The Clavey River

About 5 ½ miles below Meral's Pool, the Clavey River enters the Tuolumne from the North. Many raft trips prefer to camp at the confluence of these two rivers, which contains a large pool, gravel bars, and lies immediately upstream of the steepest and most difficult rapid of the trip, Clavey Falls.

Whether or not your party camps at this confluence or just stops to scout the rapid, take some time to appreciate your surroundings and think about the relationships between these rivers.

If you do camp here, you might want to hike up the river. A short hike upstream will take you to beautiful waterfalls, swimming holes, and all kinds of beautiful rock formations to stretch out upon or investigate.

Hydrology

The Clavey River hydrograph is entirely unimpaired by human dams, which is very unusual for a California river. Throughout the 150 square miles of watershed, there are only 2 or 3 tiny, old dams located far up in the headwaters, near Pinecrest Lake and the Emigrant Wilderness.

Concept 1. *The Clavey receives both rain and snow runoff*

The Clavey River watershed lies across the proper elevation range to receive both rainfall and snowmelt, which profoundly affects its hydrology. Winter storms in California are generally short but often intense. As you can see in the figure below, precipitation that falls as rain behaves very differently from precipitation that falls as snow. Rainwater splashes, percolates into the soils, travels through plants, runs across the surface carrying leaves and dirt, and enters the rivers in strong, dirty pulses. These pulses can get very big in a manner of hours.

Snowmelt is very different. Snowmelt can also reach very high discharges in the springtime, depending on how quickly the temperature increases. In the case of a 'rain-on-snow' event, these peaks are generally much more protracted than rain runoff.

As snow disappears from the mountains, discharge decreases and a gradual transition to baseflow occurs. This is called the spring snowmelt recession. Baseflow is groundwater that drains into the channel, which increases to high volumes shortly after the snow melts. Over the course of a few weeks, baseflow generally recedes to a stable minimum flow and the Clavey continues to stay wet through the summer and fall. During fall, the storm cycle starts once more.

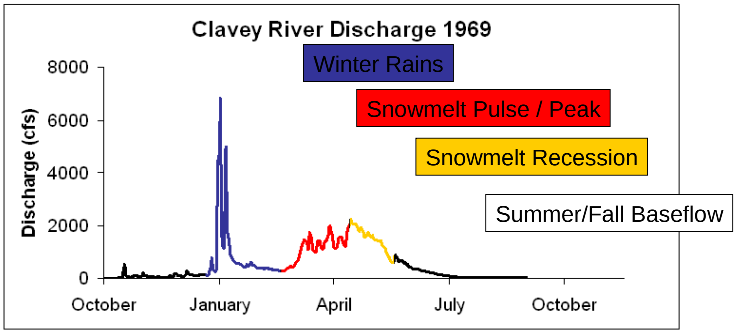


figure 2.1 Clavey River discharge hydrograph

What does it mean that the Clavey is undammed?

Dams across rivers in the Tuolumne vary greatly in size, age, and form. Natural dams include log jams or rock outcrops and falls. Over time, these dams get washed away, filled in, or eroded. Humans are responsible for the most prominent dams today.

Here are some of the common physical effects that dams have on the river.

By design, dams change the timing of flows. Depending on their usage, this could mean:

- Trapping flood flows
- Supplying water during summer months
- Pulses of water associated with energy demand

Dams interrupt the flow of sediment and wood, which is detrimental because it fills up the reservoir and reduces storage and it deprives the downstream area of an important natural component.

Dams often change the temperature of the water downstream:

- water released from the bottom of the dam is relatively cold
- water released from the top of the dam is relatively warm

Geomorphology

Concept 1. *The River Channel*

Like the Tuolumne River, the Clavey River has a mixed bedrock/alluvial channel. Over millions of years, the river has cut into the rock underlying the watershed. Simultaneously, the river carries sediment in the form of sands, gravels, cobbles, and boulders, downstream and covers the bedrock at different times and places within the river continuum.

Mixed bedrock/alluvial channels are typical of mountain rivers, particularly at this elevation in the Sierra Nevada. This type of river represents a balance between transporting forces and depositional forces. Reaches with higher transport forces, such as steep sloped drops or higher peak discharges, tend to contain more exposed bedrock. Conversely, reaches with higher sediment inputs, milder slopes and lower peak discharges tend to contain more alluvium.

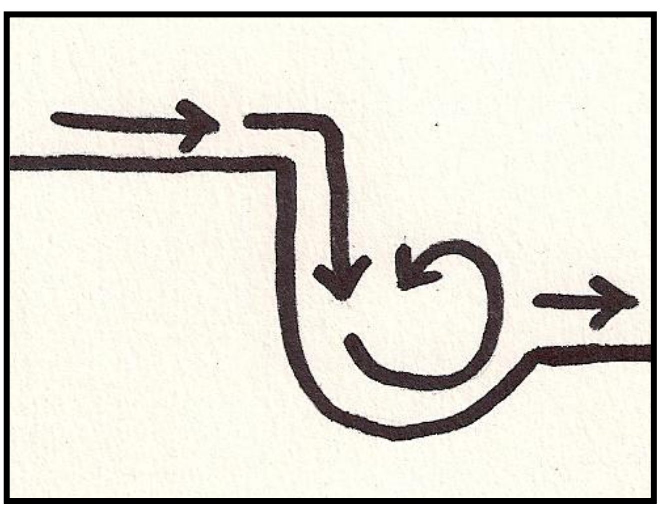
Concept 2. *Geomophic Features*

On a landscape scale, bedrock rivers adjust over time and smooth their slopes, but on the human scale river slopes are generally jagged, forming a suite of geomorphic features. Some geomorphic units you may see on the Clavey include the following:

- Bedrock Steps
- Cascades
- Rapids
- Plunge Pools

Bedrock Steps

Bedrock Steps are steep drops in the bedrock. Large bedrock steps are uncommon along the Clavey and Tuolumne because high energy water erodes them faster. Abrupt changes in channel slope like these are called knickpoints (Wohl, 2000). Knickpoints generally migrate upstream through time because of strong erosion downstream.



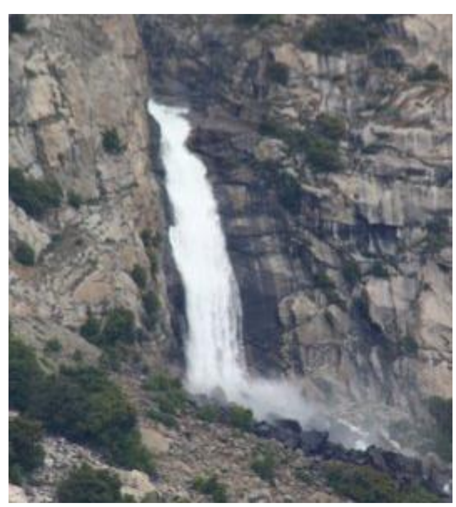


Figure 2.2 Bedrock step.

Figure 2.3 Bedrock step, Tuleelee Falls, Hetch Hetchy Reservoir. Photo: Gerhard Epke.

Cascades and rapids

Cascades and rapids are knickpoints with trapped boulders and other large sediment. Rapids are a term used loosely by boaters, but it has a specific geomorphic definition. There are no true rapids on the reach of the mainstem Tuolumne River from Meral's Pool to New Don Pedro, because the gradient of the river is not steep enough.

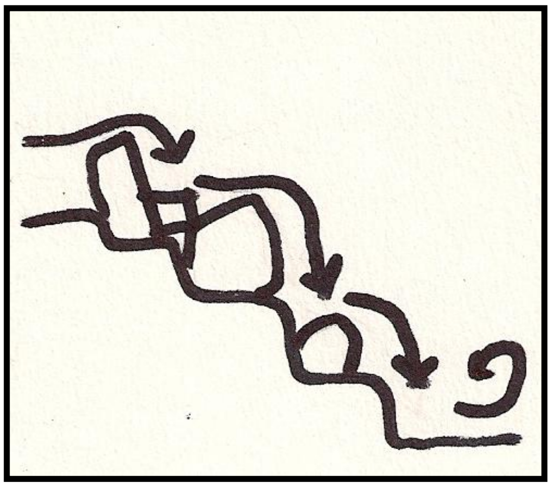


Figure 2.4 Rapid

Figure 2.5 Rapid followed by a pool on the Clavey River. Photo: Tyler Hatch.

Riffles and Glides

Riffles and Glides are lower angle features. Typically riffles are shallow enough to cause surface roughness in the water. These environments are excellent habitat for invertebrates, because of abundant water and oxygen flow. At higher discharges the sediments are easily mobilized, making riffles very transient features.

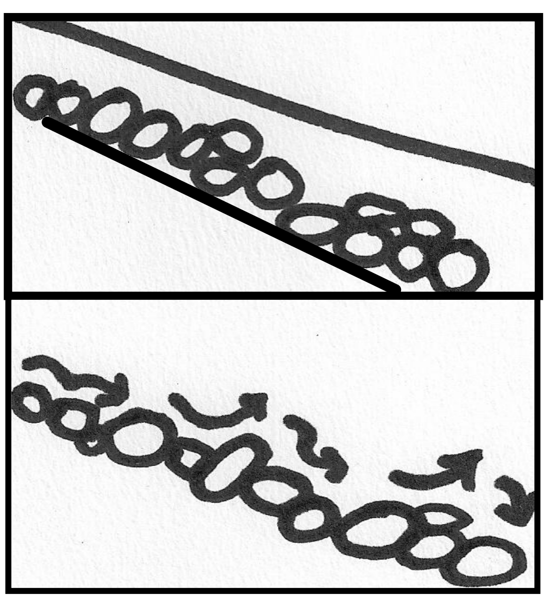


Figure 2.6 - Glide

Figure 2.7 - Riffle

Figure 2.8 - Clavey River riffle. Photo: Patrick Hilton.

