feet per second (CFS), one of which is equivalent to about seven and a half gallons per second.

The snow in the mountains above the Tuolumne heavily influences the flow of the river, due to the location, geography, and climate of the upper watershed. The flows in the hydrograph above were observed near Meral's Pool over several years prior to Hetch Hetchy's construction. Notice how, although precipitation falls during the winter months, the higher discharge tends to occur in the springtime. These types of patterns, which reflect the character of the annual flow, are called the river's 'flow regime.'

Quantifying River Discharge

Discharge is calculated as the product of the water's average velocity and the area of the river's cross section at a certain point. If you look at a given reach of a river, you'll immediately notice that the shape of the bed changes dynamically throughout the reach, as does the cross-sectional area of the river. Because the overall discharge doesn't change dramatically without external input, you should also be able to see the inverse relationship between the cross-sectional area and velocity. For example, pools that are wide and deep have slower velocity flows than the shallower rapids.

We can measure river height from a staff plate, such as in Figure 1.4. By correlating these measurements with simultaneously calculated discharge, we can determine the relationship between river height and cubic feet per second to form a rating table. At Meral's Pool, you can look up the discharge on a rating table on a placard near the water, and find out the river's CFS.

An important, yet hidden aspect of many hydrographs is that they often only display daily averages, which means that we frequently cannot see short-term or rapid fluctuations. For instance, small floods from short storms or daily summertime fluctuations from hydropower production are not visible. The hydrograph in Figure 1.5 below depicts the discharges below Holm Powerhouse on Cherry Creek every 15 minutes over 45 days in spring 2008. During the summer, when water was spilling out of the reservoirs and demand for electricity goes up, the pattern of hydropower-generating surges and water-retaining lows became the dominant hydrologic signal on the river. In early June and early July, it appears that the dam operators allowed water to pass through the turbines and down the river only during peak hours, but during the last few weeks of June, they let the turbines run almost full-time. These flows are called diel flows, in reference to their daily changes. Compare these hydropower-based flows to the natural ones before the dam in Figure 1.3.

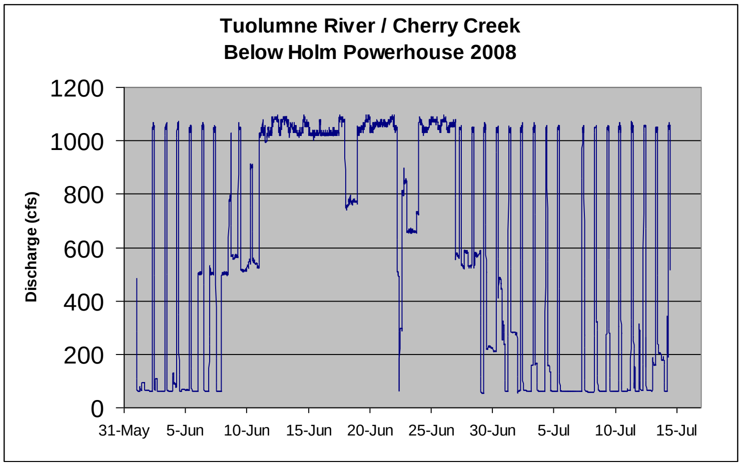

Figure 1.5 - Hydrograph of summertime discharges from Holm Powerhouse at 15-minute intervals

Geomorphology

Photo: Gerhard Epke

Make note of the geology at Meral's Pool. Almost all of the rocks here and upstream of this point are granite, an igneous rock which forms the backbone of the Sierra Nevada. Within a few miles of Meral's Pool, the Tuolumne leaves these granitic surroundings and enters metamorphic formations, which have different colors, textures, fracture patterns, and dikes. However, the river's bedrock, - its 'walls' and 'floors' – will change.

What is geomorphology? Think "geography in action." Geomorphology refers to the study of the evolution of the landscape, and includes the topography, geology, soils, climate, and hydrology of the land. Geomorphology can be difficult to grasp because of this transcendence of scale and discipline, but the evidence of these ties is all around. As you paddle down the river, pay attention to patterns in the physical landscape, such as the locations of sand and cobble bars, the sizes of their sediments, and the amount of exposed bedrock.

