**EXECUTIVE SUMMARY**
**INDEPENDENT SCIENCE REVIEW PANEL CONCEPTUAL MODEL OF WATERSHED HYDROLOGY, SURFACE WATER AND GROUNDWATER INTERACTIONS AND STREAM ECOLOGY FOR THE RUSSIAN RIVER WATERSHED**

## INTRODUCTION

The Russian River watershed encompasses 1,485 square miles of mountains and valleys in the Northern California Coastal Ranges. The watershed is primarily rural with a string of cities – Santa Rosa, Healdsburg, Cloverdale and Ukiah along Highway 101. Winegrape vineyards are a major land use supporting wineries and tourism. Other land uses include rural residential developments, timber harvesting, gravel mining, marijuana cultivation and grazing.

Water supply in the basin is largely centralized for municipalities through the Sonoma County Water Agency, but completely decentralized for agriculture and rural residential uses with each site having its own individual water source. The listing of three salmonid species, Coho and Chinook salmon and steelhead trout, as threatened and endangered, combined with the effects of droughts and climate change, will lead to conflicts between the demand for water and the needed recovery actions for the salmonids.

The Russian River Independent Science Review Panel (ISRP) was formed in 2012 to provide a process-based understanding of stream flow in the Russian River and its tributaries. Geomorphic and hydrologic features as well as current and historic human actions all affect stream flow and the availability of habitats for salmonids in the Russian River watershed. To date, scientific evaluations of the system have been narrowly focused and short-term leaving fragmented and incomplete knowledge of system functions. Without a thorough understanding of stream flow processes, many restoration projects and water management efforts are prone to failure. The ISRP provides a "conceptual model" of stream flow processes and their relationship to salmonid habitats and a set of recommendations to advance both scientific study and habitat restoration actions. A conceptual model is made up of the composition of concepts which are used to help people know, understand or simulate a subject the model represents. This conceptual model describes the physical features of the stream system including geologic and topographic features as well as climate and how these features interact to produce stream flow.

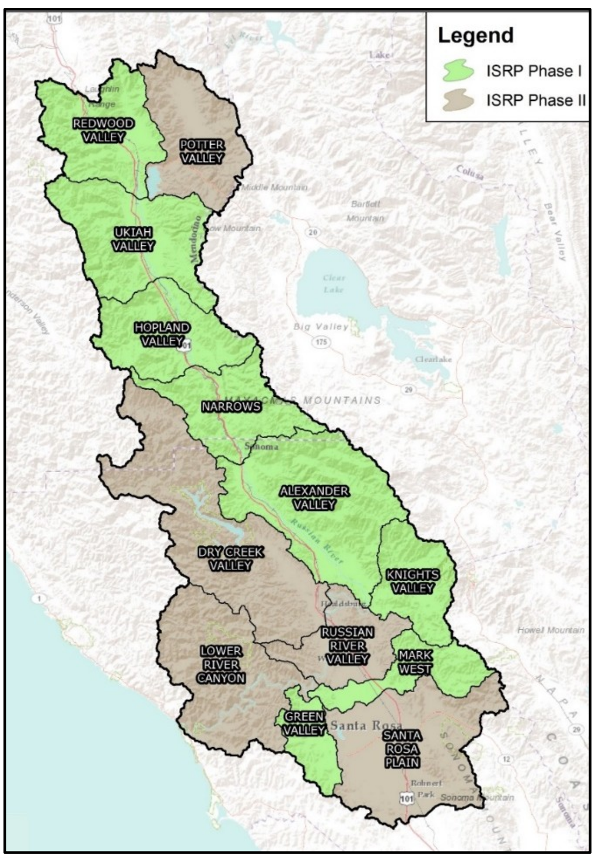



**Figure 1. The first phase of the ISRP covers the green subareas. Other subareas will be covered in future efforts.**

The ISRP is made up of nine members and represents an interdisciplinary group of experts:

- **Dr. Richard Adams**, Resource Economist
- **Dr. John Bredehoeft**, Hydrogeologist
- **Dr. James Constantz**, Hydrologist
- **Dr. Matthew Cover**, Watershed Ecologist
- **Mr. Christopher Farrar**, Hydrologist
- **Dr. Matt Kondolf**, Fluvial Geomorphologist
- **Dr. Michael Marchetti**, Ecologist
- **Dr. Vincent Resh**, Entomologist
- **Dr. F. Douglas Shields, Jr.**, Hydraulic Engineer

Each member had to pass a robust conflict of interest screening and was chosen by a selection panel made up of representatives from the Sonoma County Water Agency (SCWA), Mendocino County Russian River Flood Control and Water Conservation District (RRFC), the agricultural community in Sonoma and Mendocino Counties, National Marine Fisheries Service (NMFS), the environmental community and ISRP Chair Dr. Kondolf. The California Land

Stewardship Institute (CLSI) managed the ISRP process and provided support for the panel. Funders of the ISRP included CLSI, SCWA, RRFC, the Russian River Water Conservation Council, and numerous grapegrowers making small donations.

The ISRP's tasks were:

- To assemble and review existing data sources for the Russian River watershed.
- Hold a science forum for local researchers, agencies, and interest groups to present their current studies
- Identify major data gaps
- Evaluate monitoring methods, protocols, Quality Assurance/Quality Control (QA/QC) measures, and recommend changes and standards
- Formulate a conceptual model of the physical processes of surface and groundwater flow
- As part of the conceptual model, evaluate the ecological processes associated with the physical processes
- Prepare a report describing the watershed and conceptual model, summarizing data sources and data gaps, and recommending needed studies, needed monitoring and monitoring protocols
- Hold a public meeting to present the ISRP findings

The ISRP did not cover all issues in the Russian River watershed; their focus is stream flow processes, salmonid habitats and water use. Land use policies, environmental regulations, and water quality problems were not evaluated in great detail. The ISRP also focused on a portion of the watershed in detail (Figure 1), but described information sources and watershed processes for the entire basin.

The full ISRP report, available for download at **http://www.russianriverisrp.org**, was peer reviewed. Each peer reviewer underwent the same conflict review as the ISRP members and was selected by the same panel. Peer review comments were reviewed by the ISRP and revisions made to the report. The peer review was funded by a Rose Foundation grant to the OWL Foundation on behalf of the Sonoma County Water Coalition. The ISRP report summarizes studies and information through the end of 2015. Peer reviewers include: Dr. Alison O'Dowd, Ecologist; Dr. Hubert Morel-Seytoux, Hydrologist and Civil Engineer; Dr. Wade Martin, Economist; Dr. Jason Gurdak, Hydrologist.

**Figure 2. Alluvial valleys are one of the most distinctive features of the Russian River watershed.**

## BACKGROUND

### Geology

The most distinctive features of the Russian River system are the alluvial valleys which occur along the river (Figure 2). These valleys, Redwood, Ukiah, Hopland, Alexander and the Russian River Valley, were formed by fault blocks of the San Andreas Fault system moving at different rates relative to each other and creating local depressions known as pull-apart basins. Over time, the valleys filled with alluvium – boulders, cobble, gravel, sand and clays eroded from the surrounding mountains and delivered through landslides, debris flows and tributary streams into the basins. Pull-apart basins also occur in several tributary systems including McDowell Valley, Knights Valley, Dry Creek Valley and Potter Valley. These smaller valleys also have groundwater basins that vary in storage with the depth of the alluvial deposit. Smaller alluvial deposits occur along many creeks where there is less confinement of the channel by hillslopes. These small deposits can store groundwater as well.

The basement rock of the Russian River watershed is Franciscan Complex, a jumbled mélange of rock types that are prone to erosion and landslides (Figure 3). The mountains of the watershed are primarily Franciscan Complex with small areas of Great Valley Sequence. Franciscan Complex and Great Valley Sequence formed on the floor of ancient oceans approximately 200 million years ago.

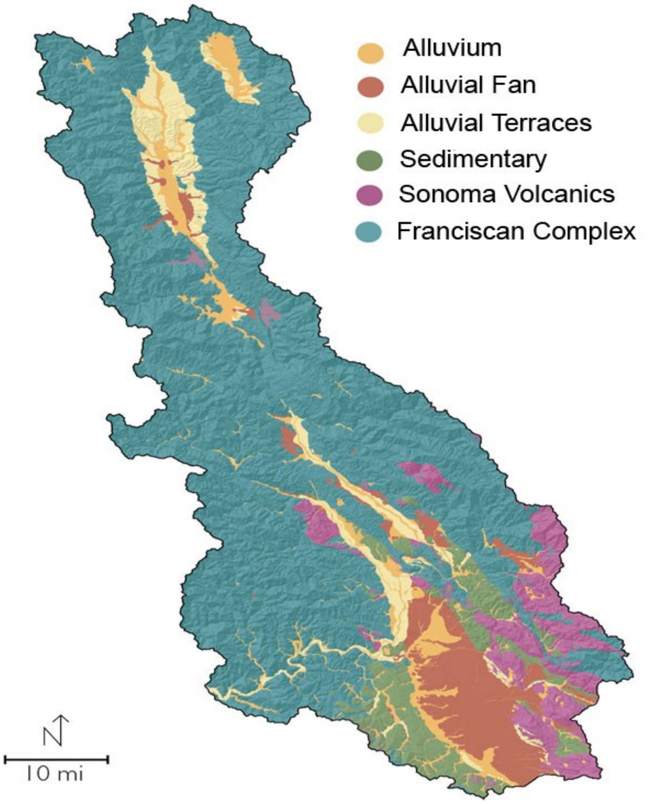



**Figure 3. Generalized geologic formations of the Russian River watershed. From: Blake et al. 2002, Graymer et al. 2007.**

Through tectonic movements of the North American and Pacific Plates, these two rock types were folded, faulted and metamorphosed along the plate boundaries. Eventually, the rocks were uplifted to form the Northern California Coastal Ranges including the Russian River basin. These rocks are low permeability; wells drilled in these rock types have very low production rates of 1-10 gallons per minute (gpm). One of the other major rock types is the Sonoma Volcanics, deposited during a period of active volcanism 8 to 2.5 million years ago. Wells in this formation can be highly productive in the 100 gpm range. More recently as the uplifted mountain and volcanic strata were eroded various sedimentary formations deposited including the Glen Ellen, Huichica, Wilson Grove, Petaluma Formations and Sand and Gravel of Cotati. Several of these, particularly Wilson Grove, can have highly productive wells.

