Geology
Tectonic setting

The coastal area of northern California is geologically active due to the interactions of moving tectonic plates. Earthquakes of varying magnitude and depth are common along the Coast Ranges. The Cascadia subduction zone intersects the earth's surface offshore, beneath the Pacific Ocean, from Cape Mendocino to British Columbia. Along this convergent plate margin, oceanic crust is subducting eastward beneath the North American tectonic plate. Fluids rise from the subducted oceanic sediment and basalt, lowering the melting temperature of overlying rocks at great depths beneath California. The ensuing melting of deep seated material creates magma, or molten rock.

The San Andreas Fault marks a transform plate margin extending southward from the Cascadia subduction zone through California and into Mexico. The sense of motion along the San Andreas Fault is right-lateral strike-slip: the Pacific tectonic plate is moving to the north relative to the North American tectonic plate. Inland, east of the San Andreas Fault, other active faults take up some of the right-lateral strike-slip motion between the large tectonic plates.

In the Outlet Creek Basin, the active Maacama fault zone, which has right-lateral strike-slip motion similar to that of the San Andreas Fault, can be traced through Willits and extends north-northwest and south-southeast along the axis of the basin (Figure). Between 1991 and 2001, Galehouse (2002) measured 7 mm per year of aseismic (without earthquakes) fault creep along the Maacama fault zone at two locations: one on West Commercial Avenue in Willits and the other on Sanford Ranch Road near Ukiah. Regional geologic studies indicate a higher rate of movement: the Maacama fault zone is slipping 14 mm per year over geologic time. This means the region occasionally experiences earthquakes large and frequent enough to accomplish the higher rate of slip.

In a localized and relatively detailed trench mapping study of the Maacama fault zone near Willits, Simpson (2005) mapped a fault 3.2- 6.5 feet (1-2 m) wide. The fault cut Pleistocene lake sediment deposits and Holocene alluvium. The older Pleistocene lake deposits had been uplifted to the surface along the fault under study, displacing the younger Holocene alluvium that is 26 feet (8 m) thick (Simpson, 2005).

Geologic Units in Outlet Creek Basin

Franciscan Complex

Geologists have subdivided the Franciscan Complex into larger map units called belts and smaller map units called terranes. The belts are found throughout much of the coastal ranges of California, whereas the terranes are more localized. In northern coastal California, McLaughlin and others (2000) provided maps and information about rock types, their ages of formation where known, and the timing of deformation of the various terranes. Ages of deformation most likely represent the timing of accretion of terranes to each other and to the western margin of the North American tectonic plate.

A geologic terrane is a large piece of the Earth's crust with shared characteristics and a common origin, usually transported great distances by plate movements (Grotzinger and others 2007). Terranes can be tens to hundreds of miles long. Accreted terranes are pieces of island arcs, seamounts, remnants of thickened oceanic plateaus, old mountain ranges, and other slivers of continental crust plastered onto the leading edge of a continent as it moves across Earth's surface (Grotzinger and others 2007). The leading edge is the tectonically active coastal area. Such areas experience frequent earthquakes and volcanic eruptions. Our western coast is the leading edge of the North American tectonic plate; it has been the site of accretion of multiple terranes through geologic time.

Geologists studied and mapped the abundance of potassium feldspar (K feldspar) in the various sandstone units in the Franciscan Complex. They learned that the amount of detrital K feldspar is generally higher in the younger, Tertiary metasandstone of Coastal Belt terranes and lower in the older, Mesozoic metasandstone of the Central belt. In the latter, geologists found evidence for low-grade greenschist- to blueschist-grade metamorphism with conversion of K feldspar to albite during subduction (and thus a loss of K feldspar after deposition of the sediments). McLaughlin and others (2000) concluded that the westward increase in K feldspar, from the older Central to the younger Coastal belt, is due to both (1) the differences in metamorphic grade between the two belts and (2) changes through time in the nature of the source area for the pre-metamorphic sediment. Outlet Creek Basin includes outcrops of both the Central and Coastal belts of the Franciscan Complex (Figure).