Glides are like riffles, but deeper and longer. Water flowing across a glide is generally moving quickly, but not as whitewater.

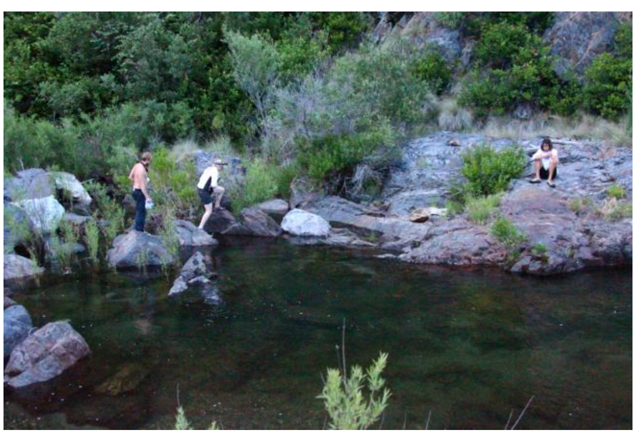
Pools

Pools form by a flow obstruction at their downstream end or by upstream scour. They often occur below steps, cascades and riffles, because high energy flows below drops scour sediment and bedrock. At the same time, downstream energy diminishes and the sediments deposit out of the current, forming an obstruction (Bierley, 05).

Riffle-Rapid-Pool Sequences

Depending on their discharge, slope, geology, and sediment characteristics, many rivers develop geomorphic sequences. A river might be described as 'step-pool' or 'pool-riffle' in reference to its physical character. These sequences arise because the energy of the water, and therefore its scouring, sorting, and depositional tendencies, are not homogenous throughout the system.

It is important to recognize that all of the features you see on the Clavey River are dynamic, both in space and time. Waterfalls, eroding at their base, move upstream over the course of thousands of years. Depending on the size of the substrate, riffles, glides, and pools may change subtly from year to year, or may change dramatically every five or ten years. These changes occur during major hydrologic events, such as winter rains or peak snowmelt runoff. At that time, current riffles may turn into pools. Similarly, present-day rapids may turn into riffles.



Have you ever thought of where it would be easiest to cross the Clavey? Usually easy crossings occur in areas with low velocity water or large boulder chains across the river. Pools contain low velocity water, but are often too deep to wade across. When crossing in a riffle, you can usually jump from boulder to boulder…but don't fall in! The water is usually moving fast and proper footing within a riffle can be hard to find.

Figure 2.9 Crossing Clavey. Photo: Patrick Hilton.

Concept 1. *How much sediment does the river move…*

- In a given year?
- In a given decade?

- In a century?

Some of the monster boulders you see around you have not moved since they fell into the river from up on the hillsides, but what about the medium sized ones? How often do they move and how much material is moving down stream?

To think about this answer, let us conduct a thought experiment. What is the discharge on the Tuolumne River today? Chances are it was somewhere around 1000 cfs.

Now, what are the sizes of rocks you think it could be moving along its bed? Are they

- One foot across?
- Three inches across?

This size is called the 'competence' of the river.

In the first few days of 1997, a large winter storm came across California and caused serious flooding around the state. Hydrologists estimate that on the Clavey River this storm was estimated to be at 47,000 cfs, something you might see once every 35 years or so. So now imagine what size rocks would be moving at 47 times the Tuolumne's discharge and you can get a sense for what happens every 35 years. Based on that, what is the scale in time that these largest rocks are operating on? What moves every 100 years? Every 1,000 years?

Vegetation

The strong, high flows of the Clavey River significantly affect the riparian vegetation. Because the Clavey receives large flow pulses, the riverbanks get scoured annually and inhibit most vegetation growth along the channel. Consequently, the riparian corridor along the Clavey River is slim. Still, the Clavey River vegetation is extremely diverse. It houses the most vegetative biodiversity of the three rivers and supports a largely native plant assemblage.

Focus On: *Foothill Pine*

Also known as "gray pine" or "spirit pine," these California native trees have a gray hue to their needles and are noticeable by their twisted conformations. They have the remarkable ability to grow in soils that do not hold a lot of moisture, which is in part why they do so well on the rocky slopes of the Tuolumne River.

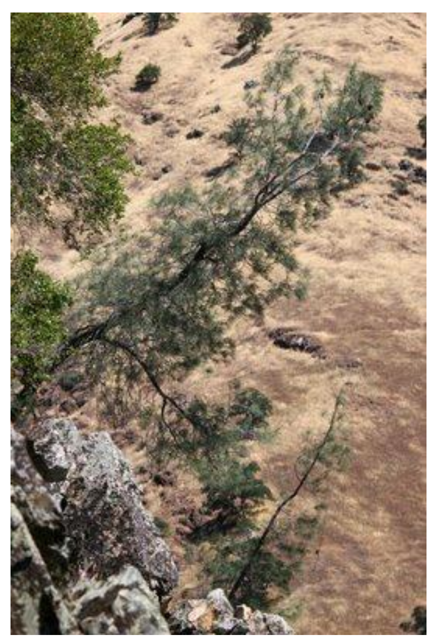


Figure 2.10 Foothill pine. Photo: Patrick Hilton

As saplings, Gray Pines grow in a relatively straight manner. As the trees grow bigger, they seem to disregard gravity. Although there is not much known about why these trees grow like this, research indicates that this may be due to genetics or due to environmental factors, such as wind.

The Native Americans that inhabited the Tuolumne River Basin named these trees "Ghost Pines" or "Spirit Pines." They believed that the sprits of the Gray Pines awoke on nights with a full moon and danced throughout the night. As soon as the light of daybreak hit their branches, they would freeze in place once more, in their twisted conformations.

Focus On: *Large Woody Debris contribution*

Large woody debris typically has a larger presence on unregulated streams, where high variance in flows provides the disturbance necessary to remove trees and transport them downstream. The presence of large woody debris along the Clavey River's channel and amidst standing trees along its hill-slopes tells a story about its hydrology.

The Clavey River is a high-gradient, high power system, which has the capacity to carry a lot of large woody debris though the river, and which sees the intra and inter-annual variance in flows to deposit that debris in various places along its banks. Large woody debris can get trapped in eddies or behind other obstructions during high flow events. As waters recede, transported debris gets left behind on shore or in the branches of standing trees. The presence of large woody debris on the hill-slopes above the river indicate how high the river became during the last major flood. Looking closely at the debris on the hillsides may also give you an idea of how long ago the river reached those higher stages.

Figure 2.11 Large woody debris build-up above the Clavey riverbank. Photo: Patrick Hilton.

Concept 2: *Organic matter contribution to the river*

We know that the alluvial deposits from upstream can provide important nutrients to the plants of the riparian ecosystem. The plants can return the favor by introducing organic matter into the river. This organic matter comes in as falling leaves, sticks and snags, dead flowers, and dispersing seeds. As they sink to the bottom, these materials start to decompose, releasing stored nutrients. Bacteria take up these nutrients, which provide energy to the plants and animals in the aquatic food web. Riparian plants' contribution may be especially important now and in the future: with the loss of historic salmon runs in the upper reaches, the Tuolumne has lost a contribution of organic matter from the once abundant decaying fish carcasses. Thus, plant material has become one of the greatest sources of nitrogen in the aquatic food web.

As plant material decays, decomposers digest and break it down into progressively finer particles. When these extra fine particles are in the water, they cause turbidity, or murkiness, which can serve as important protection from predators for aquatic invertebrates.

Figure 2.12 Decomposing organic matter on the river's substrate. Photo: Denise De Carion.

Aquatic Insects

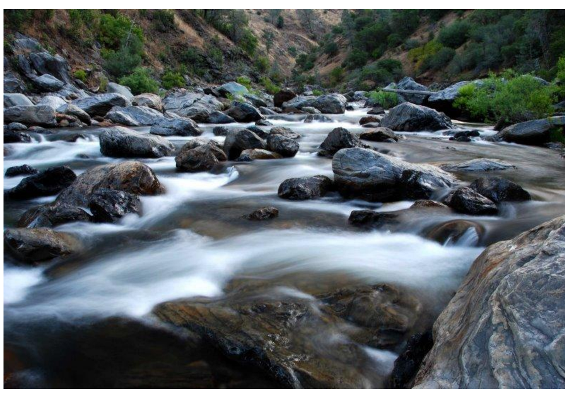


Figure 2.13 Looking upstream from Clavey River confluence. Photo: Carson Jeffres.

Figure 2.14 Blackfly larvae that is found in shallow bedrock areas and sidepools. Photo: Adam Clause.

The Clavey River is home to a unique assemblage of aquatic insects that is driven by its natural hydrologic regime, geomorphological setting, altitude, and benthic composition. The assemblage reflects what we would expect to see in a high-gradient, snowmelt-fed, unregulated river: cold water temperatures, high water quality, fast-flowing riffles, cascades, and bedrock-dominated substrate. In the lotic-erosional habitats, the aquatic insects are adapted to well-aerated and high-velocity flows; these species attach themselves to the surface of the rocks. Conversely, the lotic-depositional habitats are occupied by aquatic insects with morphological adaptations for better mobility and thus are much stronger swimmers.

Concept 1. Functional Feeding Groups

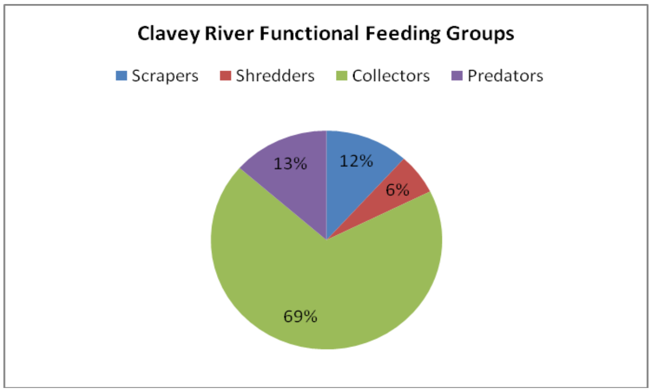


Figure 2.15 Clavey River FFGs in riffle habitat.