**Climate**

The climate of Northern California is also distinctive – hot and dry in summer and mild and wet in winter, termed a Mediterranean climate. Precipitation is primarily rainfall with large winter storm events called atmospheric rivers transporting water vapor from the tropics into California. Average annual rainfall for the entire watershed is 42 inches, but varies greatly with topography. Coastal mountains have annual rainfall totals as high as 80 inches, whereas southern portions of the watershed have only 22 inches per year. Summer temperatures average 80-90$^{o}$ F, but drop rapidly at night.

**Geomorphology**

The Russian River channel continues to adjust to natural geologic and climatic changes, land uses in its watershed as well as to direct alterations to its floodplain and channel. The dependent variables that mutually adjust in a river channel are depth, slope, velocity and roughness. When the independent variables of flow volume, or sediment supply, change from climate events (large floods), geologic events (earthquakes, landslides) or human actions, the dependent variables all adjust. For example, a decrease in sediment supply due to the construction of an on-stream dam causes an increase in channel width or depth leading to bed and bank erosion as the channel adjusts to a lower sediment supply. These adjustments will continue until a relative dynamic equilibrium is reached between the work done (sediment transported) and the load provided (sediment provided to the stream by tributaries and hill slopes).

Prior to the development of its watershed, the Russian River channel was in a state of relative dynamic equilibrium. Historic photographs show a wide, shallow channel form. Due to reduced sediment supply from large on-stream reservoirs, gravel mining, channelization and urbanization, the river channel is highly entrenched. It is likely the river channel will continue to adjust for many decades to re-establish an equilibrium condition.

**Hydrology and Groundwater**

The Russian River flows 110 miles from its headwaters in Mendocino County to the ocean. There are 43 major tributaries with the largest being the West Fork of the Russian River, Big Sulphur, Maacama, Dry, Austin, and Mark West Creeks. Stream flow in the tributaries is affected by a number of features: geology, rainfall intensity, slope, the saturation of soils, vegetative cover, and land use as well as the size and operation of diversions, reservoirs and the location and amount of groundwater pumping. Each tributary has a unique combination of these features.

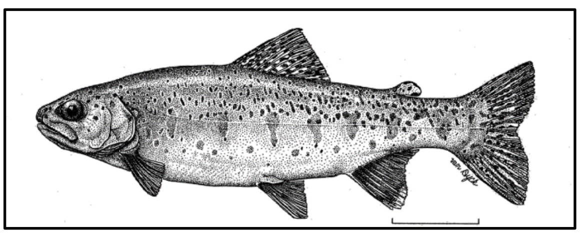
Alluvial deposits in the major river valleys form the predominant water bearing units in the Russian River basin, although several other formations also have productive aquifers. During the fall/early winter runoff from hill slopes and creeks will infiltrate into the alluvium recharging the groundwater. The groundwater level rises to intersect stream channels in the valleys and stream flow occurs. Stream flow will continue after a storm event has ended as groundwater drains from the alluvium into the creek and river channel. The geomorphology of the channel plays a major role in this process.

Exchanges between groundwater and surface water are common near streams overlying alluvial aquifer systems. While these exchanges are known to occur in areas of the Russian River watershed, no comprehensive study has mapped where and when such exchanges occur.

**<u>Salmonids</u>**

The Russian River supports three federally-listed threatened or endangered species – Chinook and Coho salmon and steelhead trout. All three species are anadromous meaning they spawn, lay eggs, incubate, hatch and rear in freshwater streams, then descend into estuaries and the ocean to feed and mature into large adults. The adults remain in the ocean for a number of years before returning to their natal streams to spawn.

Salmonids are cold water fish preferring water in the low 60s$^{o}$ F. Fish do not have the ability to regulate their body temperature as mammals do. If the water is warm, the fish is warm. Water temperature is a major limiting factor for salmonids in the Russian River. Water temperature affects salmonids in a number of ways. In cold water adults can migrate at maximum speed, rearing juveniles can grow at the fastest rate if food sources are adequate and out-migrating juveniles can out swim warm water predatory fish. Warmer water slows down salmonids and becomes lethal at 75-80 ° F.



During the summer, the primary source of cold water in tributaries is groundwater seeping into creeks or moving through the hyporheic zone between pools in gravel streambeds. Dense streamside canopy, is needed to block sunlight, create cool air temperatures at the water surface and prevent heat transfer to the water.

Chinook salmon enter the river the earliest in September to December and primarily spawn in the main stem river and lowest reaches of large tributaries. Juveniles emerge and swim to the estuary where they feed, get larger and leave for the ocean before summer heat sets in. Coho salmon enter the river in November to January for spawning and rear in tributaries with very cold water (<60$^{o}$ F). Currently, Coho salmon occur in only a few tributary creeks, primarily located in the southern portion of the basin. Steelhead trout migrate from January to April to spawn and are distributed throughout the Russian River watershed. Steelhead can withstand higher temperatures than Coho, but still require cold water at less than 70$^{o}$ F.

## <u>CONCEPTUAL MODEL OF STREAM FLOW PROCESSES</u>

The Russian River basin's distinctive feature – large alluvial valleys with large groundwater basins and smaller alluvial deposits along creeks, can provide cool groundwater to streams for salmonid habitat. The interaction of surface and groundwater in creek and river channels is an essential process for sustaining salmonid rearing habitat. The ISRP Conceptual Model focuses on defining channel types in the basin by the extent of the surface and groundwater interactions occurring. The term "groundwater" is used to mean all water existing below the water table and in the zone of saturation, or any water pumped from a well regardless of the proximity to streams. However water from collector wells is considered surface water.

### <u>Principles of Surface and Groundwater Interactions</u>

The interactions of surface and groundwater are governed in large part by the physical geological environment and the climate. Topography, soils and the physical characteristics of rock formations affect how water passes through the watershed, and into either the groundwater aquifer, or into streams as surface flow. In some stream reaches, surface water may infiltrate into alluvial aquifers ("losing reaches"), while in other stream reaches groundwater may discharge from an alluvial aquifer into the stream ("gaining reaches"). On a seasonal basis, or due to drought or high rainfall conditions, a stream reach may change from losing to gaining and back over the course of the year.

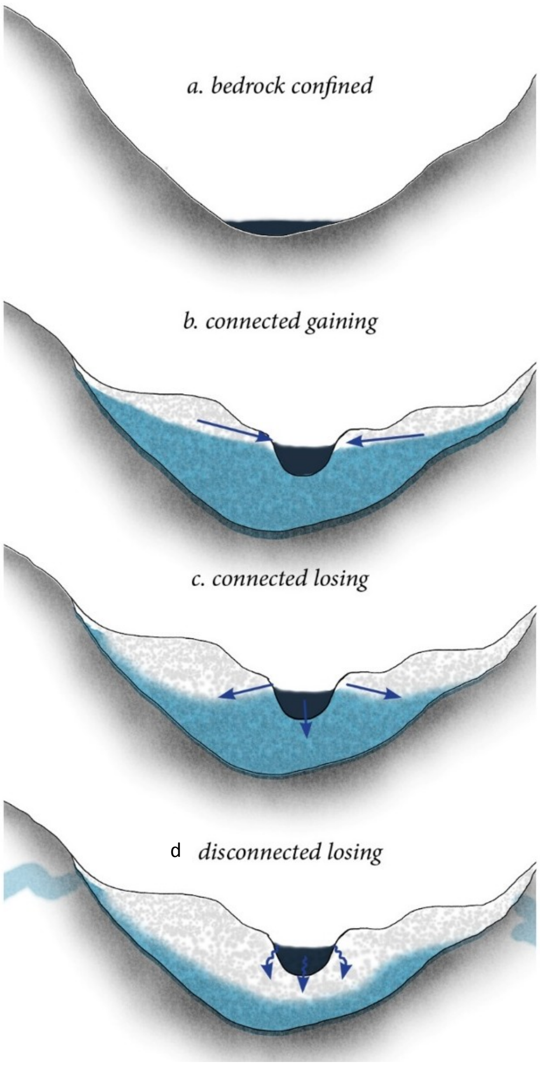



**Figure 4. Fundamentals of surface and groundwater interactions.**

On a landscape scale, surface and groundwater interactions are influenced by channel confinement, channel slope, channel complexity and geomorphic setting. In bedrock channels infiltration of surface water into the substrate is minimal, whereas in alluvial reaches water can flow partially to completely subsurface. Additionally under natural conditions, the thickness and permeability of alluvial deposits, the permeability of underlying bedrock layers and the annual rainfall/groundwater recharge will determine if summer pools persist in a stream. Bedrock layers of low permeability, such as Franciscan Complex, or Great Valley Sequence, may not discharge enough water to saturate thicker alluvial deposits whereas formations such as the Sonoma Volcanics that have higher permeability will saturate alluvial deposits and maintain summer pools. The extent of riparian shade canopy and magnitude and location of water extractions also play a major part in determining if summer pools persist. Many streams in the Russian River basin become "longitudinally disconnected" during the dry season with a series of wet/dry reaches, or may become completely dry. "Vertical connectivity" refers to the connection between surface water and the saturated zone (Figure 4).