Coastal and Central Belts

The Coastal terrane of the Coastal belt of McLaughlin and others (2000) contains sandstone, argillite and minor conglomerate forming a highly sheared mélange. Carbonate concretions contain mostly middle to late Eocene microfossils, and one Late Cretaceous age. Deformation of the mélange is late Eocene and younger.

The Yager terrane of the Coastal belt (McLaughlin and others, 2000) consists of rhythmically interbedded argillite and arkosic sandstone with minor conglomerate. Sandstone in the Yager terrane contains prominent detrital muscovite. Carbonate concretions contain middle to late Eocene microfossils. Lower beds may be older, possibly as old as Paleocene. Previous mapping noted the presence in Outlet Creek of rock types similar to those in the Yager terrane (Kilbourne, 1984).

The Central belt of the Franciscan Complex, as described by McLaughlin and others (2000), contains mélange consisting of arkosic and lithic metasandstone (containing less than 0.5% K feldspar) and meta-argillite of pumpellyite and lawsonite metamorphic grade (high pressure and relatively low temperature blueschist facies). Metasandstone is locally interleaved with chert and metabasalt. Carbonate concretions and local chert beds contain microfossils that are Late Jurassic to Late Cretaceous in age.

North of the Outlet Creek watershed, the Central Belt includes metasandstone units of unknown ages: (1) the White Rock and Fort Seward arkosic sandstone units, which may be tectonically incorporated from the younger Coastal Belt and (2) the Haman Ridge greywacke, which lacks K feldspar. To the north geologists have found minor isolated blocks of Early Jurassic to Late Cretaceous rock types in the Central Belt, including limestone, chert, pillowed and unpillowed basalt, flow breccias, submarine tuff, diabase, and blueschist (glaucophane-, lawsonite- and jadeite-bearing metamorphic rocks). The latter underwent retrograde metamorphism from much higher grade metamorphic rocks such as eclogite or amphibolite, which formed deep in the earth.

Limestone exposed north of Outlet Creek, near Covello, contains low-latitude foraminifers of Early and Late Cretaceous ages. These would have been deposited at a time when the west coast of North America was probably at a higher latitude. Thus the limestone is part of a terrane that most likely formed to the south, then moved northward with respect to North America.

Deformation of the Central belt occurred during Late Cretaceous time and possibly later as well.

<u>Pliocene-Pleistocene valley fill</u>

Woolace and others (2005) studied the valley fill in Outlet Creek watershed. The strata referred to as “valley fill” consist of fine-grained lake deposits, coarser grained alluvial gravel, and fine-grained fluvial overbank deposits. Paleocurrent data indicate that streams once flowed to the south during Quaternary and possibly late Tertiary. Woolace and others (2005) found more than 460 feet (140 m) of northward dipping sediment. The mean dip of strata is 8˚, with a range from 5˚ to 25˚. Volcanic ash layers at and near the surface are Pleistocene in age, ranging from 740,000 to 110,000 years old. The east margin of the basin is bounded by an inactive, steeply dipping fault having at least 164 feet (50 m) of displacement up to the east. Minor amounts of colluvium occur along the east margin of the basin. Since today’s surface drainage is toward the north on the valley floor, Woolace and others (2005) inferred that late Pleistocene regional deformation reversed the direction of drainage following the deposition of the Quaternary strata.

According to Simpson (2005) the area of the Maacama Fault in the southern part of Little Lake Valley contains fine-grained laterally continuous tabular beds of clayey silt, which are indicative of a low-energy lake or shallow pond, which is similar to the lake deposits reported by Woolace and others (2005). Simpson (2005) found trees in upright growth positions in the latest (uppermost) Pleistocene lake beds, indicating that a forest formed at the edge of a lake. The remains of the trees and charcoal provided radiometric carbon ages ranging from 11,350 to 22,870 years. These lake deposits are overlain by later Holocene stream deposits described below.

Holocene alluvium

A stream system deposited 8 meters of alluvium over the lake deposits. The alluvium ranges in age from mid-Holocene to 700 B.P. The establishment of the streams led to the death of the forest along the edges of the Pleistocene lake. During the latest Holocene, the creek cut down through the entire Holocene section.