Geomorphic processes tend to occur over long time scales, such as hundreds, thousands, and millions of years, but when things do happen rapidly, they tend to be unexpected. Examples include earthquakes, landslides, or floods, such as that in January of 1997. In observing a pile of rocks, gauge the stones' angular or rounded shape to get clues to the formation's age and origin. Rounded rocks may have come from the river, where the water and other rocks moved and worked them to their smoother texture. Conversely, jagged, angular rocks may have come from a relatively recent rock fall, or from old mining debris.

Occasional large floods and smaller, more constant flows transport sediment from its source as eroding bedrock to its final resting place along the river over the course of thousands of years. As these deposits accumulate, they become alluvium, rich soils that provide fertile breeding ground for plant communities.

The structure of the rocks and soil influences what life can grow on it. From the macroscopic scale of bedrock cracks or boulder or cobble size to the microscopic qualities of the texture of a rock or a sand bar's water permeability, the variable characteristics of substrate provide a large diversity of surfaces upon which life can grow.

Geomorphology can be difficult to comprehend, let alone measure, but rivers always play a major role in the evolution of the landscape, because of their ability to erode and transport material. This guide introduces specific forms and examples seen on the Tuolumne and addresses some of the conceptual pieces in an attempt to develop a picture of the river's literal foundation as dynamic and responding to other factors on both geologic and human timescales.

Primary Production

Primary producers, organisms that convert inorganic materials and energy sources to biologically useful ones, are the most fundamental component of the biological food web. In the Tuolumne, primary production occurs as photosynthesis by aquatic and terrestrial plants, as well as algae and bacteria of various forms. We refer to productive microorganisms attached to underwater substrate in moving water as periphyton, while slower waters are home to phytoplankton that float freely in the water column.

The 'productivity' of a watershed or river is a term we use to describe the amount of life there, but more productivity does not necessarily indicate a healthier river. The upper reaches of mountain rivers have naturally lower productivity than their flatland portions, due to limited nutrient supply and harsher abiotic conditions. However, native species have adapted to these conditions over an evolutionary time scale, and indices of native populations of plants and animals are more important components to determining a river's health.

Tuolumne River Vegetation

Vegetation on the Tuolumne river is unlike that of most other rivers. In systems with wide valleys, the river provides a large area with water by recharging groundwater, which percolates through sand and soil. Since the Tuolumne is a bedrock system with a v-shaped channel and minimal sediment contribution, those alluvial floodplains of high-sediment systems are absent. Because of this, there is a thin riparian corridor just below the upland hillslope vegetation. The river channel shape, small sediment load, and water availability drive the structure of the vegetation of the Tuolumne river watershed.

What to look for in observing/comparing plants and their communities
As you look further up from the river, you can see that the vegetation changes, almost in layers. Look at the trees close to the waterline and compare them to the trees up the hillslope. Pay attention to where plants are positioned along the river's edge and try to think of why this would be the case. We will be looking at some plant and tree species in depth and will be covering major themes as we move through this guide. In order for things to become clear, we will look for differences and trends in the vegetation.

Large woody debris
Trees growing alongside the river may fall into the current (Figure 1.5) due to a variety of causes, such as flood scour or disease. This debris can either be swept downstream in high velocity flows, or can remain in the river system if caught in an eddy or on a bedrock outcropping. Large woody debris used to be seen as detrimental to river systems, but now we know that its presence is important to the ecology of its river (CDEP). Large woody debris buildups add to the heterogeneity of the river system, which in turn provides more diverse habitat available for plants, insects, amphibians, reptiles, and fish.

There is a difference between the trees and plants growing directly along the river and the trees and plants growing further up the hillslope. This phenomenon has to do with the amount of water available in the soil at each location.

Figure 1.5 – Large woody debris
Photo: Patrick Hilton

Riparian plants need a constant supply of water. They are usually large, leafy plants and trees that use and lose a lot of water throughout the day. These species can only afford this kind of lifestyle if they live very close to a major water source. Hillslope plants of the Tuolumne River Basin are not immediately adjacent to the river, and so cannot afford this type of water consumption. Think back to the predominant rock type in this system: granite. Granite is not a porous material and does not hold groundwater except in narrow cracks and crevices . There is only a thin layer of topsoil that covers the granite in which the plant and tree species grow. This topsoil is not deep enough to hold much water either. Therefore, the vegetation growing on the hill slopes of the Tuolumne River must be relatively drought-resistant.

Habitat Types:

Bar/Bedrock – Along the banks of the river, you'll see the occasional bar or beach of boulders, cobbles, gravel, or sand, but you'll also see plenty of bedrock lining the river's edge. These can be challenging habitats for plants, but many are specially adapted to survive and thrive in these locations.