**<u>Channel Typology</u>**

The ISRP typology focuses on surface and groundwater interactions and differences in this process based upon geomorphology, channel confinement, stream hydrology and geology. The typology encompasses a hydrological continuum by which water moves from headwaters to the ocean (Figure 5). Along this pathway surface water will infiltrate into porous alluvial substrates and emerge at impermeable bedrock channels. The ISRP typology defines eight distinct channel types based upon depth and type of alluvial deposits and the degree of natural channel confinement. Colluvial, bedrock, and alluvial substrate types are distinguished due to differences in permeability and hydraulic conductivity, or the capacity to transmit water. Alluvial streams are further classified by the degree to which the stream is constrained by bedrock both laterally and vertically. Gaging records were analyzed to evaluate the seasonality of stream flow. Then the typology was applied to fish-bearing streams as defined by NMFS, in the 8 subareas that the ISRP evaluated in detail. Figure 6 is an example of the typology applied to one of the subareas.

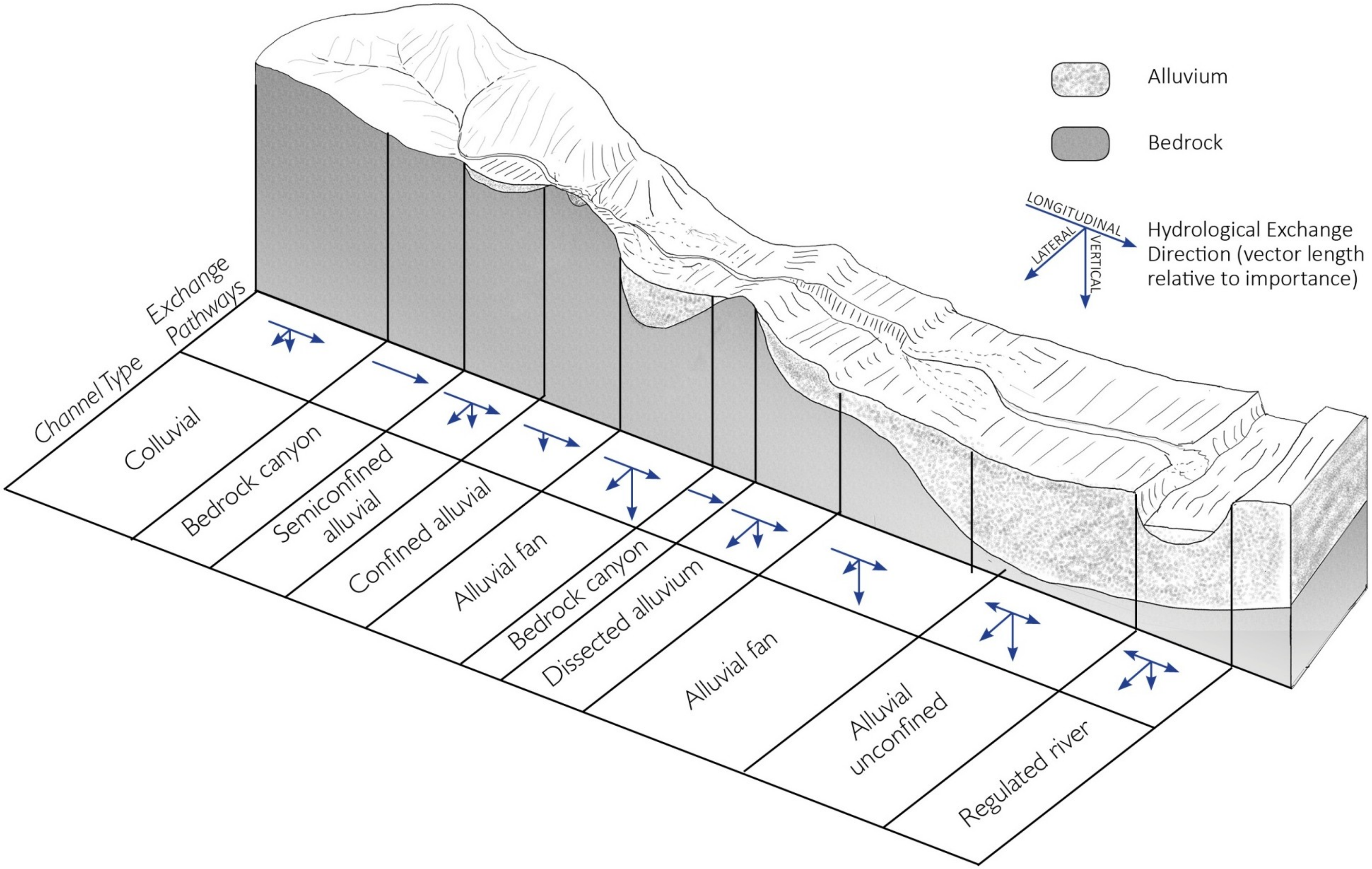



**Figure 5. Generalized diagram of surface-groundwater interactions relating to geomorphic setting for eight channel types. Arrows indicate the direction of water flow. From: Walls 2013.**

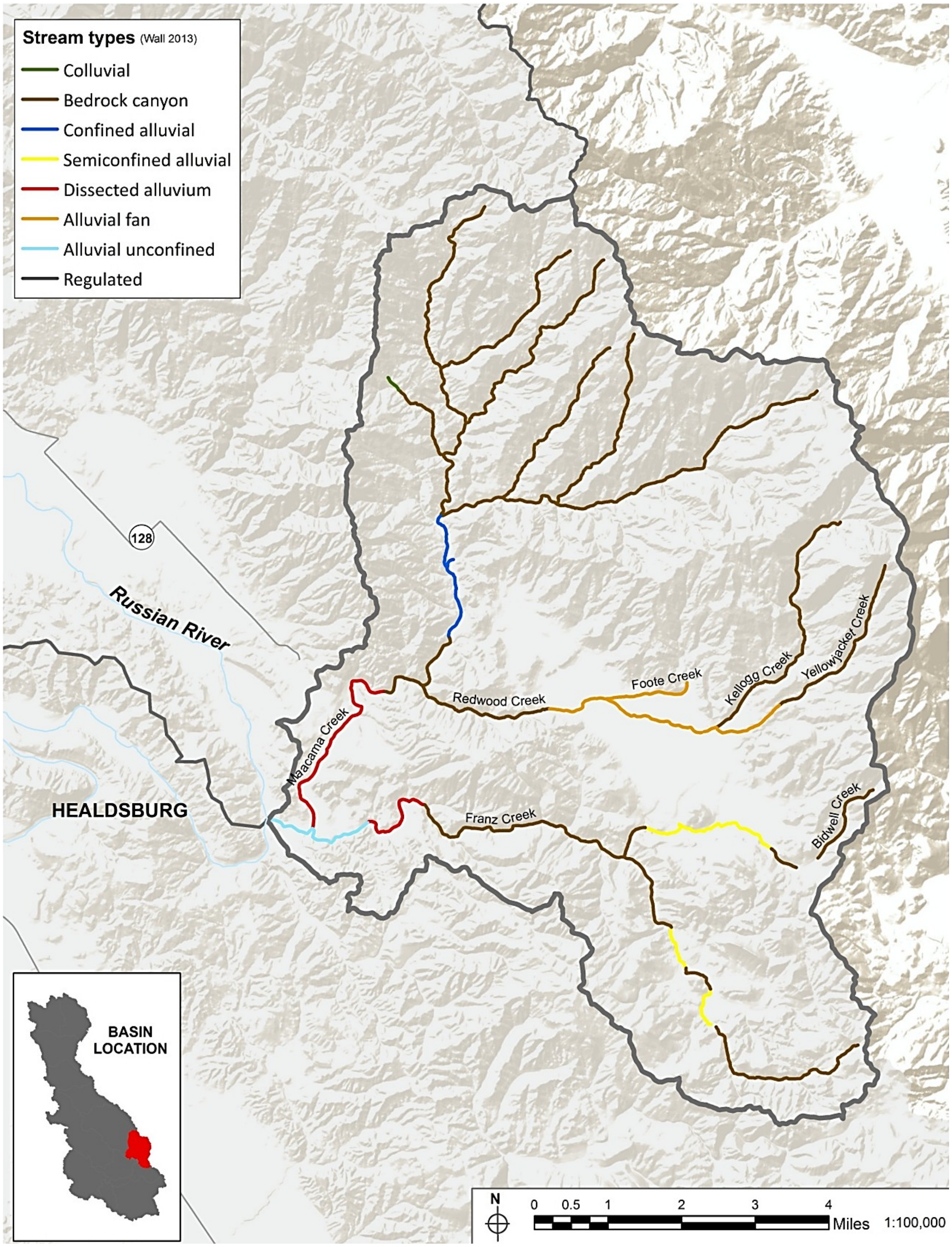



**Figure 6. Example of the application of the channel typology to fish-bearing streams in one of the eight subareas. See full report for additional maps.**

**Colluvial Channels**
Colluvial channels (COL) are streams flowing over and through unconsolidated hill slope material, or colluvium, and are located in the headwaters of drainage networks. Stream flow in colluvial channels is governed by saturation overland flow during the wet season and groundwater seepage, rather than by deeper groundwater sources. Three stream gages show ephemeral (short-lived), or intermittent flow. In the Russian River very few colluvial channels support salmonids; however, these channels support native amphibians and aquatic insects. First order headwaters streams, often colluvial channels, typically make up 50-80% of the total length of a stream network and provide a significant contribution to the total water yield of the basin. On-stream reservoirs are the primary water developments in colluvial channels.