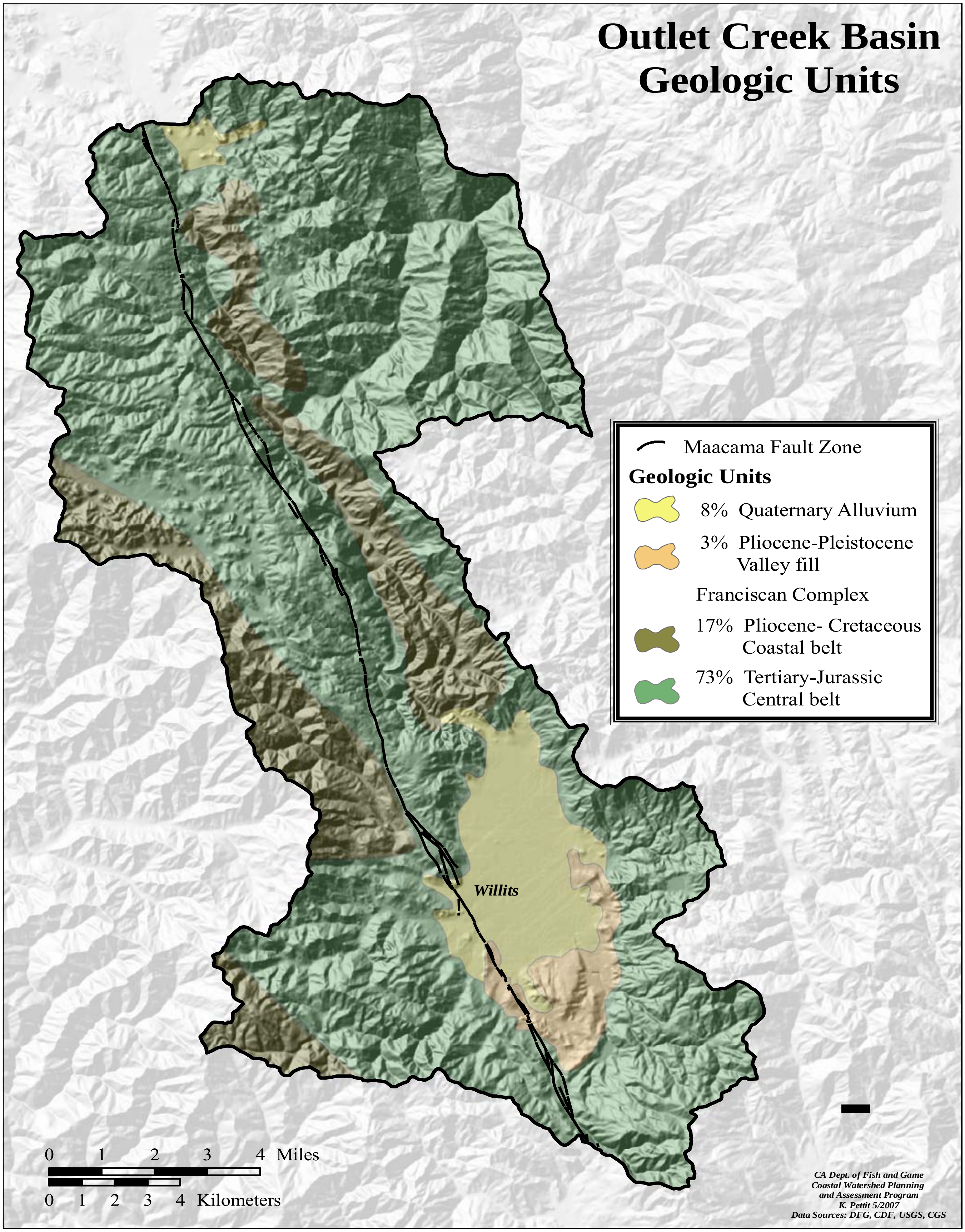


Figure X. Geologic terranes and percent composition in Outlet Creek Basin.

Fine Sediment

The Northern and Middle subbasins are more geologically similar than the Southern Subbasin. All three subbasins are composed of soft to very soft terrain and somewhat to very high erodability. Based on geomorphic terrain, rock and soil conditions and relative erodability, the Southern Subbasin has the highest relative degree of stream disturbance.