The percent composition of functional feeding groups of the riffles of Clavey River demonstrate that an abundance of collectors are present. Scrapers and predators have similar percent composition, while shredders are the least numerous. This data is consistent with what we would expect to find occupying cobble-

Concept 2. EPT Metric

Ecologists often use an **EPT Metric**— **Ephemeroptera** (mayflies), **Plecoptera**(stoneflies), and **Trichoptera** (caddisflies)—as indicators of stream ecosystem health. If EPT is high, the stream ecosystem is regarded to be healthy because these three orders are physiologically sensitive to degraded water quality. The Clavey River's high water quality provides suitable conditions to support a rich assemblage of EPT families. This assemblage highlights the absence of adverse human impacts that are common to other rivers, such as water diversions, agricultural and urban runoff, and sedimentation. In fact, the only significant human impacts stem from the thousands of river rafters who stop at the Clavey River confluence each summer.

The Clavey River is a healthy ecosystem, but it is not extremely productive. The river is **oligotrophic**; the low nutrient content offers relatively less food for aquatic insects. Therefore, the number of individuals that can be supported in its waters is limited.

Focus On: *Ephemeroptera (Mayflies)*

MAYFLY LIFE CYCLE

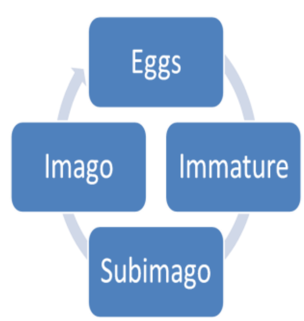


Figure 2.16 Heptageniidae larvae. Photo: Adam Clause.

Figure 2.17 Mayfly life cycle.

Habitat: Ephemeropteran nymphs are often found in rocky-bottomed, running-water habitat in headwater streams such as the Clavey River.

Life Cycle: Ephemeropterans spend the majority of their lives as aquatic larvae, a period that generally lasts 3-6 months and involves feeding on fine particulate organic matter and periphyton. Nymphs then emerge from their exoskeletons directly from the substrate of the river or from the water's surface, at which point they are in the **subimago** stage (the sexually immature adult stage). As subimagoes, they are covered in **microtrichia**, or tiny hairs, which allow them to overcome the surface tension at the water's surface. All males and some females then become **imagoes**, or sexually mature adults, at which time they begin to fly around in search of a mate. The adult stage is very short, generally lasting 2-3 days. After males and females swarm together to sexually reproduce, the females lay eggs. The life cycle is completed when the adults die and become a food source for other animals.

Distinguishing Features: Ephemeropterans have two to three **cerci**, or tail-like projections, gills along the abdomen, and one claw per **tarsus** (leg-like appendage).

Fun Fact: Ephemeropterans tend to emerge in great numbers. If you have ever observed a mayfly hatch, you know the tell-tale signs: flashes and boils at the water's surface, and trout and insectivorous birds congregate to prey on the newly metamorphosed imagoes.

Focus On: *Heptageniid and baetid mayflies*

Within the order Ephemeroptera, there are two common families found in the Clavey River: Heptageniidae and Baetidae. These two families have distinct differences in terms of life-history strategies, morphological features, habitat and food preferences, and reproduction. For example, heptageniids are hydrodynamically adapted to live in rock crevices in fast-flowing riffles where the water velocity is close to zero. They have large, shovel-shaped heads, flattened bodies, eyes on the top of their heads, and large arms for crawling and clinging to rocks. These morphological adaptations allow them to occupy a specific habitat: the underside of rocks in high-velocity riffles. During the nighttime, they crawl to the tops of rocks and feed on periphyton.

Conversely, baetids are adapted to be strong swimmers in relatively lower-velocity habitats such as pools and their margins. They have tubular, streamlined bodies. Baetids also seek refuge underneath rocks. During the nighttime, they often drift around in the water to collect FPOM, because they are well concealed from insectivorous fishes in the dark.

By comparing these two families, it is easy to understand how the presence of such aquatic insects can provide important information about the physical, hydrological and ecological components of the river.

Family	Heptageniidae	Baetidae
Morphological Distinction	Shovel-head, flattened, large legs, eyes on top of head	Streamlined, relatively long antennae, tubular body
Habitat	Lotic-erosional; boundary layer	Lotic-erosional and –depositional
FFG	Scrapers	Collector-filterers
Mode of Habit	Clingers	Swimmers
Life Cycle	1 generation/year	Multiple generations/year

Figure 2.18 Comparison Chart of Heptageniid and Baetid Mayflies.

Focus On: *Plecoptera (Stoneflies)*

Figure 2.19 Pteronarcyidae exuvia. Photo: Denise De Carion.

Figure 2.20 Pteronarcyid adult. Photo: Denise De Carion.

Plecopteran larvae are often found in fast-flowing, clean and cool rivers such as the Clavey River. Within one stream reach, stonefly nymph distributions can vary greatly depending on the availability of the following microhabitats: bedrock surfaces, leaf packs, and the hyporheic zone. Adults inhabit riparian vegetation, rocks, or debris flows.

The life cycle of the plecopterans that inhabit Clavey River are usually 1-3 years. Adult males attract females by drumming their abdomen against the substrate. Females lay their eggs in gelatinous balls directly on the substrate or in the water.

Distinguishing Features: Generally speaking, stoneflies have two **cerci**, or tail-like projections, no or few gills along the abdomen, and two claws per tarsus.

There are three common families of plecopterans found in the Clavey River: Pteronarcyidae, Perlidae, and Perlodidae. Plecopterans are extremely sensitive to degraded water quality conditions because they have rudimentary gills. They often inhabit well-aerated riffles in order to extract oxygen that is dissolved in the water. It is for this reason that they often exhibit certain motions (e.g., pushups) in order to increase the oxygen concentration gradient and why they experience mortality in low dissolved-oxygen zones.

Focus On: *Salmonflies and perlid stoneflies*

Pteronarcyid stoneflies (giant stoneflies or salmonflies) have the largest body size of all stonefly families found in the Tuolumne River watershed. They live in both lotic-erosional and lotic-depositional habitats where they cling to the substrate. They are shredders—feeding mainly on detritus and algae. In addition, their tolerance value is the lowest possible (zero), because they cannot tolerate any degree of degraded water quality (Barbour et al. 1999).

Perlid stoneflies occupy lotic-erosional habitats, where they also cling to the substrate. However, this stonefly family is a predator. Their prey includes other aquatic insect families such as chironomids (midges), trichopterans (caddisflies) to ephemeropterans (mayflies). Their sensitivity rating is higher than pteronarycids, but it is still only a value of 1.

Family	Habitat	FFG	Habit	Sensitivity Rating (0-10)
Pteronarcyidae	Lotic-erosional and – depositional	Shredders	Clingers	0
Perlidae	Lotic-erosional	Engulfer-predators	Clingers	1

Figure 2.21 Pteronarcyidae and perlidae comparison chart.

Amphibians

Focus On: *Foothill Yellow-Legged Frog (Rana boylii)*

Figure 2.22 Foothill yellow-legged frog. Photo: Adam Clause.

Tadpoles, metamorphs and adults occupy stream reaches characterized by boulders, cobbles and large woody debris. They prefer to inhabit riffles and pools that have a mixture of sun and shade for concealment and thermoregulation. During the breeding season, they lay their eggs underneath large rocks in reaches that minimize impacts from changes in hydrologic flow regime, in order to avoid scouring (washing away) and desiccation (de-watering). The Clavey River provides all of the heterogeneous habitat features that *Rana boylii* require.

Foothill yellow-legged frogs are specialists; they require specific hydrologic parameters to thrive. For example, they depend on natural, seasonally-timed water flows, such as the spring-snowmelt recession *(See page X)*. This recession limb provides the required conditions for eggs to survive. Also, they have a specific tolerance range for water temperatures (13-21 degrees Celsius).

Why is Rana boylii found in the Clavey River?

A Species of Special Concern, this native frog species thrives in the Clavey River due to its **natural hydrograph**, **complex physical habitats**, and **food availability**.

The foothill yellow-legged frog historically occupied the mainstem Tuolumne River, but the regulation of water has interfered with its ability to successfully procreate. The daily change in water flows **scour** and **desiccate** egg masses that females attach to the cobbles in the river. Luckily, the Clavey River provides a suitable refuge for this population.

Handling precaution:

Please be a steward to the population of foothill yellow-legged frogs in the Clavey River. Do not handle them. If you see a frog, you can identify it using the list of distinguishing features. Note that Pacific tree frogs only have dark eye stripes.

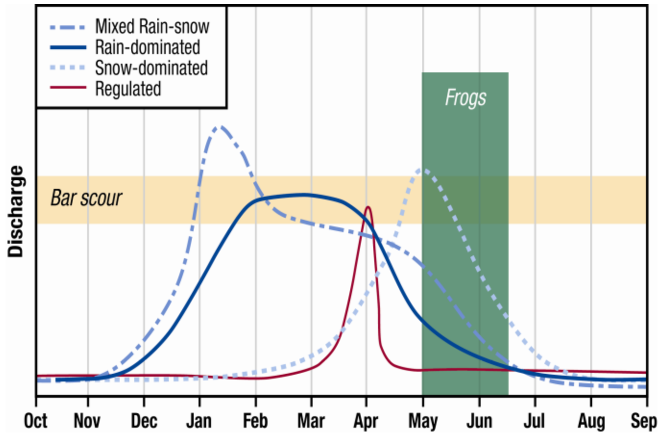


Figure 2.15 Foothill yellow-legged frogs have a small window of time to reproduce successfully [**Green Box**]. The spring-snowmelt hydrograph must recede gradually to prevent **bar scour** or **desiccation** [**Dotted Line**]. (Yarnell, in review, 2009).