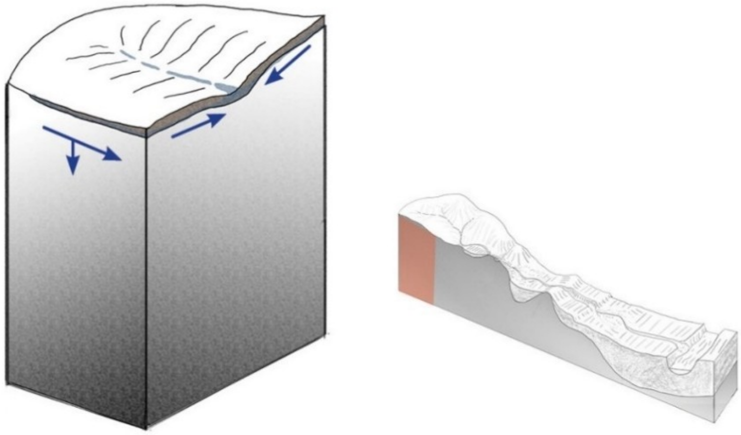


**Figure 7. Conceptual diagram of a colluvial channel. Example of colluvial stream channel, Frasier Creek tributary to Big Sulphur Creek**

**Bedrock Canyon Channels**
Bedrock canyon (BRK) reaches located in the mountains of the watershed are characterized by moderate to high channel slopes (1-8%), confinement by steep hill slopes and exposed bedrock at, or just below, the streambed. There is little or no overbank or in-channel alluvium storage. In the Russian River drainage, six stream flow gages in these channels showed year round flow most years except in droughts. In late summer when there may no longer be longitudinal flow, isolated pools often remain. Bedrock is relatively impermeable preventing infiltration of water. Fractures and fissures in the bedrock may also deliver water to the channel. The majority of CDFW biological inventories of juvenile steelhead trout were done in bedrock streams demonstrating the use of these channels for steelhead rearing. Human land uses are limited by the steep topography of these channels; however, rural residences may be numerous with direct diversions and shallow wells affecting flows as occurs in Mark West Creek. On-stream dams, or direct diversions to off-stream reservoirs can affect flows. Illegal diversions for marijuana cultivation may also reduce summer flows.

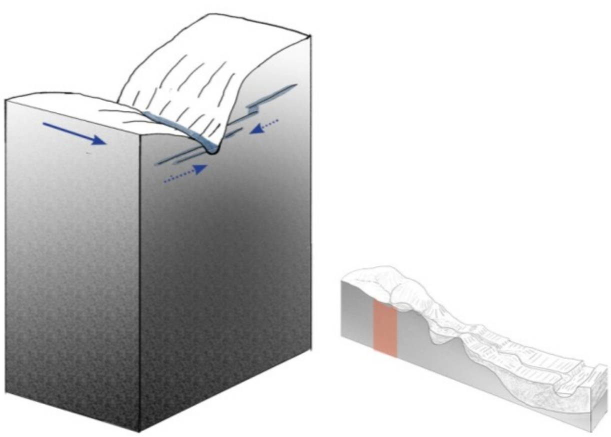


**Figure 8. Conceptual diagram of a bedrock canyon channel. Bedrock reach of Mark West Creek.**

**Confined Alluvial Channels**
Confined alluvial (CON) reaches are constrained by valley walls, but have lower gradients than bedrock channels at 1% to 4% slope. Sediment supply exceeds transport capacity and these channels have gravel bars, but no floodplains. Pools and riffles may also occur with water going subsurface at the riffle head and re-emerging at the riffle tail and into the pool. Six gaging records occur in these channels; the majority show year round flow and two have very short-term records showing summer dry conditions.

Salmonids may use these channels for spawning and rearing, and may move to nearby bedrock channels with more consistent flow for summer rearing. With no floodplains in this channel type, human uses consist of rural residential, roads along the creek, on-stream dams, or direct diversions into off-stream reservoirs. Roads can cause partial to complete channelization and loss of riparian vegetation. These impacts can reduce habitat quality for salmonids.

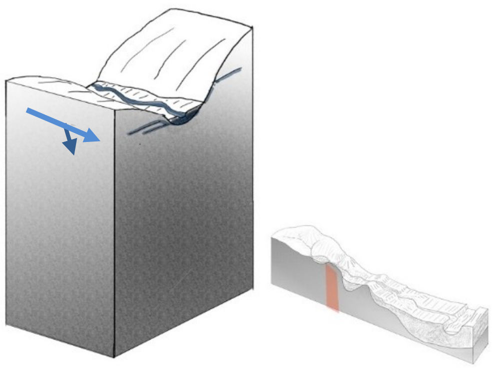


**Figure 9. Conceptual diagram of confined alluvial channel. Confined alluvial channel in Big Sulphur Creek.**

**Semiconfined Alluvial Channels**
Alluvial reaches with clearly developed floodplains, but where one bank is constrained by a valley wall are classified as semiconfined alluvial channels (SEM). This channel type is found where pull-apart fault activity forms depressions allowing for deposition of alluvium, or near the confluence of the stream with the Russian River. This channel type has slopes of 1%-4%. Semiconfined channels may have pool-riffle morphology similar to confined alluvial channels as well as braiding, secondary channels and floodplain sloughs and wetlands. Groundwater will interact with surface flows in both the vertical and lateral directions. Six stream flow gages show year round flow, but some smaller streams went intermittent for one to two months per year. As with confined alluvial channels salmonids may use semiconfined alluvial channels for spawning and rearing, but may move to bedrock channels with more consistent flow for summer rearing.

Most of the floodplains adjacent to these channels are developed for agriculture, or housing. Water developments such as direct diversions and shallow wells can affect fish habitats. Use of off-stream storage with winter diversions can greatly reduce impacts.

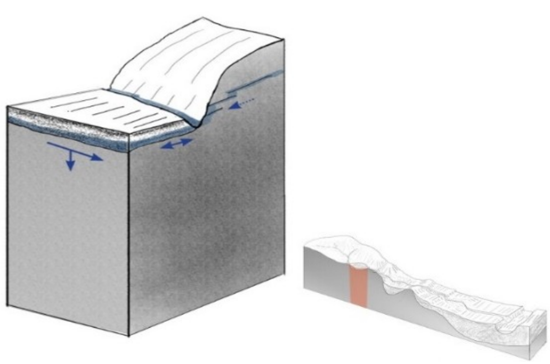


**Figure 10. Conceptual diagram of semiconfined alluvial channel. Semiconfined alluvial channel of Feliz Creek.**

**Dissected Alluvium Channels**

Dissected alluvium channels (DIS) are incised into older Pleistocene-era alluvium termed Loosely Consolidated Deposits. This older alluvium is limited in distribution, consists of high amounts of clay, and creates channels with very tall, competent banks. Channel slopes vary between 1% and 4%. Depending upon the depth and composition of the alluvium, flow may be subsurface during the summer, or perennial if the channel has eroded to bedrock. Stream gage data is limited to three sites and shows years of perennial flow and years with summer dry conditions. If flows are year round, salmonids may spawn and rear in these channels.

Human uses include agriculture and housing. On-steam reservoirs and direct diversions affect fish habitats. Wells in Loosely Consolidated Deposits are typically low production and inadequate for agriculture, but may be adequate for houses.

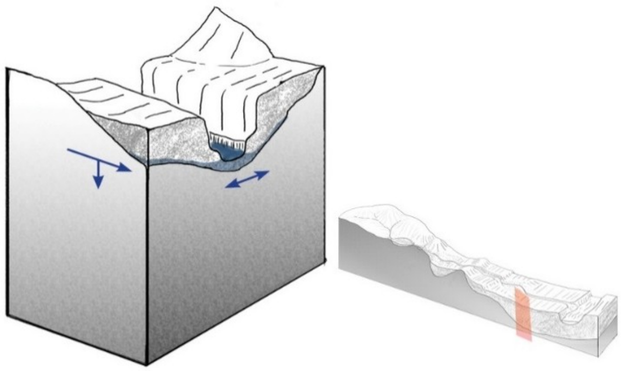


**Figure 11. Conceptual diagram of dissected alluvium channel. Dissected alluvium bank along the West Fork of the Russian River.**

**Alluvial Fan Channels**

Alluvial fans (FAN) are cone, or fan-shaped, deposits that form at the transition between a high slope bedrock channel and the valley floor. Braided, or multi-channeled, systems are common on fans with channel migration over the fan during large flow events. Alluvial fans are found throughout the major alluvial valleys and in the tributary creek valleys. Alluvial fan channels are typically steeper than other alluvial channels at 2%-4% slope. Alluvial fans are made up of boulders, cobble and gravel. Water flowing over the fan infiltrates and is often completely subsurface. Surface water emerges at the base of the fan forming wetlands, or in river flow. Three stream flow gages show seasonally-dry conditions and dry conditions between winter storms.