In the Tuolumne, water levels can fluctuate on an annual, monthly, daily, or even hourly basis, sometimes changing the shapes, compositions, and locations of bars with changes in flow. Because of this, bars are a difficult place to survive, and you won't see much plant life in the most hydrologically active places. In the less-frequently disturbed bars and beaches, however, you'll notice small, low-lying grasses and forbs in addition to the young willows, alders and ashes that have established themselves since the last scouring flood. These are all plants that are suited to this rough environment, through adaptations like rapid growth and reproduction, tolerance for inundation, and resistance to being washed away.

Plants growing on bedrock also tend to be small, but more frequently because they have little space to grow in the sandy crevices of large rock. The plants that do establish themselves tend to be higher up on the rocks, where floods are less frequent.

Riparian – Moving up from the gravel bars onto the banks of the river, you will notice changes in the density, types, and species of plants around. On many California rivers, riparian habitats immediately adjacent to the river hold some of the most diverse plant communities of any in the state. This is thanks to a regular water supply from both groundwater and the river, which provides nutrient-rich alluvial sediment. On the Tuolumne, however, river water levels are regulated by people, and the majority of rock upstream is bedrock, which doesn't provide much sediment. Consequently, the types of plants you see and the structures of the plant communities will be different from other riparian ecosystems you may be familiar with from other rivers. For example, common riparian trees aren't seen in high abundance here, such as the Fremont cottonwood.

Hillslope – Above the riparian zone, you'll see a rapid gain in elevation, with steep hills on either side of the river. The plants on these hills get their water from the ground, but also from the occasional rainstorm, especially in the wintertime. Depending on height up the slope and which direction the slope is facing, the plants get more sunlight, which can dry them out. For this reason, you might notice that hillslope communities, especially those on river right, tend to be dominated by annual grasses and forbs, with only the occasional oak or pine.

Aquatic Insects

Photo: Patrick Hilton (left) and Adam Clause (right).

Aquatic entomology is a branch of zoology that focuses on water-dwelling insects. These and other animals are part of complex food webs with multiple trophic levels, which are akin to links on a food chain, from primary producer to tertiary consumer.

In the Tuolumne River watershed, there are many insects that spend the juvenile stage of their biphasic (two-stage) life cycle as aquatic larvae, before transforming into terrestrial adults. In both phases, these insects are important to the ecology and food web of the Tuolumne River. The aquatic larvae act as primary consumers, feeding on photosynthetic material such as algae, decomposing leaf litter, and aquatic plants.

Aquatic insects contribute to the food web on multiple levels. The primary consumer larvae fall prey to insect secondary consumers, who go on to become food for tertiary consumers that prey solely on aquatic insects, such as pike minnow, juvenile Sierra newts, and American dippers. After the aquatic larvae transition to terrestrial adulthood, they not only feed terrestrial-dwelling animals, such as insectivorous birds, but also fall to the water's surface at the end of their life cycle, feeding rainbow trout.

The Tuolumne river is an example of a high-gradient upland watershed with large substratum, or rocks below the soil. Consequently, the complement of invertebrates in this system is typical of this type of system, including Coleoptera (beetles), Diptera (true flies), Ephemeroptera (mayflies), Megaloptera (alderflies, dobson flies, fishflies), Odonata (dragonflies and damselflies), Plecoptera (stoneflies), and Trichoptera (caddisflies).

Concept 1

Aquatic insects have specialized feeding preferences and can be classified in 1 of 4 ***functional feeding groups****:*

Figure 1.6 - Blackfly larvae (order: Diptera; family: Simuliidae) use silk glands in the mouth to attach themselves to bedrock and filter fine particulate organic matter from the water (*Pers. comm.*, Sharon Lawler). Photo: Denise De Carion.

1. ***Collectors,*** including collector-filterers that attach themselves to a substrate and filter decomposing fine particulate organic matter (FPOM) directly from passing water or the substrate, and collector-gatherers that move around on the surface of their habitats to gather FPOM from the water.

2. ***Scrapers*** feed on periphyton on the substrate. They have specialized mouthparts that allow them to scrape the algae off of the surfaces of rocks.

What are the primary food sources for aquatic insects?