Fun Fact: The tadpole stage lasts for one season, and then the swimming juveniles metamorphose into adults. Often you will see foothill yellow-legged frogs jump quickly into the water to seek refuge from danger, but usually when they spend most of their time sunning themselves on warm rocks.

Distinguishing features:

- Body size: 1.5 – 3.5 inches
- Gray, brown, reddish or olive
- Spotted yellow legs
- Call is seldom heard
- Pale triangular patch on snout

Human Impacts: In addition to human interference with reproduction via dam regulation, they have been extirpated from many of their natural habitats in other ranges due to predation by invasive bullfrogs, nonnative fishes, and pesticide pollution.

Fishes

The Clavey River and its fish assemblage have been evolving together for thousands of years. Not only have the fish species evolved with the river, but they have also evolved alongside each other. Since the Clavey river remains an unregulated system, its native fish species continue to thrive. Its native fish assemblage is still largely intact and includes:

- Headwaters: Rainbow trout
- Middle reaches: rainbow trout, Sacramento sucker, California roach
- Lower reaches: Sacramento pikeminnow, hardhead, sucker, and roach.

The presence of alien brook trout alters the native fish assemblage in the headwater tributaries only. The brook trout population was introduced to the Clavey River by fish stocking in the upper meadows.

Focus on: *Clavey River Cross Section*

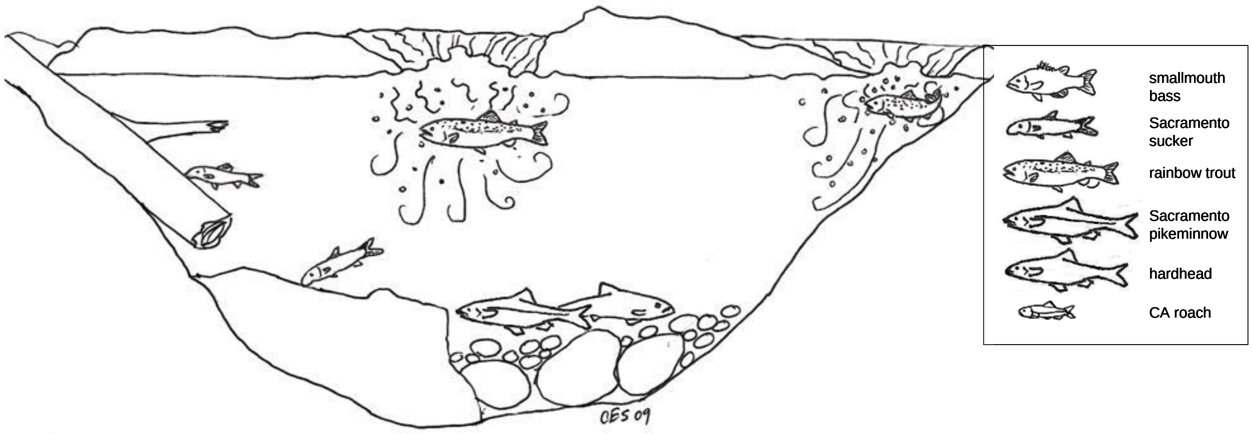


Figure 2.23 Schematic cross section of the Clavey River showing fish distributions within the river.

The Clavey riverbed is composed of mostly bedrock, boulder, and cobble. The riverbank contains relatively little vegetation. Large woody debris can be found in the channel or above the riverbank. Sacramento suckers graze on the bottom of pools while rainbow trout inhabit the high-velocity, highly oxygenated flows. California roach (not depicted) inhabit the calmer edgewaters. Large Sacramento pikeminnow and hardhead can be seen in the bottom of deep pools.

Focus on: *Sacramento Pikeminnow and Hardhead*

Sacramento pikeminnow and hardhead are two native minnows that occur both in the Clavey River and the mainstem Tuolumne. They also inhabit the same type of habitats with low-flow streams and deep pools. Neither species does well in the presence of alien smallmouth bass. While hardhead are passive herbivores, pikeminnow are top predators in native systems feeding on invertebrates and other small fish.

Figure 2.24 Sacramento pikeminnow. Photo: Claire Stouthamer.

Figure 2.25 Hardhead. Photo: Peter Moyle.

Sacramento pikeminnow and hardhead co-occur quite often with Sacramento suckers and look similar to one another, so telling them apart can be tricky. Here are some helpful hints to make sure that you can properly name these fish:

	Sacramento Pikeminnow	Hardhead
Body shape	Large (up to over 1m), elongate, pointed head	Large (up to over 60 cm), deeper, heavier, rounder head
Mouth	Large, no obvious bridge of skin connecting the upper lip to the head	Moderate, small bridge of skin connecting the upper lip to the head
Coloration	Brown-olive on the back and yellow on the belly	Brown and dusky bronze on the back
Life strategy	Predators that feed on large prey, including other fish	Omnivores that feed mostly on aquatic insects and aquatic plant material
Temperature preferences	18-28°C summer temperatures	24-28°C optimal temperature
Spawning season	April-May, mainly at night	April-May

Figure 2.26 Sacramento pikeminnow and hardhead comparison chart.


Figure 2.27. Hardhead and pikeminnow mouth comparison. The hardhead is depicted on the left, without frenem and the Sacramento pikeminnow is depicted on the left with frenem.

Fun Fact*:* both Sacramento pikeminnow and hardhead have an elegant warning signal called "fear substance." This substance is released when a minnow is injured so the skin is broken. Other minnows can smell this substance very quickly, upon which they will flee or hide. Therefore, minnows can, quite literally, "smell fear."

Concept 1: *Clavey River resident coastal rainbow trout*

Clavey River has an intact native rainbow trout population. Many rainbow trout populations in California have been damaged by water impoundments (dams, diversions, levees, etc.), degraded water quality, high water temperatures, competition with invasive species, and genetic mixing. Luckily, the Clavey River trout assemblage has been able to avoid these detriments. The unaltered flows provide the rainbow trout with the same flows with which they have evolved. These natural flows, along with minimal human disturbance, sustain the population while simultaneously making it harder for invasive fish to establish.

Concept 2: *Physical and hydrological environment drives fish assemblages*

Fish are highly influenced by the velocity of the water which they inhabit. As you know, the Clavey River reaches high velocity flows during the winter and spring. The native fish assemblage is adapted to spawning during these high spring flows so their offspring can have plenty of food and stable nursery habitat during the spring snowmelt recession.

Fish are highly dependent on water temperature. Because of the nature of Clavey being an unregulated river, its water is cold in the winter and spring during high flows and warmer in the summer during low flows. Since the Clavey hydrograph has not been impacted by human activity, the native assemblage of fish is very well adapted to this natural fluctuation in temperature.

Focus on: *California Roach*

Figure 2.28 California roach. Photo: Peter Moyle.

California Roach thrive in a wide range of habitats from cold, clear, well-aerated trout streams, such as the middle reaches of the Clavey River, to large river channels, such as the Mainstem Tuolumne, to warm, oxygen-deprived tiny foothill streams. This adaptation allows them to live in streams that become much smaller and warmer during the summer. In the Clavey River, roach feed on drift organisms in fast currents and browse for other insects on the bottom of the river.

Although California roach can inhabit a wide variety of environments, they are often excluded by piscivorous fish. The presence of the voracious alien predator, the smallmouth bass reduces their presence in the North Fork.

California roach is one of the smaller fish that inhabit the Clavey River. As an adult it can reach up to 10 cm long. They have relatively large eyes and heads, small mouths, and a rather thin body. The upper half of the fish is usually a dark dusky grey or steel blue while the lower half of the fish is a dull silver color. During breeding season, California roach develop red-orange patches on their fins to send out mating signals to the other fish.

Fun Fact: Tuolumne County has its own endemic red hills roach, which is a subspecies of the California roach. The red hills roach is distinctive from the California roach due to its “chisel lip”. The chisel lip allows the red hills roach to scrape algae from rocks. This population can be found near Chinese Camp, in the Red Hills of Tuolumne County.

Concept 3: *Clavey River food web*

Clavey river does not support smallmouth bass and only contains its native fish assemblage, so the top predator in the system is the Sacramento pikeminnow. California roach, Sacramento suckers, and hardhead are the grazers of the fish assemblage. Rainbow trout are facultatively piscivorous, but feed mostly on invertebrates in the water currents. The native assemblage is what drives the food web of the Clavey River.