Alluvial fans do not provide suitable habitat for salmonid spawning and rearing. Intermittent fan channels may limit adult and juvenile migrations between the main river and bedrock channels in the mountains. Rapid dewatering of fan channels may strand fish. Many fans are used for farming and are managed to have a single channel

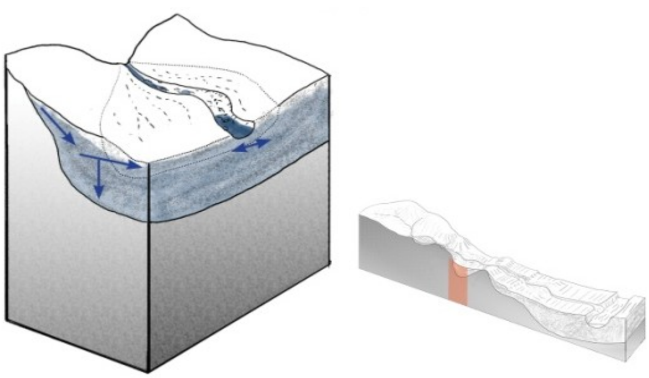


**Figure 12. Conceptual diagram of alluvial fan channel. Alluvial fan channel of Morrison Creek.**

**Unconfined Alluvial Channels**

Streams crossing the floor of the alluvial valleys between the mountains and the river are unconfined alluvial channels (UNC). Historically these less than 1% slope channels meandered over the valley floor creating floodplains through over bank deposition and periodically formed new channels through avulsion events. Side channels, oxbows and wetlands likely occurred on the floodplains of these channels. Unconfined alluvial channels would have had pool/riffle morphology. The alluvial valleys along the Russian River once likely had high groundwater levels in late winter and spring; unconfined alluvial streams were gaining reaches during these seasons. Over the dry season, these channels would have been losing streams and likely intermittent to dry. Currently with significant incision of the main river channel and associated lowered groundwater levels, unconfined alluvial channels are now dry for long periods of the year and may become intermittent between storms in the winter. These conditions can strand salmonids and limit the period of flow for migration of adults and juveniles between the river and mountain creeks. There are no stream flow gaging records in unconfined alluvial channels. Unconfined alluvial streams are the most highly modified stream types. Many have been straightened, confined between levees and cleared of vegetation removing the fluvial processes needed for the creation and maintenance of stream habitats including pools, riffles and floodplains.

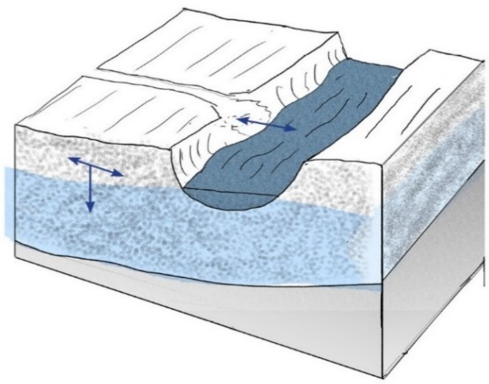


**Figure 13. Conceptual diagram of unconfined alluvial channel. Unconfined alluvial channel of Sausal Creek.**

**Regulated channel**

Regulated channels (REG) consist of the Russian River below Coyote Dam and Dry Creek below Warm Springs Dam. The low slope (<1%) Russian River channel is primarily unconfined alluvial and would have historically meandered, and had a frequently inundated floodplain with side channels, sloughs and wetlands. Currently the Russian River channel in its alluvial valleys is highly incised (18-20 ft.) and narrow. The summer groundwater level has dropped to meet the lowered elevation of the incised river bed. Historic USGS records show the river had groundwater-fed pools connected by low surface flows, and was wide and shallow. In dry years, the river was dry. With the development of the Potter Valley Project and Coyote Dam, dry season releases changed the river to primarily warm water habitat.

**Figure 14. Regulated river channel of the Russian River with Coyote dam and Lake Mendocino. Channel erosion along the highly incised Russian River channel.**

| Channel Type | Size of Alluvial Deposit | Channel Slope Classes (%) | Months of Continuous Stream Flow from Gaging Records | Water Temperature in Summer | Types of Human Use | Resiliency to Drought | Effects of Main Stem Stage Fluctuations | Vulner-ability to Bank Erosion |
|---|---|---|---|---|---|---|---|---|
| Colluvial (COL) | None | >8 | <6 | Dry soon after rain. | On-stream dams | Dry most of the time--no resiliency | N/A | Medium |
| Bedrock Canyon (BRK) | None | 0-1, 1-2, 2-4, 4-8, >8 | 12 | Cool when groundwater fed and has riparian canopy | On-stream dams, direct diversions, wells for agriculture and rural residential uses. | High | N/A | Low |
| Confined Alluvial (CON) | Small | 0-1, 1-2, 2-4 | 6-12 | Cool when groundwater fed, sensitive to riparian canopy | On-stream dams, direct diversions to off-stream storage for agriculture and residential uses | Moderate | Low | Low |
| Semi-confined Alluvial (SEM) | Medium | 0-1, 1-2, 2-4 | 10-12 | Cool when groundwater fed, sensitive to canopy cover and pool depth | Direct diversions, wells in floodplain, floodplain development, direct diversion into off-stream ponds for agriculture or housing. | Moderate, depends on alluvial deposit thickness | Vulnerable if no grade control at confluence with main stem. | Medium |
| Dissected Alluvium (DIS) | Medium | 0-1, 1-2, 2-4 | 8-12 | Variable temperatures sensitive to surface water/groundwater interactions and riparian canopy | On-stream reservoirs, direct diversions to off-stream storage, wells in floodplain for agriculture and housing. | Variable | Low | Medium |
| Alluvial Fan (FAN) | medium or large | 0-1, 1-2, 2-4 | 5-9 | Warm, poorly shaded, does not support riparian corridor, has oak savannah | Wells, winter direct diversion into off-stream storage for agriculture. | Low | Vulnerable | High |
| Un-confined Alluvial (UNC) | Large | 0-1 | No gages, 3-12 estimated | Variable temperatures, sensitive to surface water/groundwater interactions and riparian canopy. | Most extreme effects – gravel mining, channelization, wells, on-stream reservoirs, direct diversions into off-stream reservoirs, floodplain development for agriculture and housing. | Low, depends on location relative to regulated channel | Very vulnerable | High |
| Regulated (REG) | small, medium, or large | 0-1 | 12 | Warm | Most extreme effects – gravel mining, channelization, wells, floodplain development, large on-stream reservoir. | High | N/A | High |

**Table 1. Geomorphic and hydrological characteristics of stream channel types.**

| Species | Timing | Habitat Requirements: Channel Slope, Flow Conditions, Complexity of Channel | Colluvial | Bedrock | Confined alluvial | Semiconfined alluvial | Alluvial fan | Dissected alluvium | Unconfined alluvial | Regulated |
|---|---|---|---|---|---|---|---|---|---|---|
| **Adult Migration** | | | | | | | | | | |
| Chinook | Sept-Dec | 0-1%; sufficient stream flow and depth | | | | | | | | |
| Coho | Nov-Jan | 0-3%; sufficient stream flow and depth | | | | | | | | |
| Steelhead | Jan-Apr | 0-4%; sufficient stream flow and depth | | | | | | | | |
| **Spawning and Egg Incubation** | | | | | | | | | | |
| Chinook | Oct-Feb | 0-1%; PR; intragravel flow; high DO; low fines; little scour | | | | | | | | |
| Coho | Nov-Mar | 1-3%; PR, FPR; intragravel flow; high DO; low fines; little scour | | | | | | | | |
| Steelhead | Jan-May | 1-4%; FPR, PB, SP; intragravel flow; high DO; low fines; little scour | | | | | | | | |
| **Rearing: Spring-Summer-Fall** | | | | | | | | | | |
| Chinook | Dec-May | low velocity margins; floodplain; cover; food supply | | | | | | | | |
| Coho | Feb-Dec | perennial flow; large woody debris; cool temps; cover; food supply | | | | | | | | |
| Steelhead | Mar-Dec | perennial flow or isolated pools; cool temps; cover; food supply | | | | | | | | |
| **Rearing: Winter** | | | | | | | | | | |
| Chinook | - | N/A | | | | | | | | |
| Coho | Dec-Mar | large woody debris; flow refugia: floodplains, alcoves, backwater | | | | | | | | |
| Steelhead | Dec-Mar | flow refugia: unembedded substrate, cobble, boulder | | | | | | | | |
| **Smolt Outmigration** | | | | | | | | | | |
| Chinook | Mar-Jun | sufficient flow and depth | | | | | | | | |
| Coho | Mar-Jun | sufficient flow and depth | | | | | | | | |
| Steelhead | Apr-July | sufficient flow and depth | | | | | | | | |

**Table 2. Those channel types that are expected to consistently satisfy salmonid habitat requirements are indicated in black; channel types that may satisfy habitat requirements depending on local conditions are indicated in grey; channel types that are not expected to satisfy habitat requirements are white.**

## EFFECTS OF HUMAN DEVELOPMENTS

It is important to understand historical stream flow conditions in the Russian River and its tributaries as it is these conditions that salmonids are adapted to. Additionally many of the past changes to the river, creeks or watershed continue to affect the system and fish habitats. The full ISRP report includes detailed descriptions of historical conditions and developments in the watershed and each of the eight watershed subareas.