Table X. Geologic attributes related to erodability in the Outlet Creek Basin.

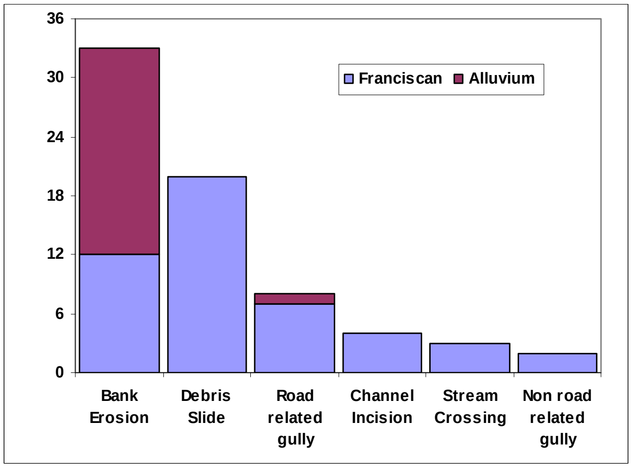
Geologic Area	Northern	Middle	Southern
Predominant Geologic Unit(s)	Coastal and Central Belt terranes	Coastal and Central Belt terranes	Alluvium, Valley Fill, Coastal and Central Belt terranes
Predominant Rock/Soil Conditions	Relatively strong, intact sandstone and argillite; thin, sandy soils.	Relatively strong, intact sandstone and argillite; thin, sandy soils.	Unconsolidated silt, sand, and gravel, includes floodplain deposits as well as active bed load.
Geomorphic Terrain	Soft	Soft	Very Soft
Relative Erodability	Somewhat High	Somewhat High	Very High
Probable Mass Wasting	Debris slides; scattered deep seated rock slides	Debris slides; scattered deep seated rock slides	Sediment transport and deposition via gully and stream bank erosion.
Relative Degree of Stream Disturbance	High in specific areas throughout this subbasin.	Variable though out this subbasin.	Highest in this subbasin.

It has been estimated that “one-half of all the sediment transported during a 10-year period upstream of the Scott Dam on the mainstem Eel was moved during the three highest days of flow during the 1964 flood” (Brown and Ritter 1971 in USEPA 2004). Given the close proximity and similar geology between the Eel River and Outlet Creek Basins, possibly similar amounts of sediment were transported from the upper reaches into Outlet Creek during this same time period. It is likely that 40 years later, the sediment contributed from the 1964 flood is still moving through Outlet Creek, the mainstem Eel, through the estuary, and out to the Pacific Ocean.

In 2005, the U.S. EPA listed the Upper Eel, including the Outlet Creek basin as sediment impaired. Only Franciscan and Alluvium terrane types were found to contribute sediment in the Outlet Basin. Franciscan and Alluvium terranes were found to contribute 69% and 31%, respectively (U.S. EPA 2005). Stream banks composed of Alluvium terrane located in Little Lake Valley contribute fine sediment. Franciscan terrane composes most of the headwaters of creeks in the Southern Subbasin and the creeks located in the Lower and Middle subbasins contribute sediment from bank erosion. Debris slides located on Franciscan terrane contribute fine sediment. Fine sediment from bank erosion of streams in Little Lake Valley and debris slides throughout the basin maybe limiting the health and productivity of salmonids in the Outlet Creek Basin (Figure X. Occurrence and type of sediment delivery by terrain type).

Debris slides and bank erosion are estimated to contribute over 2,500 cubic yards of sediment to the Outlet Creek Basin. Road related gullies and channel incision contribute close to 1,000 cubic yards of sediment. The total measured erosion was highest for debris slides and bank erosion. Bank erosion of streams running through Little Lake Valley likely deliver the most fine sediment to the basin. Debris slides located throughout the basin are also a major contributor of fine sediment. Fine sediment is from bank erosion and debris slides are limiting the health and productivity of salmonids in the Outlet Creek Basin (Figure Y. Total measured erosion and source of sediment delivery).