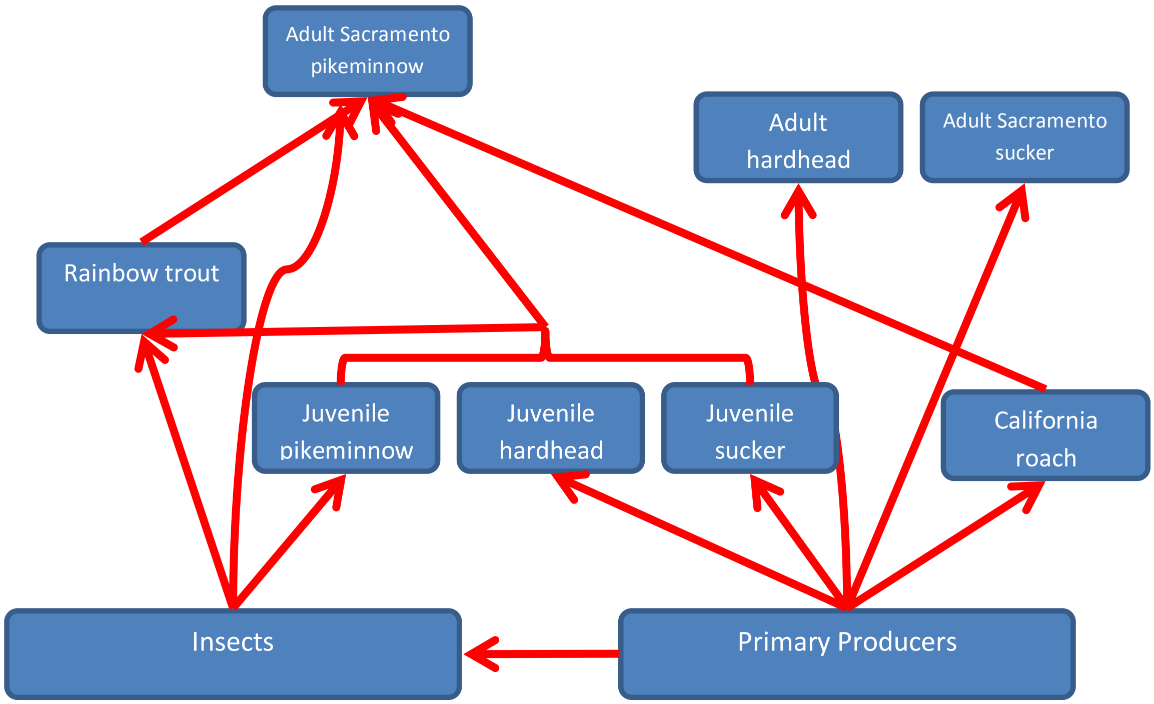


Figure 2.29 Clavey River food web.

Concept 4: *Brown trout stocking in the Clavey River*

The resilience of the native rainbow trout population was thoroughly tested in the mid-seventies, when Department of Fish and Game biologist attempted to "superimpose" a population of brown trout on the rainbow trout population. During this time period, people were more concerned with creating a good sport fishery rather than preserving the native fish populations of the river. Over 1975 and 1976, more than 100,000 brown trout fingerlings were stocked in the river! Initially, they were able to grow faster than the native rainbow trout, but despite the higher growth rates and the massive fish stocking, the brown trout population was not able to sustain itself. Looking back, it is fortunate that the brown trout population did no make it, or else the Clavey River would not likely have its native fish assemblage that it does today. This fish assemblage has a good chance of surviving, as long as Clavey River remains wild, scenic, undammed, and unstocked.

Microcosm: Swimming Hole and Water Slide

Upstream from the confluence of the Clavey and Tuolumne Rivers there are a series of pools. Beyond the first major waterfall, there is a large pool, commonly used by many rafters as a swimming hole.

Although a beautiful place to relax and cool off, there is much more to this location then simple recreation.

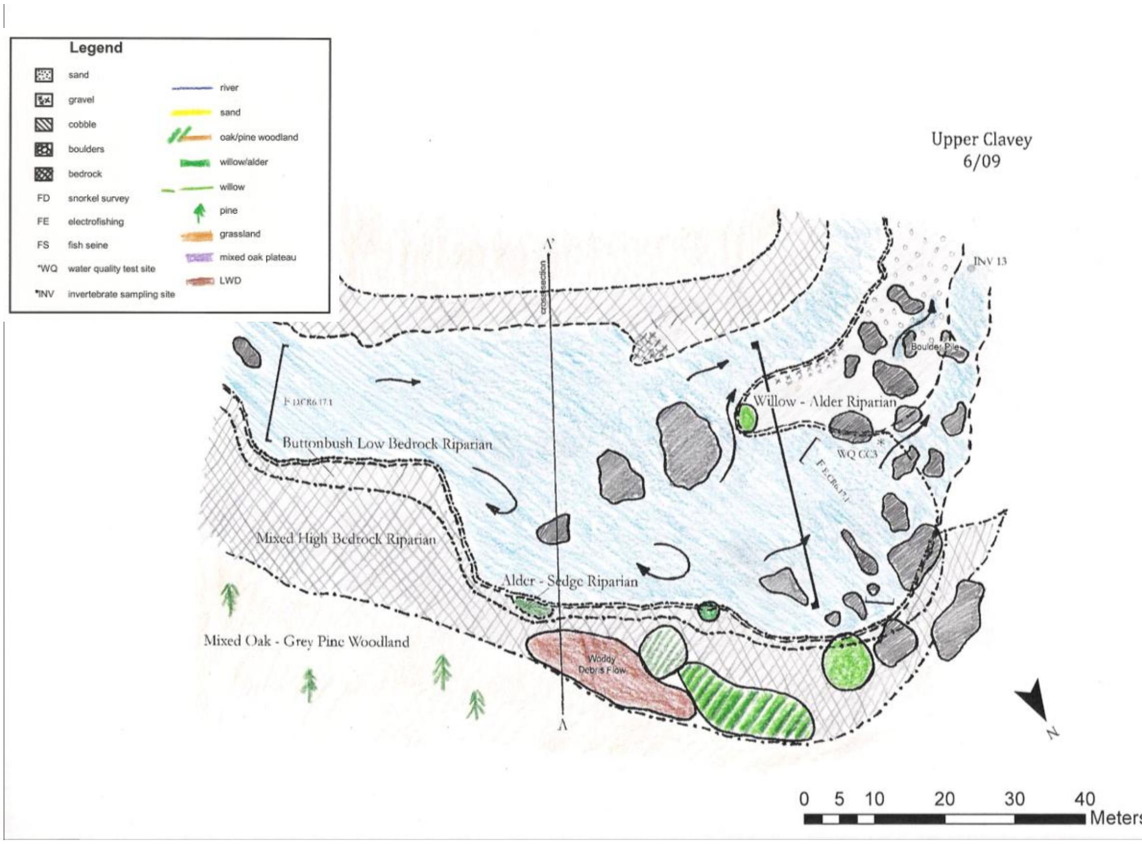


Figure 2.30 Upstream Clavey River microcosm site.

This pool is a perfect example of the rapid-pool-riffle sequence discussed earlier in the section. Higher kinetic energy and scouring at the upstream end of the pool results in deeper water, which gradually gets shallower near the tail-out. It is interesting to note the location of the high-water mark. This can be observed from the trim-line (where vegetation was scoured along the shore), or from deposits of wood and flood debris. While using this elevation to extrapolate the height of winter floods, think about how the current geomorphic units would look under this much water and which hydrologic characteristics would be present. This raises the question of the role that channel width plays during these discharges. Observe the different distribution of sediment sizes on river left of the pool and compare those sizes to the distribution of sediment above the cascade at the head of the pool.

The increased sedimentation of this lower gradient section supports a greater diversity of riparian plant species, including sedges, buttonbush, several species of willow, and even flow- and water-dependent marsh plants like the cattails in the boulder section adjacent to the pool. The stalks of these plants provide shelter from high flows and predation to many organisms, including aquatic invertebrates, amphibians, and fish. The roots of the riparian vegetation also serve a purpose, stabilizing the substrate and allowing for the retention and addition of more cobbles and sands in a positive-feedback loop. Upstream and on river left of the pool there is a large mass of large woody debris, which has accumulated over several years of high floods. Because these pieces of wood are carried up onto the bank, they and the nutrients they hold do not recycle through the mainstem, further reducing the Clavey's nutrient contribution to the mainstem Tuolumne.

Within this pool and the riffle directly below it, representatives from six of the seven possible orders and all of the major families were sampled. This level of diversity reflects the heterogeneity of the habitat and presence of marginal riparian vegetation. Higher densities of invertebrates can typically be found within the marginal vegetation. Not only is this riparia home to higher densities, different orders are typically more closely related with the vegetation then with the well-oxygenated riffle regions. Case-building caddisflies (Order Trichoptera) and true fly larvae (Order Diptera) are more common there.

Fish also commonly break up the pool into microhabitats. Juvenile Sacramento pikeminnow prefer the shallow, slow-moving water along the margins and in the willow stands on the downstream side of the pool. The deeper waters of the main pool are dominated by larger fish such as adult pikeminnow, rainbow trout and Sacramento sucker. The rainbow trout prefer the areas right underneath the cascade at the head of the pool where dissolved oxygen is highest and the flows are strongest. They like to hide behind the 'bubble curtain', the trail of bubbles resulting from the fall of water into the plunge pool. Suckers are likely to be near the bottom of the pool, in the deeper regions away from the margins. Pikeminnow are the most mobile and are likely to be seen in intermediate depths.

The Clavey and Tuolumne Confluence

Concept 1: *Confluence Hydrology*

The confluence of the Clavey and Tuolumne Rivers is the meeting of an unregulated and a highly regulated river. Although the Tuolumne watershed is significantly larger above this point, a comparison of each river's characteristics can suggest what the Tuolumne might be doing without the reservoir system.

The relative impact of the dams decreases during wet years, when the reservoirs are full and spilling water. However, if the reservoirs upstream are filling or low, Clavey River might contribute more water into the mainstem than the mainstem Tuolumne did upstream from the Clavey confluence.