### Historical Conditions

We can speculate on the pre-development conditions of the Russian River based on historical journals, photographs and maps as well as USGS measurements. The Russian River once had a wide and shallow channel which meandered over the floodplain in its alluvial valleys. Side channels, sloughs and backwaters, riparian forest and wetlands likely marked the floodplains. The river channel was wide and held islands of riparian forest. Runoff from the hillslopes would recharge the groundwater and fill the floodplain sloughs and wetlands; creeks and the river would have risen slowly until all of this water storage area was filled. In summer there were groundwater filled pools in the river; discharge measurements show a small trickle of flow between pools. Some of the USGS measurements show dry tributary channels and an 1851 journal describes a completely dry river channel during a year with below average rainfall.

Tributary streams in the valleys may have had pools over the summer in some locations, but were also noted as dry in several source documents. Bedrock creeks and alluvial creeks of various levels of confinement would have had year round flow in many locations.

### Development of the Watershed

The river floodplains were developed for agricultural uses such as fruit orchards and dairies beginning in the late 1800s. Once Coyote Dam was built in 1959 and the river was channelized in the 1960s, agriculture expanded on the floodplains. As of 2014, there were 61,000 acres of vineyard on the floodplains and hillsides of the watershed along with 6,260 acres of pear and apple orchards, and 10,700 acres of irrigated pasture. Timber harvesting and burning cleared land for grazing and later development of vineyards.

Gravel mining in the Russian River watershed intensified in the 1960s. In some locations the channel was lowered more than 50 feet. Starting in 1968, gravel pits were dug 50 to 80 feet deep in the floodplain of the Russian River Valley. Over a nine year period from 1981-90 a total of 10 million tons of gravel was extracted from river and creek channels and over 24 million tons of gravel was extracted from floodplain pits in Sonoma County. Gravel mining in Mendocino County occurred in the river channel, numerous creek channels and more recently floodplain pits.

Human population in the watershed increased from 65,000 in 1950 to over 400,000 in 2015. The City of Santa Rosa

**Figure 15. Left: Russian River and the Perkins Street bridge in the Ukiah Valley subarea. Note the wide shallow river channel. Right: Stage crosses Russian River in Alexander Valley subarea.**

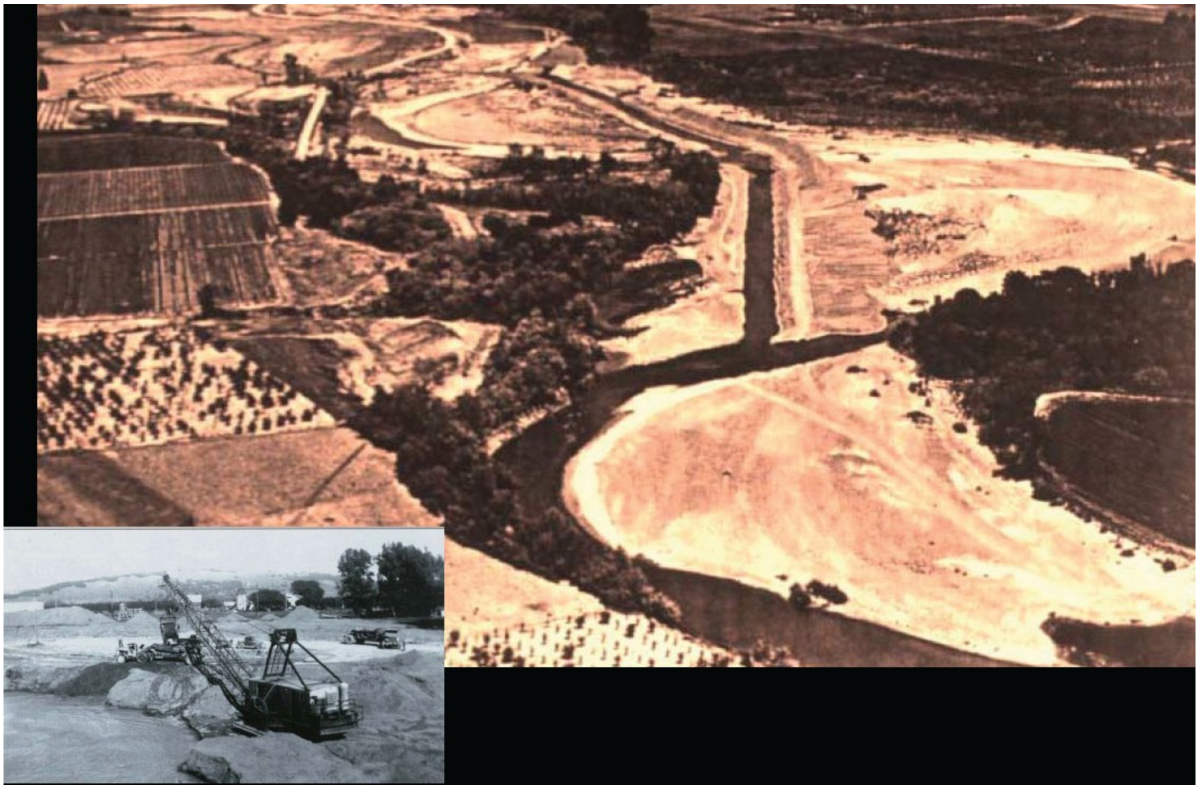


**Figure 16. Clearing and dredging of the Russian River channel in the 1950s, aerial photograph looking downstream from Healdsburg.**

expanded to cover 41.5 square miles or 26,560 acres. Rural residential land uses have also expanded, particularly in western Sonoma County.

<u>Water Development</u>
Water was needed for both urban and agricultural expansion. The first major change in the hydrology of the Russian River occurred in 1908 with the construction of the Potter Valley Project that diverts water from the main stem Eel River into the East Fork of the Russian River to generate hydropower. In 1922 Lake Pillsbury was constructed to provide a year round diversion through the tunnel. Between 1922 and 1983 the Potter Valley Project diverted 154,000 acre-feet (AF) per year. Re-licensing of the project in 2002 reduced the diversion to an average of 72,000 AF per year.

In 1959, the Army Corps of Engineers (USACE) constructed the Coyote Dam across the East Fork of the Russian River to create Lake Mendocino for water supply, flood control, and recreation. Lake Mendocino impounds water diverted from the Eel River as well as East Fork flows. Coyote Dam is operated primarily for flood control in winter by holding back releases as the storm moves through, then releases water at up to 6,500 cfs for several days to a week to reduce the reservoir level and maintain space to hold the next major storm.

In the dry season, Coyote Dam releases water primarily for urban supply to the Sonoma County Water Agency (SCWA) collection wells at Mirabel in the Lower River Canyon subarea. The SCWA provides water to Sonoma County cities and out of basin transfers to Southern Sonoma and Marin Counties. In 1982 the Army Corps of Engineers built the Warm Springs Dam on Dry Creek in Sonoma County.

Approximately 2,500 small reservoirs and diversions are scattered throughout the Russian River watershed. In general, agricultural lands and rural residential sites have individual water rights rather than a water district. The exception is the Mendocino County Russian River Flood Control and Water Conservation District (RRFC) which holds rights to 8,000 AF in Lake Mendocino. This water is delivered to diverters along 14 miles of the Russian River through releases from the

**Figure 17. Small creek dammed to supply water for illegal diversion for marijuana growing. From: Giusti 2010.**

Coyote Dam. Direct diversions of surface water into off-stream ponds, and on-stream reservoirs are permitted as appropriative water rights by the State Water Resources Control Board (SWRCB). Water use under riparian diversions and appropriative rights is reported to the SWRCB annually. Use of groundwater for agricultural or rural residential uses is not currently regulated or reported. The 2015 Sustainable Groundwater Management Act (SGMA) will require preparation of sustainable groundwater management plans for the two medium priority groundwater basins, the Redwood Valley/Ukiah Valley basin and the Santa Rosa Plain basin. Illegal diversions for marijuana cultivations are widespread and believed to be negatively impacting salmonid rearing habitats. Marijuana has its greatest water demand in late summer/early fall when stream flow is lowest.

**Channel Clearing and Stabilization**

As the Russian River developed many streams were modified. The 1930-50s period saw several government agencies initiate programs to change creek and river channels. The Soil Conservation Service (now the Natural Resource Conservation Service) recommended the use of car frames, or entire car bodies for bank stabilization. The U.S. Army Corps of Engineers implemented the Russian River Channel Improvement Project between 1956 and 1963. This project dredged a pilot river channel through reaches of the river in the Ukiah, Hopland and Alexander Valleys (Figure 18). Bulldozers removed gravel bars, large wood, vegetation and islands, and changed the meandering channel into a fairly straight, trapezoidal channel. Flood flows move faster in this constructed channel, causing more channel erosion. Numerous bank revetments were also installed along the channel to stabilize the banks including lines of metal jacks, flexible fencing, or wire mesh.

Landowners also used bulldozers to straighten stream channels, particularly unconfined alluvial and alluvial fan channels, to make the channel narrow and make more land available for farming. Urban development frequently changed natural creeks into large pipes.