- **Periphyton**: microscopic primary producers that attach themselves to bedrock, boulder, cobble, or gravel substrate underwater
- **Phytoplankton**: free-floating primary producers
- **Macrophytes**: aquatic plants that grow in the water
- **Detritus**: decomposing organic material, such as fallen leaf litter and dead animals
- **Large woody debris**

What habitats do you see?

Lotic-erosional

- Coarse sediments such as cobbles, pebbles, and riffles
- Periphyton on the coarse sediment in riffles
- Accumulated detritus

Lotic-depositional

- Finer sediments, such as sand and silt
- Macrophytes within the fine sediments
- Detritus in backwaters

Reference: Merritt and Cummins 2008

3. ***Predators*** attack and ingest other insects and piercers attack and suck the fluids from other insects.

4. ***Shredders*** feed on coarse particulate organic matter (CPOM) such as macrophytes, detritus, and large woody debris. They use their mouthparts to shred plant matter, which then provides FPOM for collector-gatherers.

Concept 2

The community composition of aquatic insects indicates stream health. Biologists often refer to the aquatic bugs as indicator species, because they are physiologically sensitive to disturbance in aquatic systems like the dam-regulated Tuolumne River. Aquatic insects have specific tolerance ranges for water-quality parameters such as dissolved oxygen, pH, and chemical pollution levels. They also require habitats that are not unnaturally disturbed.

Over thousands of years, the communities of aquatic insects have adapted to the historic natural hydrologic flow regime-- the spring-snowmelt recession (Figure 1.3). Today, frequent disturbances in the form of diel flow pulses released from Hetch Hetchy Reservoir alternately scour and then desiccate the substrate. The frequency of scouring and desiccation reduces the diversity of aquatic insects, which then adversely affects higher trophic levels. The sensitivity of an indicator species is on a zero-to-ten scale of tolerance, where zero represents insects with the lowest tolerance for degraded water quality, and ten represents the highest tolerance. High tolerance, toward ten, indicates the ability to persist in highly polluted and hypoxic conditions. In the Tuolumne River watershed, there is a wide range of tolerance values present, ranging from Pteronarcyidae with a rating of zero, to Chironomidae, with a high tolerance of eight.

Amphibians

Pictured above: Pacific treefrog tadpole (left) and Foothill yellow-legged frog (right). Photos: Adam Clause.

Herpetology is the scientific study of amphibians and reptiles. In the Tuolumne River watershed, there are five different aquatic amphibians: foothill yellow-legged frog, western toad, Pacific tree frog, American bullfrog, and Sierra newt.

Similar to aquatic insects, aquatic amphibians have a biphasic life cycle comprised of a juvenile aquatic stage (tadpole or larva) and an adult terrestrial stage (frog, toad, or newt). Except for newt larvae, which are carnivorous, juvenile amphibians feed on periphyton, while adults often eat the adult aquatic insects. They occupy an important trophic role— tadpoles provide food for higher trophic levels in the aquatic food web (e.g., fish) and adult amphibians serve as a food resource for other terrestrial animals, including reptiles, birds, and mammals.

Hydrologic flow regime, water temperature and food availability influence the distribution and abundance of aquatic amphibians in the watershed. Some amphibians are specialists that can only persist within a narrow range of a given environmental conditions, such as warm temperature or specific flow, while other amphibians are generalists that can thrive in varying environmental conditions. Generally, sensitive specialists are more likely to occupy tributaries that still retain a natural hydrograph (e.g., foothill yellow-legged frog), while less sensitive species can be foundthroughout the watershed (e.g., Pacific tree frog).