Non-earth flow and earthflow without an associated land use yielded the most fine sediment in the Outlet Creek Basin. Non-earthflow timber, road, and agriculture/grazing-related land activities yield sediment. Non-earthflow related sediment from timber harvest, roads, and agriculture/grazing activities are contributing to instream fine sediment accumulation which is limiting the health and productivity of salmonids in the Outlet Creek Basin (Figure X. Percent of the total non-earthflow or earthflow sediment yield and related land activity).



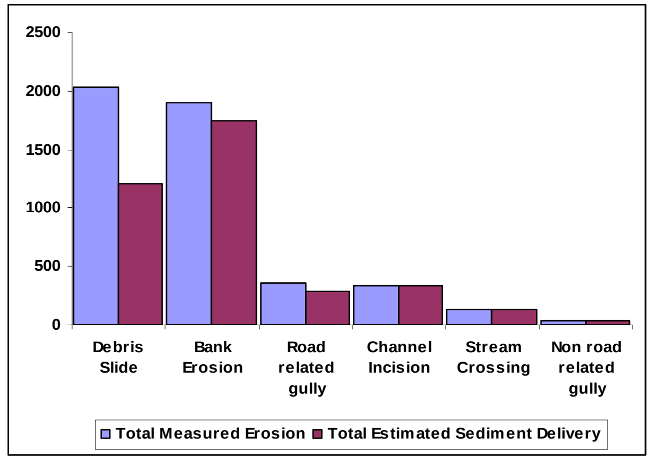


Figure X. Occurrence and type of sediment delivery by terrain type and Figure Y. Total measured erosion and source of sediment delivery. Data courtesy of US EPA.

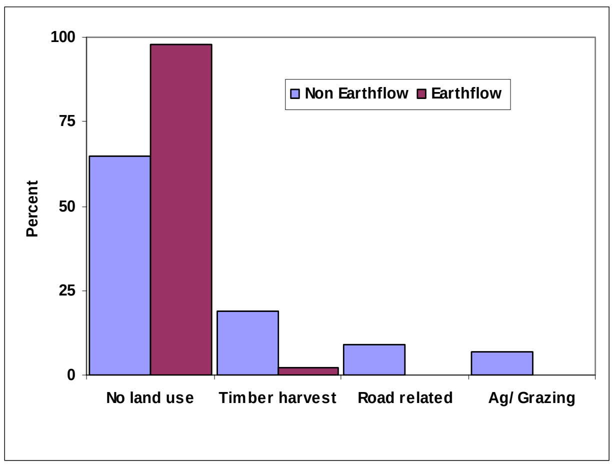


Figure X. Percent of the total non-earthflow or earthflow sediment yield and related land activity. Data courtesy US EPA.

Fluvial Geomorphology

The Outlet Creek basin is a relatively medium-sized headwater of the Eel River System, approximately 160 square miles. The hydrology of Outlet Creek Basin can be divided into three functions: the source headwaters, the depositional valley floor, and the slower transport reaches. The headwaters streams include Berry, Davis, Baechtel, Broaddus and Willits creeks and the smaller perennial streams that flow in to them. During the winter months, these streams flow into the north section of the valley floor creating a seasonal lake named Little Lake. The overflow from Little Lake creates the mainstem of Outlet Creek. The mainstem of Outlet Creek becomes constricted as it travels north along Sherwood Ridge and Highway 101. The gradient decreases above the confluence with Long Valley Creek and the channel widens. Outlet Creek turns east and is bound on the south-side by Shimmin Ridge where it meets up with the mainstem of the Eel River (Figure X. Stream gradient in the Outlet Creek Basin).

Forty eight percent of the streams in the Outlet Creek Basin are mostly high gradient (>20%) and are referred to as source reaches because they provide substrate. Transport reaches compose 37% which move the substrate downstream. Depositional reaches compose 14% of the basin’s streams. Substrate accumulates in these areas which provides spawning habitat for salmonids. Too much fine substrate can cause aggradation and embeddedness rendering the reach unsuitable for spawning.