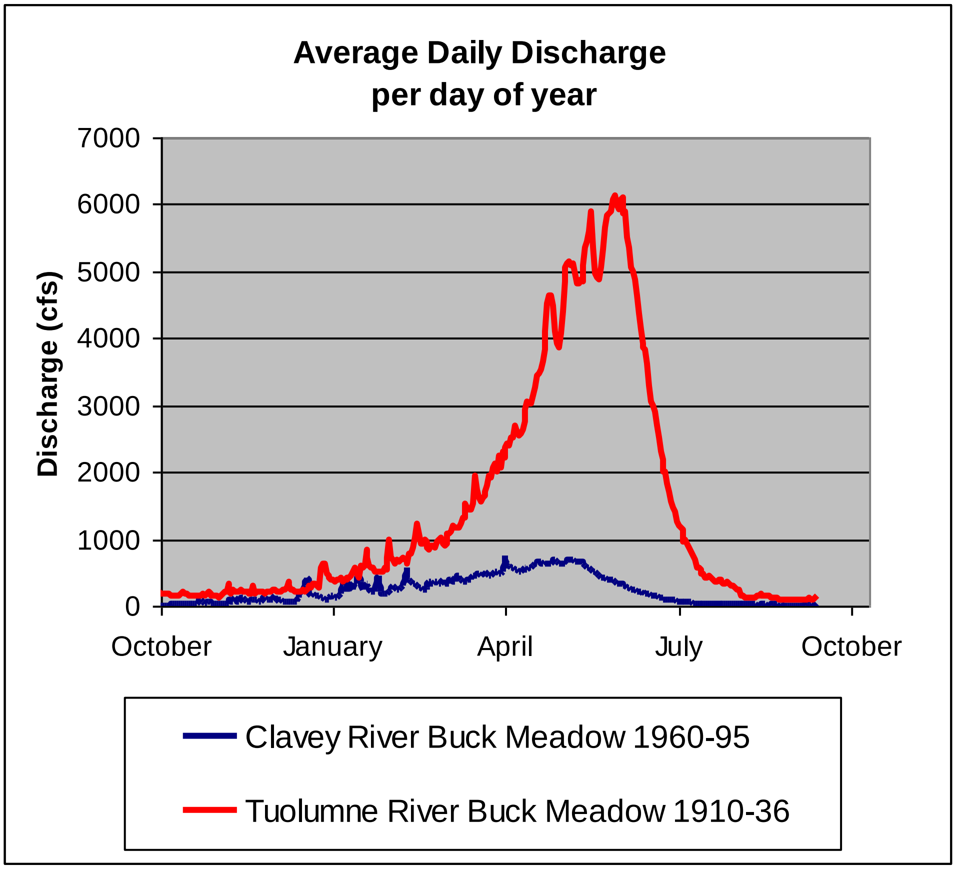


Figure 2.31 Daily average discharges from discontinued US Geologic Survey Gauges near the confluence. Although the O'Shaughnessy Dam was constructed on the Tuolumne during this period of time, the figure clearly shows the magnitude of difference between the two rivers.

Concept 2. *Water quality*

In general, rivers and streams of the Sierra Nevada have relatively good water quality. What does this mean? Water quality can be a hard term to define due to the fact that so many different influences that can positively or negatively affect it. Some of the main areas of concern can be pH, turbidity, dissolved oxygen, nutrients, metals, bacteria, algae, and temperature.

Turbidity is a measure of the clarity of water, which can be seen by the naked eye. Electronic turbidity sensors work by sending light in the water and detecting how much light is reflected back. The more light that is reflected back, the more turbid the water is. Turbidity is generally caused by fine sediments suspended in the water, but biological factors such as plankton or tannins from trees also contribute. During most of the year, the Clavey and the Tuolumne Rivers have very low turbidity, but various upstream factors might cause a turbid plume to flow downstream

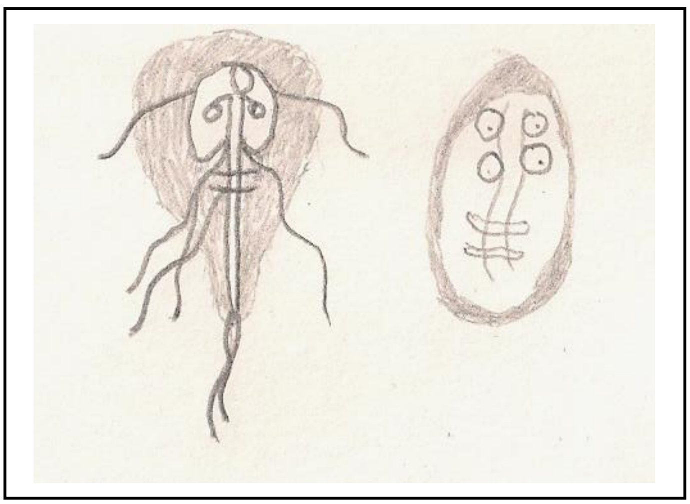
Dissolved Oxygen (DO) is an especially inportant component of water quality for aquatic organisms. The Tuolumne River, with its clean water and aerating rapids maintains consistently healthy DO levels. Microorganisms, plants, bugs, and fish use dissolved oxygen for respiration. In places where primary productivity is very high, DO levels can fluctuate widely between day and night. Low DO levels can be threatening to fish, but is of no concern among the rapids that keep DO stable.

Do not drink the water! Even though you may be thirsty and the water looks cold and clean, there are non-visible contaminates. One such contaminate is Giardia Lamblia, which is a protozoa that can cause flu-like symptoms when you get home from your trip.

Focus On: *Giardia*

Figure 2.32 Giardia lamblia cyst.

Giardia comes from mammals, humans and animals. It is



deposited into the water through feces. You can get giardia if you drink untreated water, which makes water filters a vital tool for river rafters. Your rafting guides will be sure to filter all water before giving it to you.

However, if you do get giardia, the symptoms are anorexia, fatigue, weight loss, diaria, vomiting, abdominal cramps, and fever. You will not have symptoms until a few days after you

Why might the Tuolumne River be turbid?

If you happen to see the Clavey or the Tuolumne become turbid, it might be the effect of one of the following causes:

- High flows carrying sand and sediment downstream
- Recent runoff from areas that have been in a fire (ash and other loose sediment can wash into the river)
- Landslides depositing high volumes of fine sediments.
- Can you think of others?

Although fine sediment is a natural component of the river, organisms adapted to live in the Tuolumne prefer clear water. Clear water benefits aquatic plants and algae by allowing light to penetrate deeper into the water, unclogs interstitial spaces along the bed for invertebrates, and allows visual fish to detect their food.

ingest the cyst, but if you develop symptoms, go see a doctor who can prescribe medication to rid your system of these organisms.

Concept 3: *Temperature*

One of the most important water quality parameters is temperature. Almost all aquatic organisms have a specific temperature range that they require for survival. In general the Tuolumne is a cold river, so there is little harmful algal growth or other water quality detriments. The Clavey and mainstem Tuolumne temperature data display that the waters are at their warmest during the evening. This evening high temperature occurs, because the heated water from the day continues to flow down the river during the evening. The Clavey is much warmer than the mainstem. The dams regulating the mainstem Tuolumne discharge the water from the bottom of the dam, which keeps the river at a constant low temperature.

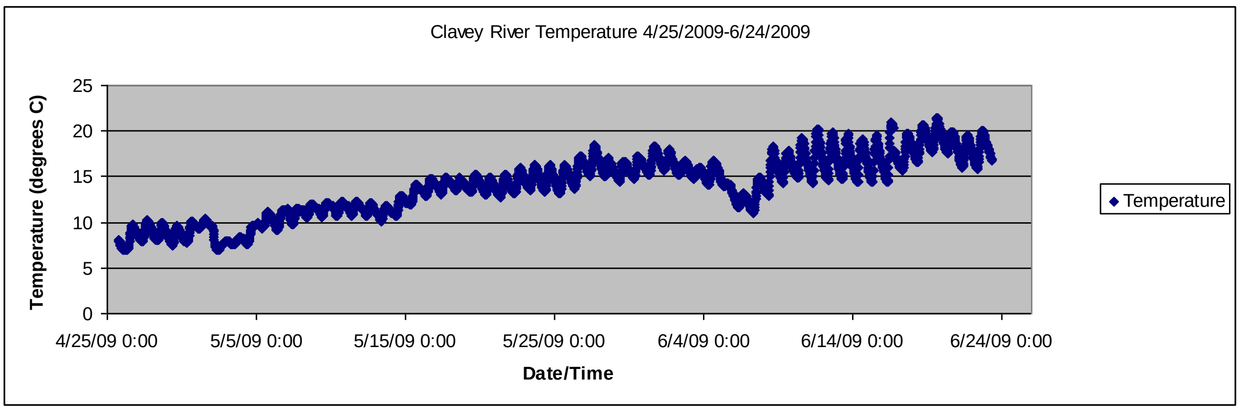


Figure 2.33 Clavey River temperatures between 4/25/2009-6/24/2009.

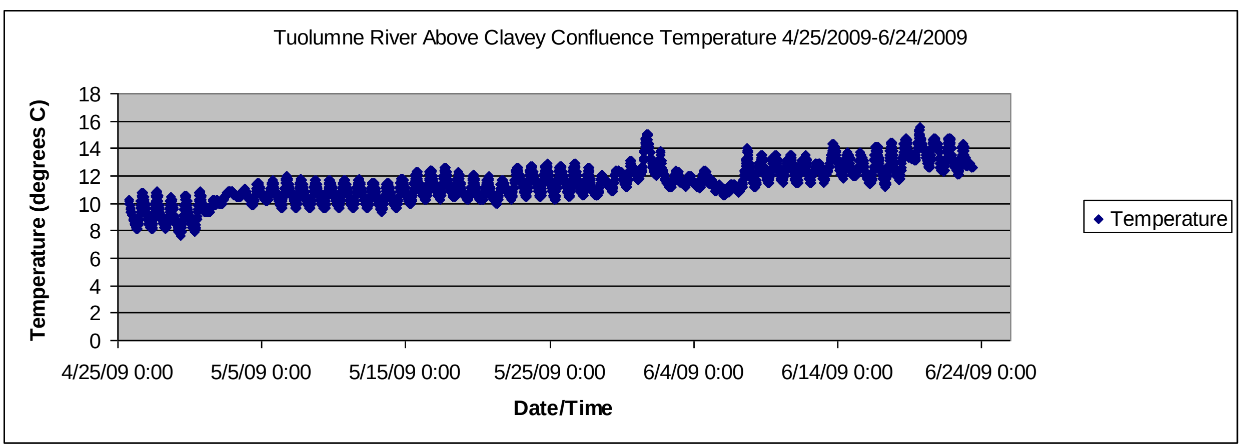


Figure 2.34 Mainstem Tuolumne River temperatures between 4/25/2009-6/24/2009.