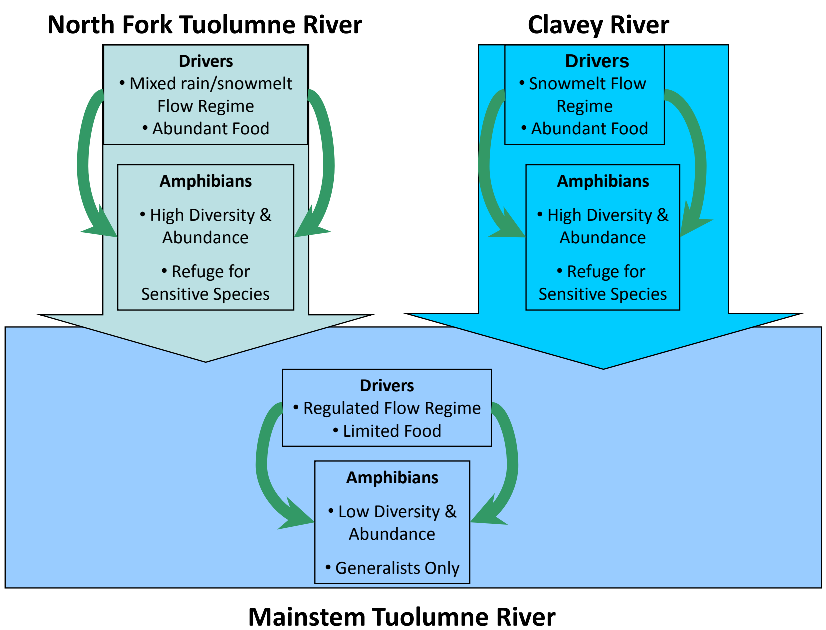

Figure 1.7 - A model of the main drivers that influence amphibian populations in the Tuolumne River watershed. Arrows indicate direction of impact.

Fishes[1]

The Tuolumne is contains only a few major species of fish. The native Tuolumne River fish *assemblage* (grouping of fish species which have coevolved to typically occur together) includes California roach, hardhead, rainbow trout, Sacramento pikeminnow, and Sacramento suckers. There are also a few invasive fish species, primarily present due to human influence. These invaders are smallmouth bass, brown trout and brook trout. The distribution of these species occurs thanks primarily to three main physical factors: water temperature, flow velocity, and habitat complexity.

Water temperature is contingent on many things. Much of the water flowing through the mainstem Tuolumne comes from either Hetch Hetchy Reservoir or Cherry Lake. With deep reservoirs like these, a temperature gradient forms between the warm surface water and the hypolimnion, or layer of cold deep water at the bottom. Because these reservoirs release hypolimnetic water from the bottom of their respective dams, water temperatures in the mainstem are more or less constantly cold, even in the summer, causing historically warm summer flows to perish.

Many native fish prefer this cold water coming from the reservoirs. As colder water contains higher levels of dissolved gases, it allows fish to easily get the oxygen they need from the water. Trout, in particular, require cold temperatures and high oxygen levels to thrive, but many other native fish species cannot persist under the same circumstances. Consequently, the hypolimnetic releases from the reservoirs effectively reduce the available habitat of important species like Sacramento pikeminnow and hardhead. Figure 1.8 shows the ideal temperatures (in degrees Centrigrade) that each species needs to live comfortably and reproduce.

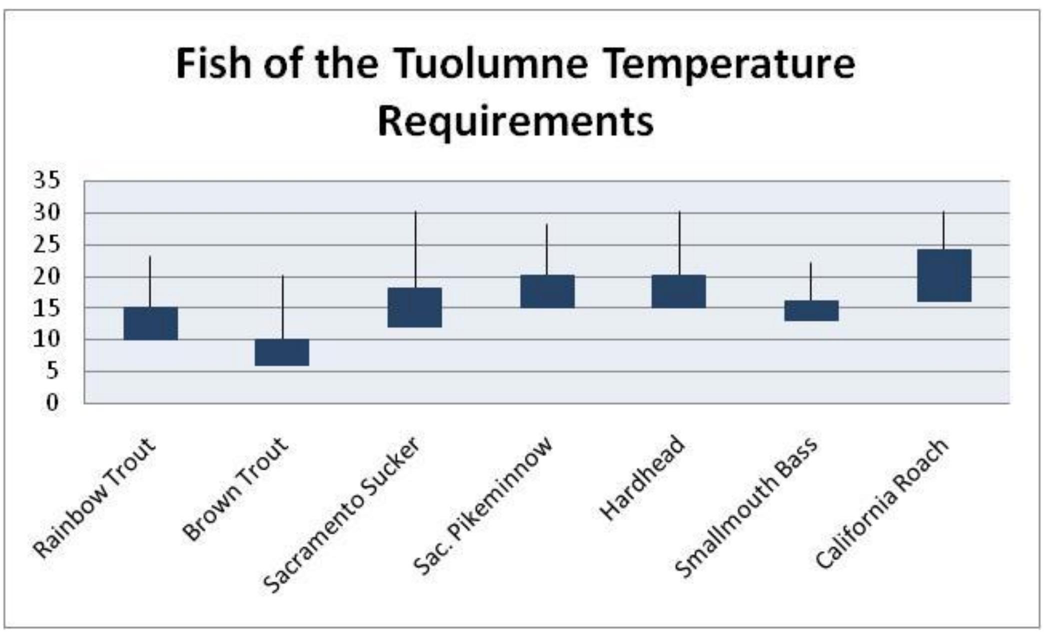

Figure 1.8 – Temperature values obtained from Moyle, 2002

[1] Unless otherwise mentioned, all identifying characters, physiological tolerances and life cycle information are taken from Inland Fishes of California by Peter B. Moyle.