**Fish Management**

Salmonid populations in the Russian River system have been significantly affected by watershed development. There are no population records for any of the three species prior to major harvests of the fish for canneries in the 1880s and planting of hatchery stock. Coho salmon and steelhead trout are well documented as occurring in the system; Chinook salmon may not have been native to the Russian River.

Between 1872 and 1995, six Chinook, five Coho and seven steelhead stocks were introduced into the Russian River from other basins for total plantings of 30 million hatchery-reared steelhead, 8 million Chinook salmon and 2.1 million Coho salmon. The planting of out-of-basin salmonid stocks caused a loss of genetic diversity with reduced fitness of each population to adapt to changing conditions, displacement of native stocks, disease and competition of native fish with hatchery fish.

During the 1950s, rotenone was used to poison all the fish in some tributaries and then hatchery salmonids were planted to increase sport fishing. Follow-up evaluations, completed from 1960-63, found native sucker and minnow species had returned to most reaches of the tributaries with steelhead trout found in the bedrock channels.

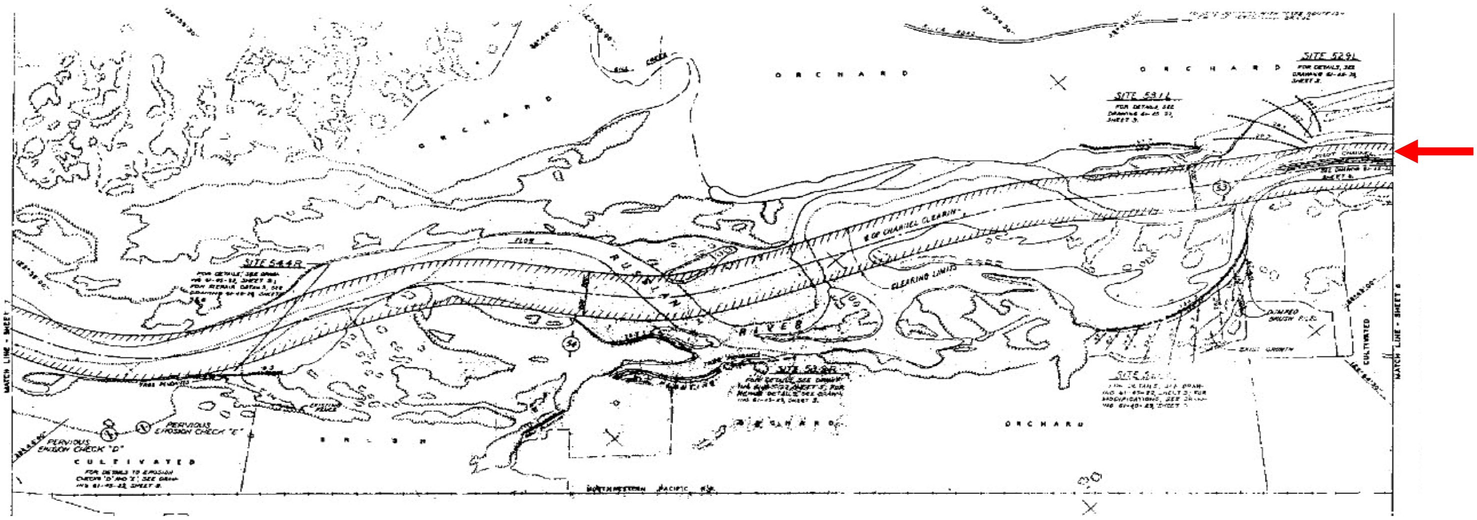


**Figure 18. Design drawing of Army Corps of Engineers' Russian River Channel Improvement Project Pilot Channel (see arrow) drawn over the natural meandering river channel and riparian corridor. This project removed significant fish and wildlife habitat and channelized the river. From USACE 1965b**

**<u>Ongoing Efforts to Restore the System</u>**

There are a number of efforts to restore salmonid habitat in the Russian River watershed. These efforts include:

- Biological Opinion (BO) for Water Supply, Flood Control and Channel Maintenance required reductions of dry season releases from Coyote Dam, studies of the effects of flood season releases on the erosion of the Russian River channel, restoration of habitats on Dry Creek and other actions. While the restoration actions and dry season flow reductions have progressed, the USACE has not completed the studies of the effects of Coyote Dam flood operations on the Russian River.
- Endangered Species Recovery Plans. A recovery plan for Coho salmon was released in 2012. A recovery plan for Chinook salmon and steelhead trout was released in November 2015. Both of these plans outline extensive actions needed by numerous land uses to recover these species.
- Russian River Coho Salmon Captive Broodstock Program. This program raises Coho salmon for release into the wild. PIT (passive integrated transponders) are placed in a percentage of the Coho for tracking fish movements.
- California Department of Fish and Wildlife (CDFW) administers the Fisheries Restoration Grant Program. Completed projects are outlined on the website wildlife.ca.gov/Grants/FRGP.
- Sonoma County Water Agency (SCWA) is leading the effort outlined in the BO to restore salmonid habitats on six miles of Dry Creek.
- A number of organizations implement restoration projects including Russian Riverkeeper, Trout Unlimited, Resource Conservation Districts, and the California Land Stewardship Institute (Fish Friendly Farming Program).
- Agricultural Water Enhancement Program. a project of the Natural Resource Conservation Service (NRCS) and the California Land Stewardship Institute, worked with grapegrowers to construct over $7.5 million in off-stream ponds to reduce direct diversions for frost control. The NRCS also funds erosion control, irrigation management and habitat improvement projects on agricultural lands.
- Russian River Habitat Blueprint. The National Oceanic Atmospheric Administration (NOAA) selected the Russian River as a Habitat Focus Area. A selection of NOAA agencies is working with local agencies and organizations on six different projects/studies.

Development of the Russian River watershed has had the following effects:

**Main Stem River**

- Lake Mendocino and the Potter Valley Project provide substantial benefits for people including: municipal and agricultural water supply, flood control, recreation and dry season cold water releases to the Upper Russian River.

- Coyote Dam retains the sediment supply needed by the Russian River to maintain an equilibrium channel and the Russian River has been channelized and mined for gravel. Consequently, the river has eroded down into its alluvial floodplain and is significantly entrenched (18-20 ft.).
- Industrial gravel mining of the river channel downstream of Healdsburg in the Russian River Valley has contributed to significant entrenchment (18-20 ft.) of the river channel.
- The Russian River channel in the Alexander Valley is less entrenched (~12 ft.) than upstream or downstream reaches, but still lacks complex aquatic habitats.
- Between 1956-1963 the Army Corps of Engineers completed the Russian River Channel Improvement Project that implemented 635 acres of vegetation clearing, 210,000 cubic yards of channel excavation, installation of 10.8 miles of jacklines, 4.4 miles of flexible fence, 2.0 miles of willow planting with wire mesh and 11.3 miles of willow only planting. These actions contributed to the entrenchment of the river channel, conversion of floodplain habitats to human uses and the direct removal of complex aquatic habitats and riparian forest.
- Entrenchment of the main stem river prevents floodplain inundation resulting in higher velocity flows in the channel causing channel erosion, loss of instream fish habitat, bank erosion, loss of riparian forest and creation of channel geometry that does not support regeneration of the riparian and aquatic ecosystem. Natural adjustment of the channel and recovery of dynamic equilibrium in the Russian River channel could require hundreds of years.
- Surveys of the river channel show a small level of recovery in a few locations, but the channel in all its alluvial reaches is still entrenched and out of equilibrium.
- Channel entrenchment lowers the groundwater level in the alluvial unconfined aquifers in the valleys adjacent to the river. This drop in groundwater level can affect the duration of stream flow in the unconfined alluvial creeks on the valley floor.
- Dry season hydrology of the Russian River was first changed by the Potter Valley Project and later by releases from Lake Mendocino. The East Fork Russian River had flows of 2-3 cfs in the summer prior to 1908. Early gaging data for the West Fork and main stem Russian River indicate very low flows with isolated pools and hyporheic flows in the Redwood, Ukiah, Hopland and Alexander Valleys. Cold groundwater would have filled these pools and may have supported native fishes including salmonids. In dry years historic accounts describe a river channel that was dry in the Mendocino portion of the river and had isolated pools in Alexander Valley. Currently, with simplified geometry and augmented flows, the river provides limited habitat for salmonids.
- Through channelization projects and floodplain development, the oxbow marshes, slough channels, riparian forest and off-channel habitats that once occurred on the Russian River floodplain in its valley reaches were developed for agricultural, urban and rural residential uses.
- Coho salmon and steelhead trout historically occurred in the Russian River. Coho and steelhead use tributary streams and, if cold oxygenated water was present, would have used the main stem river for spawning and rearing.
- The Environmental Protection Agency has listed the Russian River under the Clean Water Act as impaired by excessive fine sediment and high water temperatures.
- The complex and dynamic fluvial habitats of the main stem river likely supported very different aquatic biodiversity and community structure than in the present-day river, but little reliable historical data is available. In recent years the main stem and the largest tributaries have supported a Chinook salmon population, but this species was not necessarily a large component of the historical ecosystem.

**Tributaries**

- The entrenchment of the main stem river channel drops the base level of the stream network causing backcutting up alluvial creeks until a hard point such as a culvert or bedrock is reached. This process deepens and narrows the tributary channels eroding out instream habitat and riparian forest.
- Backcutting up tributaries affects infrastructure including bridges, sewer and water lines, and other utilities.