Both the rivers are steadily increasing in temperature but the mainstem increases less. Since there is more water in the mainstem, the large river is more resistant to temperature change. Closer by the dams on the mainstem Tuolumne, there will be less temperature change, because the water is being discharged at almost a constant temperature regardless of season.

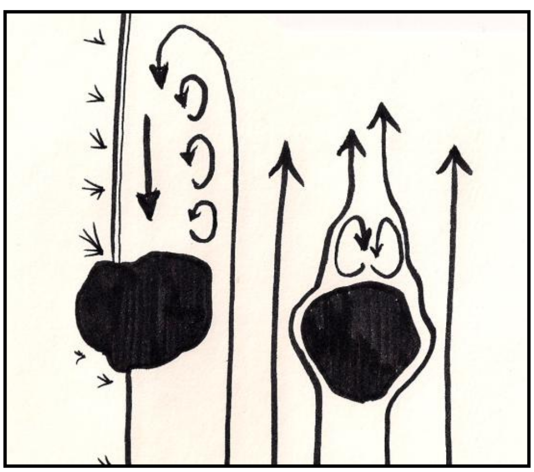
Concept 4. *Hydraulic features*

Hydraulic features are water-forms that occur in the river and along its edges as a result of the interaction between the water's velocity and momentum and the river's physical form, such as boulders causing flow obstruction. Eddies, holes, and waves, which are classic hydraulic forms, are visible at the Clavey confluence and rapid. A brief discussion of the characteristics and functions of each will help develop an understanding of what is happening at this location and at all along the river.

These hydraulic forms are dynamic because they are a relationship between the water, which changes annually, and flow obstructions, which do not. This means that at increasing water levels an eddy becomes a hole becomes the trough of a wave. The hydraulic forces of any particular location change over orders of magnitude and depositional areas can turn to scouring ones and back again across large changes in discharge.

Eddies are locations in the river where flow obstruction creates no flow or upstream flow.

As in the figure below, eddies often occur along the bank, but they also occur behind most large boulders or bedrock outcrops that are not submerged. Boater and fish often use eddies as refuges from the fast-moving current.



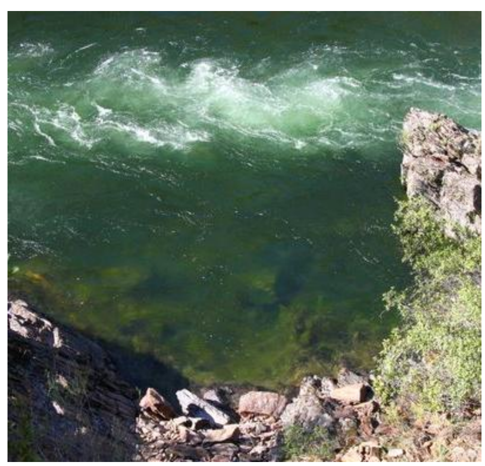


Figure 2.35 Eddy formation and water currents

Figure 2.36 Eddies. Photo: Patrick Hilton.

Eddies are examples of horizontally oriented flow separation from the rest of the river. Figure 2.35 shows how these flow separation cells, or vorticies, can be oriented parallel or perpendicular to one another. Eddies are depositional zones for appropriately sized particles. During flood flows eddies can accumulate cobbles and boulders but at rafting flows eddies are typically depositional zones for sands, fine sediment, and organic material.

Holes occur downstream of submerged flow obstructions, resulting vertically oriented flow separation and a single vortex. Holes have a wide range of characteristics as a function of the water velocity, depth flowing over the rock, and depth behind the rock (Wyrick 08). Accordingly, these characteristics have a wide range of implications for boating and geomorphic scour. Holes that become submerged by deep tailwaters are generally less menacing to boats and cause less scour.

An important component of a hole is the hydraulic jump at the downstream end. As water speeds up rushing over the top of a rock and down the far side, a threshold is reached within the physical characteristics of the medium and it becomes supercritical. At supercritical flows viscous and drag forces become reduced and, while still turbulent, the water molecules align themselves differently. Hydraulic jumps happen when this water transitions back to subcritical, resulting in an elevated pillow at the crest of the recirculation.

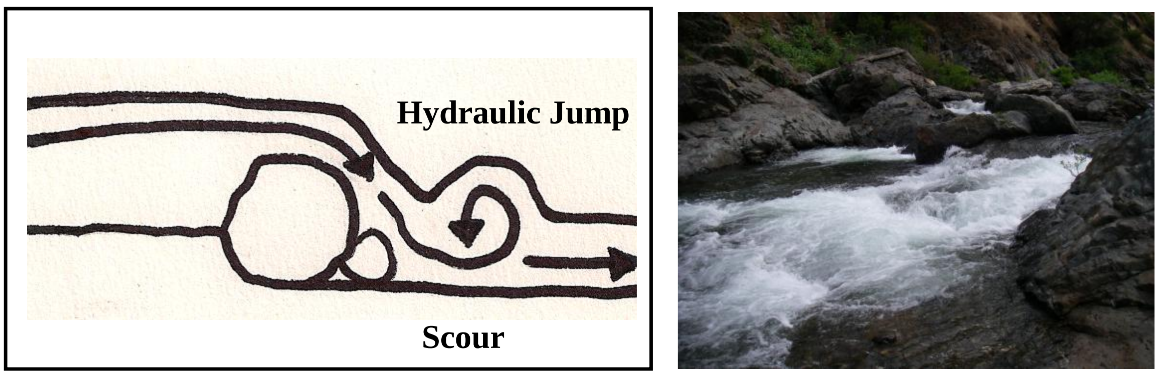


Figure 2.37 Holes have tremendous scouring potential, because they direct the force of the water at the bed. Photo: Patrick Hilton.

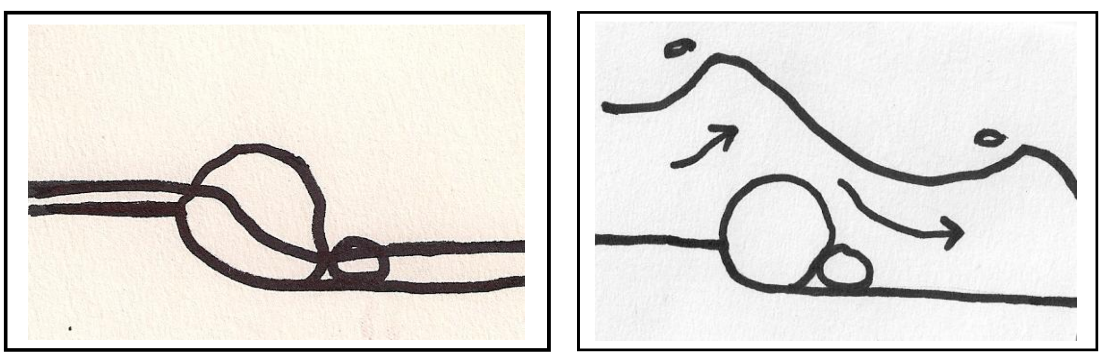


Figure 2.38 Low water becomes an eddy, high water becomes a wave.

As water levels continue to rise above flow obstructions, holes become **waves,** vortices disappear, and scouring zones transition back to depositional zones. The character of the bar above Clavey Rapid is an expression of this deposition and scour pattern as a result of the bedrock outcrop just upstream. At summer discharges this flow obstruction creates a large eddy where fine sediment deposits. Typical winter flood flows scour directly behind the rock and maintain a deep pool there but at very high flows this rock and the one upstream of it deflect the river highest velocities towards the Clavey and river right.

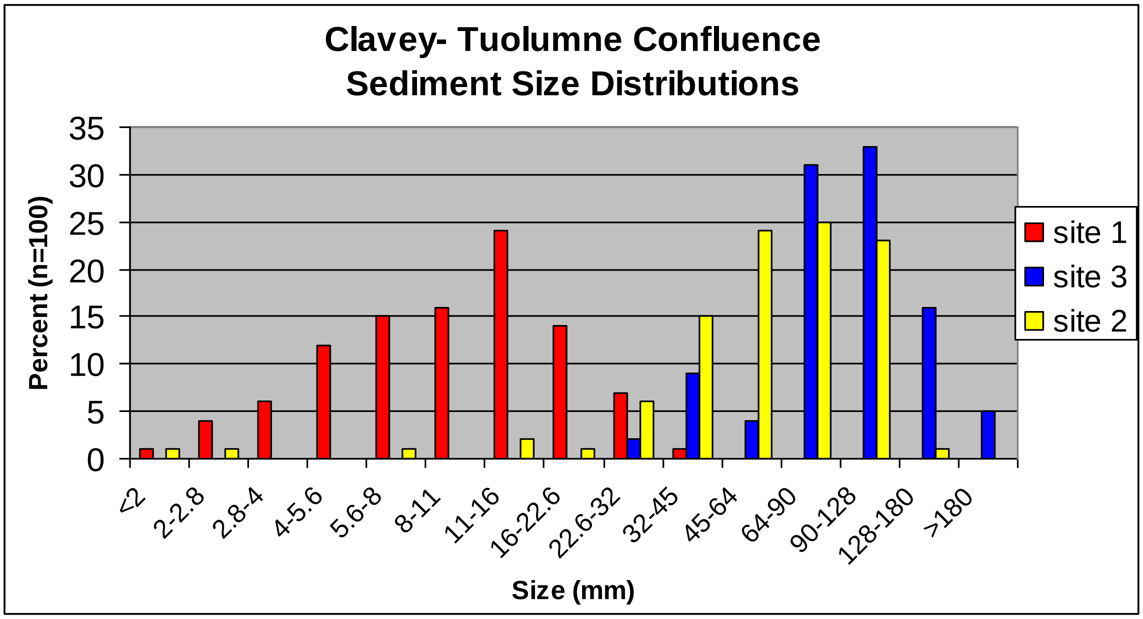


Figure 2.39 Sediment size distributions along the Clavey-Tuolumne confluence

Results of a pebble size test indicate how the bedrock features controlling bar formation are also responsible for sorting.