Fish also depend on proper water flows. High velocity flows often push *young-of-year* fish (the youngest age class of a fish population) downstream, because they do not swim as well as adults and require slow-water habitats. These flows can also flush adults of some species downstream as well, particularly if they cannot find necessary refuges such as flooded side habitats or eddies to keep them in place.

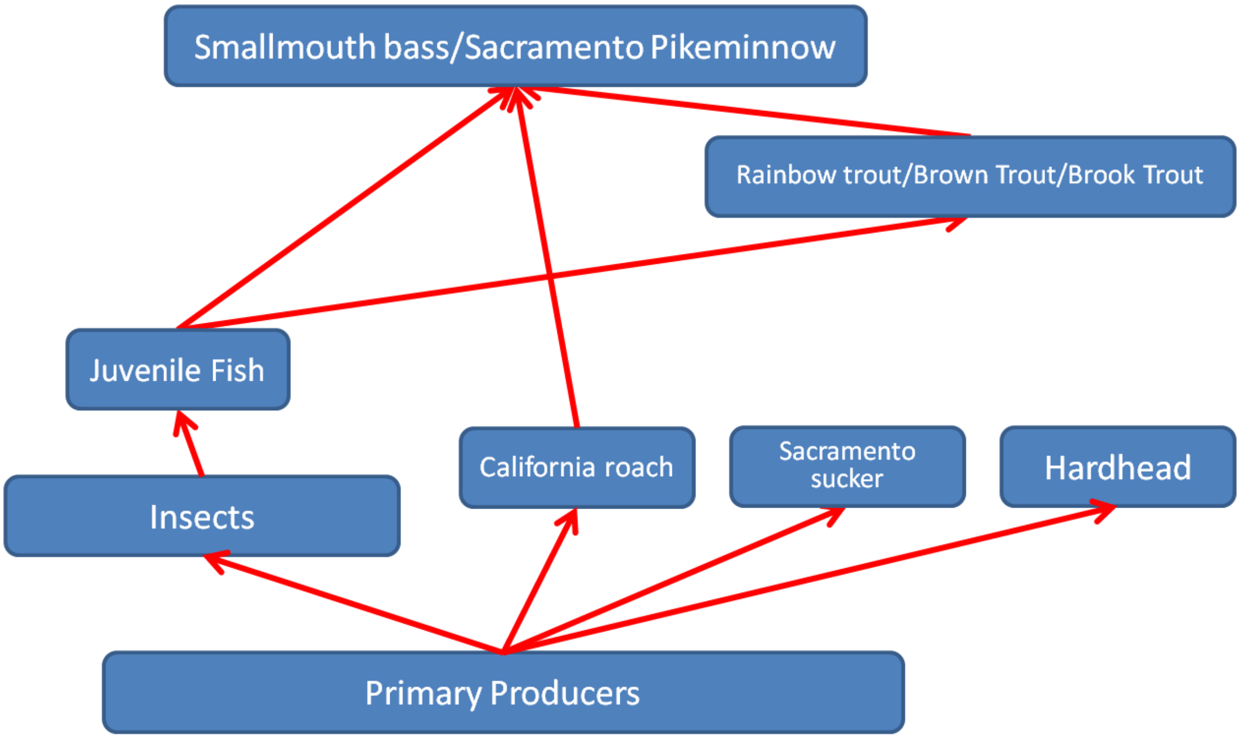

Figure 1.9 General trophic relationships between Tuolumne fish and their food web

The California Department of Fish & Game has designated the Tuolumne as a Heritage & Wild Trout river, thanks to rainbow trout, the only remaining salmonid native to the Tuolumne drainage. Rainbow trout are easily recognized by their dual dorsal fins, prominent lateral stripe and distinctive spots (Figure 1.10).