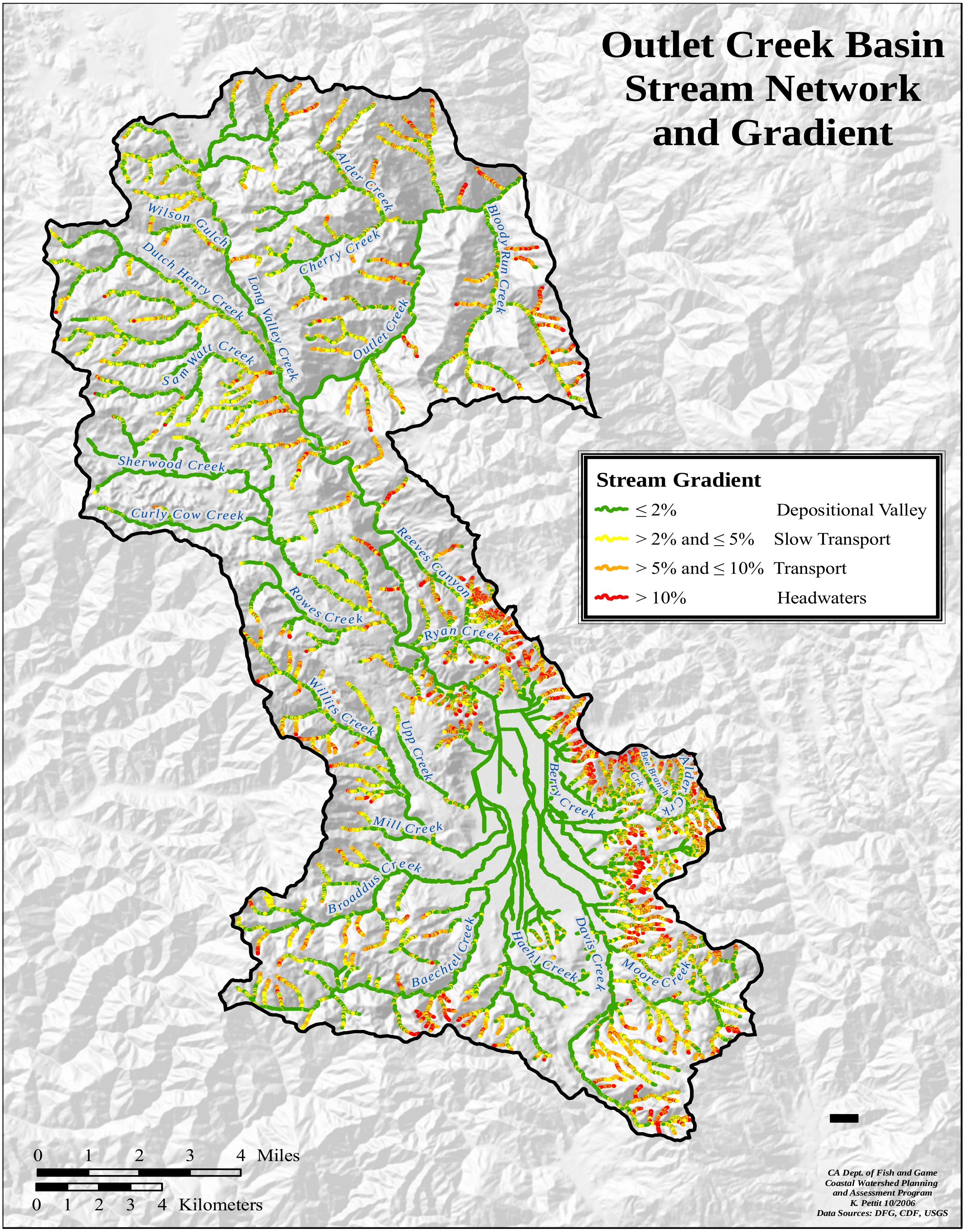


Figure X. Stream gradient in the Outlet Creek Basin.

Most of the creeks in the Outlet Creek Basin are first and second order and become intermittent in the late summer and early fall. Outlet Creek is a Third order stream from the confluence with the mainstem Eel to Little Lake Valley (Figure X. Stream order of the major streams in the Outlet Creek Basin).