Clavey Confluence Geomorphology

If you hiked up the Clavey River you probably got a sense for the geomorphic differences between this river and the Tuolumne. Although the Tuolumne carries much more water annually, the Clavey, with its steeper gradient and different geology, delivers a significant amount of sediment, which has interesting implications here at the confluence and downstream.

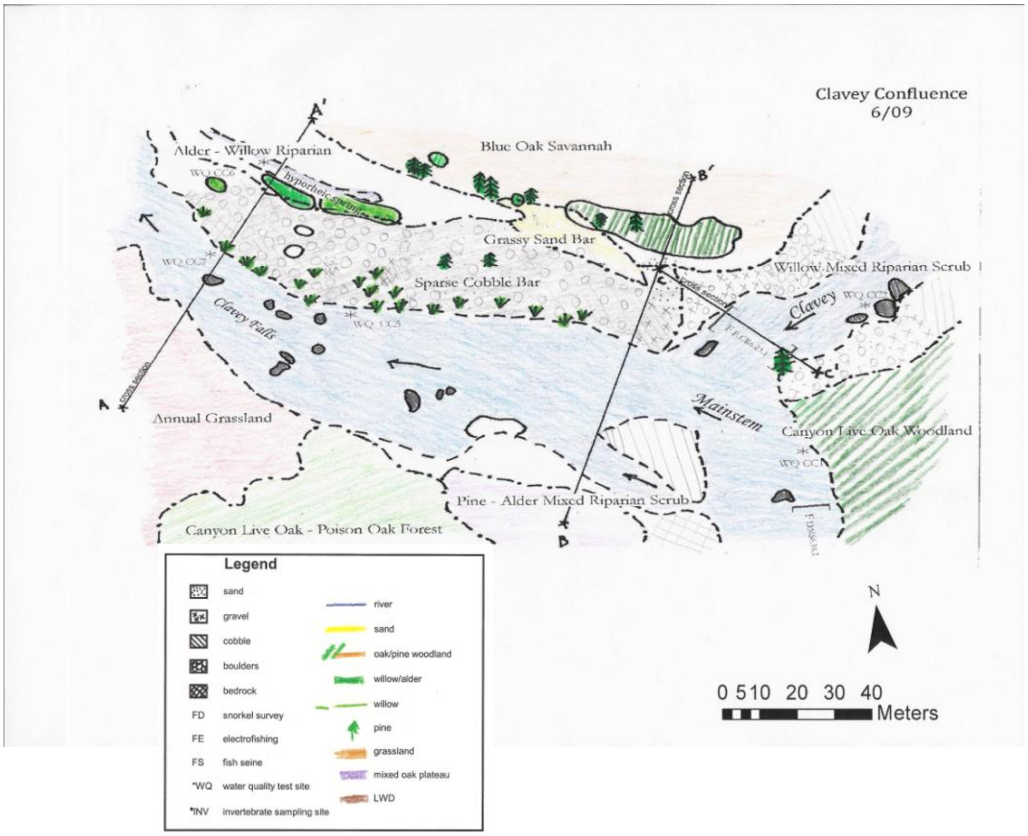


Figure 2.40 A map of the Clavey and Tuolumne River Confluence.

Concept 1. *The Confluence of Rivers and Orientation of Downstream Processes*

A glance at the map or confluence illustrates the point that when rivers converge and the momentum of their waters collide the direction of flow, sediment scour, and deposition can change. Here, although the Tuolumne meets the Clavey at a gradual left bend, the downstream river channel is forced across the river to the opposite bank.

The Junction Bar at this confluence is a dominant geomorphic feature. The right bank downstream of the Clavey river mouth is a long, poorly sorted bar of coarse sediment because it becomes a depositional backwater when the river levels are at flood stage.

Notice where and what types of rock compose the highest deposits for clues about what geomorphic environment its represents at extremely high flows.

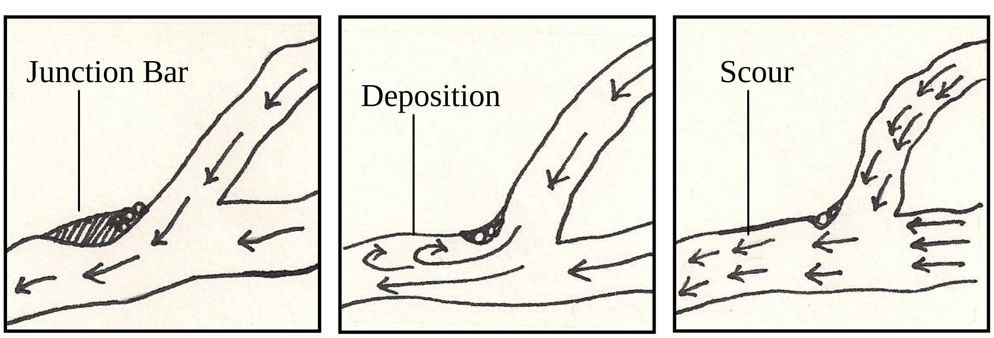


Figure 2.41 Tributary Junction Bar at 3 different water levels: intermediate, high, and flood stages, which have different geomorphic properties

This deposit also has characteristics of a longitudinal bar, which are elongated depositional features either in the center or along the banks of rivers. The ridgeline down the center of this bar probably indicates scouring against the right bank at very high flows, maybe facilitated by a lower Clavey river and less forcing to river left.

Concept 2. *Why The Confluence Forms Clavey Rapid*

That the largest rapid on this stretch of river occurs directly at the confluence of the largest tributary should have you suspicious of a potential relationship between the two. Why would a tributary confluence cause a rapid downstream?

Sediment Deposition

One important factor is the sediment delivered to the Tuolumne, some of which deposits, backs up water and sediment behind it, and forms the pool upstream. Although the Tuolumne has a great competence, it could be that the Clavey transports sufficient sediment to back it up at this point.

Debris Flows

Debris Flows are masses of unconsolidated material that move rapidly downhill. With high densities and velocity, they are able to transport very large material. A large debris flow from the Clavey river within the last few hundred years could explain how the Clavey transported some of the very large material here.

- The presence of very large boulders in Clavey Rapid and up on shore
- The scoured banks of the Clavey River
- Unsorted deposits including both smooth and angular rocks

Can you find other evidence of a historic debris flow?

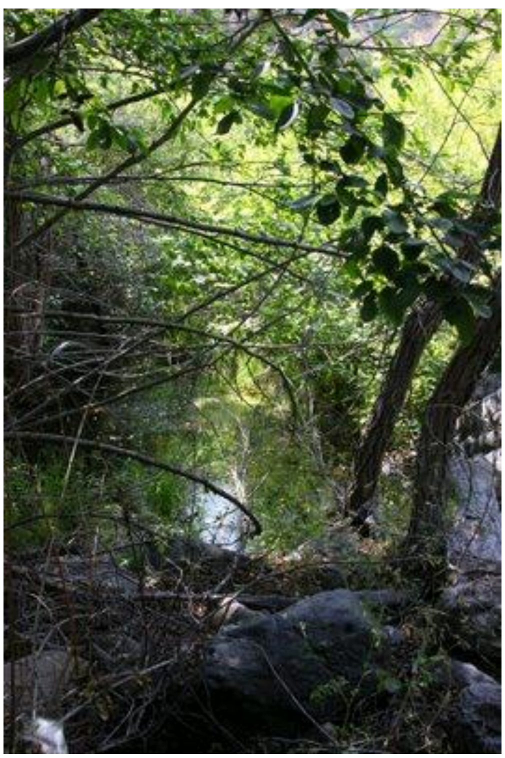
Channel width

The channel width is important factor in determining where sediment deposits. The cross-sectional area of the river directly downstream of the confluence is significantly wider than it is upstream, meaning that as the rivers rise to flood flow, the downstream scour is not necessarily intensified because water can spread out laterally (Leopold, 1953).

Figure 2.42 The mainstem of the Tuolumne River widens after the Clavey River confluence.

Bedrock outcrops also determine the location of many rapids. Bands of erosionally resistant bedrock crossing the channel are visible below many rapids here on the Tuolumne. If you hike downstream of the rapids, especially at low water, you can see the bedrock outcrop, with a large white dyke running across it. Bands of erosionally resistant bedrock like these contribute to the immobilization of large boulders, as you can see in the fall, which subsequently block more sediment upstream.

Focus On: *Hyporheic Flow*



Have you noticed the large stand of vegetation downstream of the confluence on river right? There must be a significant amount of water reaching these trees and plant in order to sustain them. Due to the porous material that makes up the confluence bar, water flows from the Clavey underground and re-emerges in this spot. Water flowing underground in this fashion is known as hyporheic flow. This causes a constant stream of water that creates a unique habitat.

The Clavey River is a dynamic system from which we can learn a tremendous amount. The undammed Clavey provides us an interesting model for considering the historical Tuolumne before it was harnessed, but its present state and confluence with the mainstem is just as fascinating. Although it is considered an oligotrophic system, it contains a tremendous variety of habitats that create a template for a complex terrestrial and aquatic food web. If you have the opportunity to explore the confluence or hike up the Clavey, you won't be disappointed.

Figure 2.43 Hyporheic flow at the Clavey confluence. Photo: Patrick Hilton.