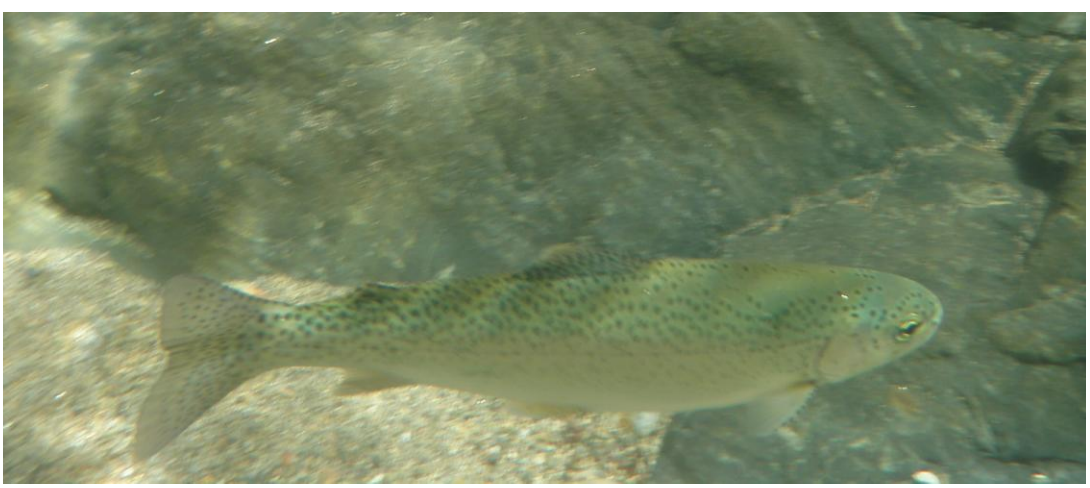

Figure 1.10 Tuolumne River Rainbow Trout

Trout require clean gravel beds to spawn successfully. During the spawning season, adults will form redds, or shallow nests in the gravel. In these redds, females lay eggs which the males then fertilize. After they hatch, the alevin, or larval fish, rely entirely upon the yolk sac from their eggs. Once the alevin has absorbed all of its yolk and is able to swim, it becomes a fry. The fry will continue to grow, and as it grows it will change from fry to parr (characterized by distinctive vertical bands called parr marks) to juvenile, and finally to adult (Figure 1.11). Although they feed primarily on aquatic invertebrates, trout will also consume other fish once they reach a certain size. Adult trout tend to spend most of their time in pools below riffles, moving into the riffles when they are foraging for aquatic insects (Moyle, 2002).

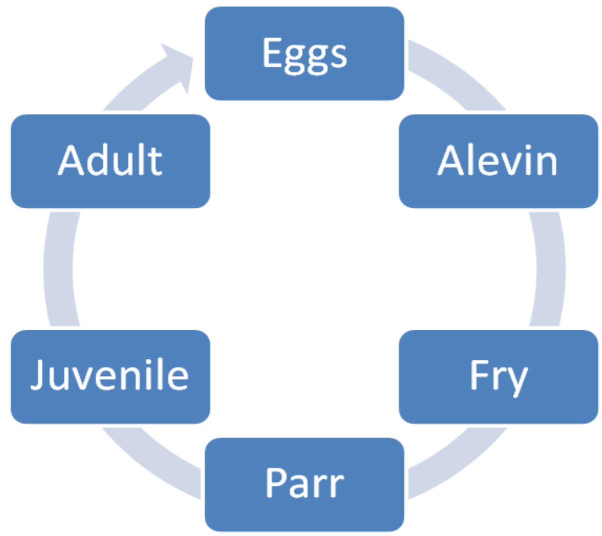

Figure 1.11 - Typified trout life cycle

Floating down the river, hiking up one of its side canyons, or sitting quietly on the shore are excellent ways of learning about the watershed of the Tuolumne and developing a personal understanding of the interwoven natural histories within. With an appreciation for the geomorphic and hydrologic processes that are occurring, and how they affect and respond to changes in plant and animal distributions, you can equip yourself to explore and draw connections between the things you see. After reading this guide, you will be able to understand the relationships between discharges, sediment distribution, water quality, habitat formation, and the intensity of species relationships. You'll understand how the physical template also drives primary production, disturbance, movement, and the continuity of the rivers character.

In this reach of river, San Francisco's dams tightly regulate the discharge for most of the year, with dramatic effects across the food web. These beautiful 18 miles of wilderness have a long history of being touched by human hands. While you float down and come in contact with so much nature, keep an eye out for those fingerprints as well.