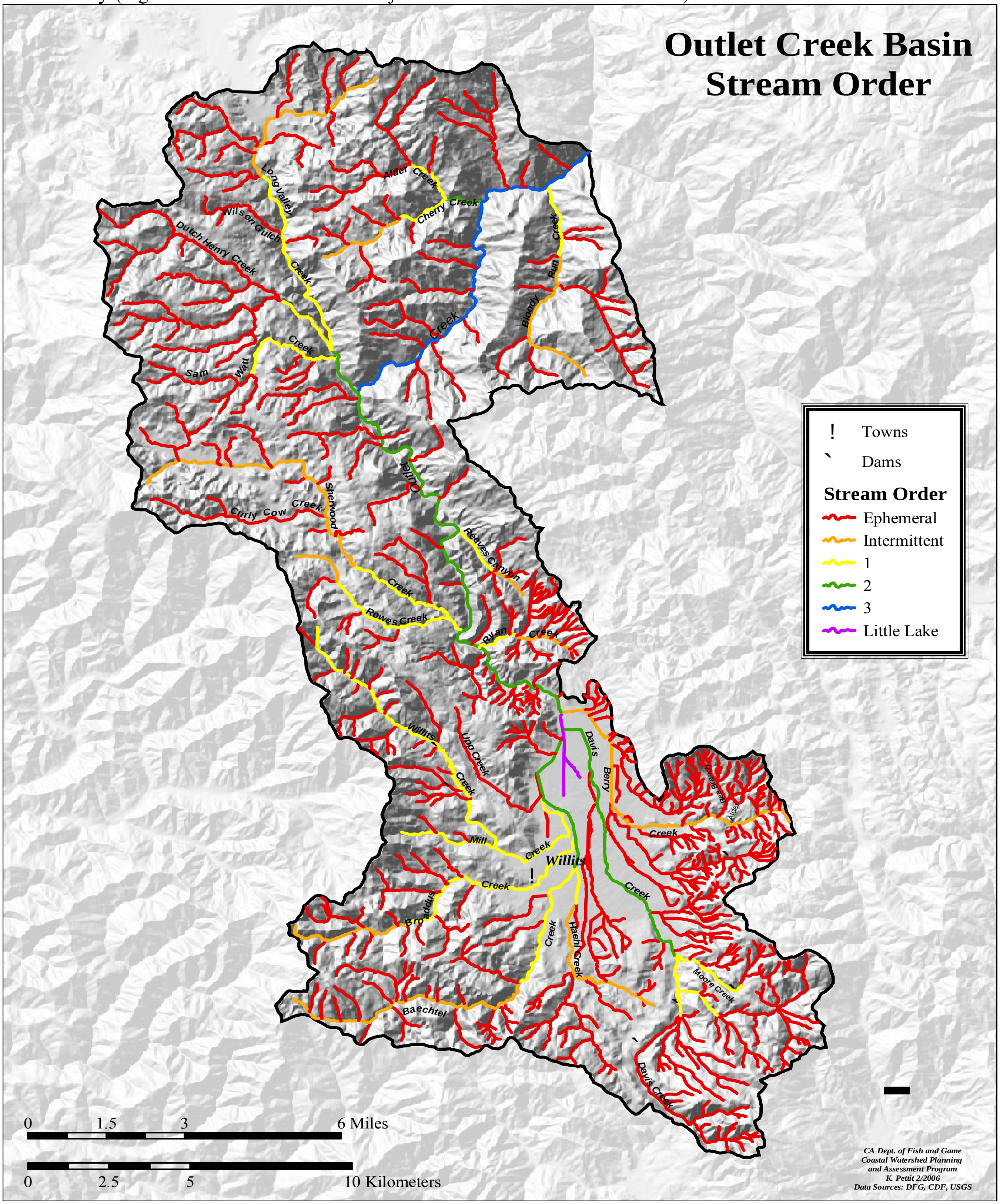


Figure X. Stream order of the major streams in the Outlet Creek Basin.

Vegetation

Outlet Basin is dominated by hardwood forest with mixed conifer/hardwood and herbaceous vegetation. There are a few areas mostly near the coast that have patches of conifer forest. Urban/residential and agricultural areas total 2% of the basin (Figure X).

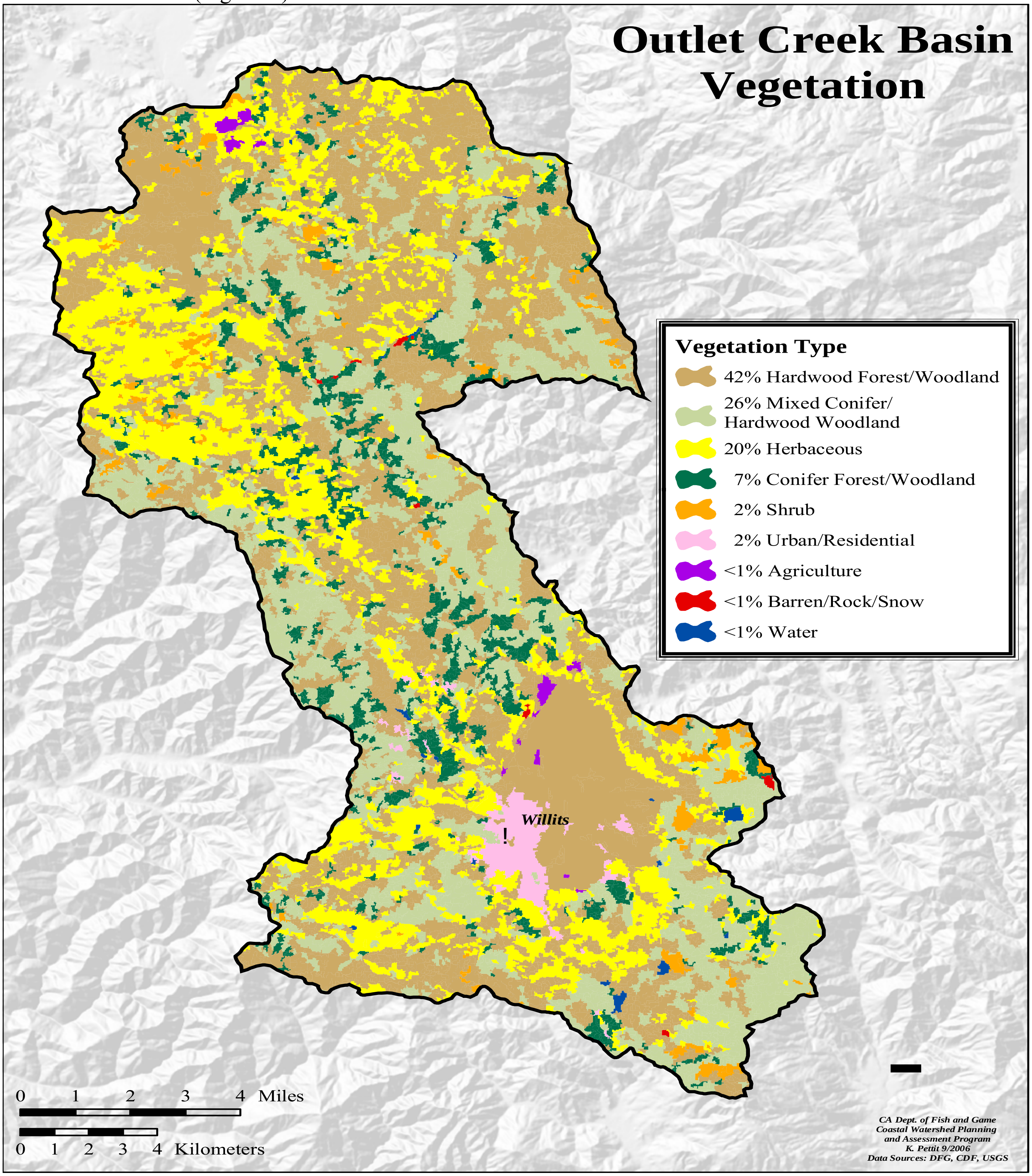


Figure X. Vegetation type in the Outlet Creek Basin.