- Salmonid migration barriers are created when entrenchment causes the tributary to deepen downstream of the hard point. Removing the culvert will temporarily provide salmonid access upstream, but allows the backcutting to continue past the hard point to the rest of the alluvial channel eventually creating another barrier at the next hard point.
- The entrenchment of the main stem river affects groundwater levels in the adjacent valley alluvium and in the unconfined alluvial creeks in the valley. The lower base level of the river causes tributaries to go subsurface before reaching the river in the Ukiah/Hopland Valley likely affecting salmonid migrations in the spring. Changes in river stage from reservoir releases may increase this effect.
- Developments in tributary watersheds such as water diversions, agricultural and rural residential development, creek channelization, logging and urbanization have altered watershed processes and creeks reducing salmonid habitats and contributing to channel incision.
- Coyote Valley Dam and Warm Springs Dam inundated and blocked access to 86 to 169 miles of spawning and rearing habitat (Steiner 1996). However, reservoir releases benefit Chinook salmon using the main stem, Coho salmon in Dry Creek and steelhead trout below Coyote Dam.
- Rotenone was used in tributary streams in the 1960s to kill "rough" fish so hatchery trout could be planted in tributaries. Follow up studies found that the rough fish returned with steelhead primarily living in bedrock channels and native warm water fish living in downstream alluvial channels. The results of this experiment indicate the natural distribution of native fish in the system.
- Salmonid populations in the Russian River have been significantly affected by widespread and long-term planting of hatchery salmon and steelhead trout between 1872 to 1995.
- Urbanization has completely removed miles of salmonid habitat from use due to the permanent nature of roads, houses and infrastructure adjacent to the creek channels. NMFS terms urban creeks as "non-recoverable".
- Although historical data on the abundance of aquatic life is virtually nonexistent, the limited records suggest that the lower basin tributaries once supported a native fish assemblage including a large Coho salmon population. This population dropped to <100 adult fish in the late 2000s. The upper basin tributaries historically supported an intact native fish community including abundant steelhead, although population levels for historical and present-day populations are unknown.
- The main stem river and its network of tributary creeks are one system which transports water and sediment from headwaters to the ocean. Management actions for the main stem should not be considered separately from the tributary system.
- There are numerous efforts occurring in the Russian River watershed to restore stream habitats, remove migration barriers, change water management and reduce fine sediment levels all to support and recover salmonids.

**Figure 19. Flood in 1940 on Russian River at Healdsburg with peak flow of 67,000 cfs. This flood caused $2,935,000 in damage ($50 million in 2016 dollars) and inundated over 29,000 acres.**

**Figure 20. Failure of 20 ft. tall bank along the Russian River channel in the Ukiah Valley in the winter of 1997. The gravel bar likely was formed from the collapsed bank.**

**DATA SOURCES AND DATA GAPS**

A matrix of the available sources of scientific information was created for the Russian River watershed.
Table A lists the available sources of data for a range of subjects, the information/measurements that have not yet been completed, termed data gaps, and recommended studies. Monitoring protocols are listed for each subject in the full ISRP report. The report and table are available at [http://www.russianriverisrp.org](http://www.russianriverisrp.org).

**Figure 21. Coho Salmon adults in the Russian River**

## RECOMMENDATIONS

The ISRP recommends several different types of actions:

- A whole system approach is needed and all areas of the Russian River watershed require the detailed review completed for eight subareas by this report. The remaining five subareas should also be evaluated.
- Prioritized studies to fill major data gaps.
- Development of a numerical model of the watershed that uses the recommended monitoring data, simulates surface and groundwater interactions and can be used to evaluate effects of changes in water use and can be used with salmonid data to prioritize restoration actions.
- Development of economic incentives to change water management.
- Restoration recommendations for each channel type.

### Major Findings and Prioritized Data Collection

The following section identifies major data gaps, which limit our ability to prioritize tributary streams, or reaches of streams, that need water management, or restoration actions. Filling the data gaps will require incremental improvements by monitoring up to 5 tributaries at a time, coordinating monitoring with agency efforts, coordinating with modeling efforts and using established monitoring protocols. The ISRP recognizes that addressing the data gaps will take time and funding, but has prioritized data needs to make monitoring efforts the most cost-effective.

Tributary streams are the focus for the monitoring and information development. This first round of monitoring would address five tributaries. We recommend Forsythe, Feliz, Maacama, Mark West and Green Valley Creeks. The monitoring data would be used in the numeric model. The model outcomes would be used to define and prioritize stream restoration and water management projects. It is likely to be more cost-effective to have an academic institution conduct the monitoring in partnership with nonprofit organizations that can arrange access to private lands and work with landowners. Agency personnel would also be welcomed. This first round of monitoring and modeling should be done in conjunction with an advisory group made of government agencies, landowners and community groups. Another five tributaries would then be identified for monitoring and modeling. All new monitoring should be coordinated with ongoing monitoring efforts.

We also recommend a collaborative groundwater monitoring program begin in the Redwood/Ukiah Valley aquifer. This basin has been ranked as a medium priority and it is in the interest of the landowners in the basin to develop this information. This information can be used to evaluate the effect of changes in river stage on groundwater level.

### Aquatic Communities

There is very little comprehensive ecological data on the aquatic communities in the Russian River and its tributaries. For the major tributaries, the current data cannot be used to determine the priority creek reaches for salmonids, identify problems and improve habitats. For steelhead trout, although listed as threatened not endangered, there have been few studies and no population estimates.

Existing studies primarily consist of single-day qualitative habitat surveys of creeks, one-time collection of benthic macro-invertebrates, or juvenile salmonids, often without adequate field data to determine the location of the sampling. The main stem river has been studied in greater detail with annual spawner studies in certain locations since 2002. One long-term study (Merritt Smith Consulting 2003) reviewed 7 creeks and seined fish twice a year. On several of these creeks a variety of reaches were sampled, and the best rearing habitats were determined. Survivorship in each sampled reach over a number of years was analyzed allowing for the effects of environmental factors to be evaluated. This study found years with spring rain to have the best survivorship for steelhead while dry years resulted in poor juvenile survival. In Green Valley Creek and other Coho streams sophisticated PIT tag technology tracks fish released from the Broodstock Program. Carcass/spawner surveys and snorkel surveys for juveniles are also done. Fish survival was studied with monitoring of stream flow, water temperature and dissolved oxygen in 2010, a fairly wet year. The conclusion of the study was, while no habitat units in Green Valley Creek dried out, a seasonal reduction in dissolved oxygen in pools limited survivorship of Coho salmon. Dissolved oxygen is a function of both water temperature and water turbulence and thus the level of stream flow. This study of both fish habitat and physical features of the habitat provides the greatest insight into what human actions need to be changed to create sustainable salmonid habitat over the long term. Other native fish, amphibians, aquatic insects are largely unstudied despite the ecological relationships juvenile salmonids have to food sources (aquatic insect nymphs) and predators (pike minnow).

The questions aquatic community studies need to answer include:

- What is the assemblage and abundance of native fish and aquatic life in each tributary?
- What channel types in each tributary provide rearing habitat for salmonids, spawning habitat and migratory corridors?
- What are the primary physical habitat features limiting survivorship in different channel types in various tributaries?

To adequately characterize aquatic communities a coordinated, comprehensive, adaptive, and consistent biological research program covering the entire watershed is needed. This program should be coordinated (i.e. not piecemeal) and consider the whole watershed. It should be comprehensive, in that it includes multiple taxonomic groups of aquatic biota (fish, amphibians, reptiles, invertebrates), and that it focuses on both community and population level interactions. It should be adaptive, in that as more information is acquired and we gain a greater understanding of the watershed, the program will evolve to ask and answer new questions and address changing watershed conditions.

The first phase should include a study examining the distribution of aquatic biota across all major tributaries and main stem reaches. A second phase would then establish a series of long-term ecological monitoring sites to better understand population and community dynamics of target species. Finally, the program should be consistent, and use established and repeatable methodologies that are tailored to this system and the research questions under scrutiny.

The goal of the first phase of this program is to understand the distribution of aquatic organisms across the watershed. For fish the program could use the EPA Rapid Bioassessment Protocol (Barbour et al. 1999). This protocol has the advantages that it can be used in most streams and it is an efficient way to rapidly survey fish biodiversity. Phase two of the program will require a consistent method of examining target populations and life stages to determine population dynamics. The Coastal Monitoring Program (Adams et al. 2001) has been used in the Russian River Coho salmon streams and may be applied to steelhead streams in the near future. The Coastal Monitoring Program, if augmented to survey for all fish species, would be a good method to systematically collect biological data over a broad geographic area. Ideally this program would be coordinated with the recommended stream flow gaging, groundwater monitoring, and the use of the channel typology to gain a thorough understanding of aquatic habitat conditions and stressors.

For stream invertebrates, we recommend a sampling methodology that will rapidly sample each major habitat type present in a sampling reach and provide for the collection of representative specimens. Additionally some limited sampling of adult aquatic insects (often necessary for species level determinations) will be needed through use of emergence, pan, or light traps.

A rough estimate for the initial number of sampling locations needed to develop an understanding of aquatic species distributions throughout the watershed is approximately 150. This would provide for sampling the main stem river and 3-5 sites in every major tributary stream. Sites would be located on all channel types in the stream typology, and would include the full range of stream habitats and flow regimes, including intermittent streams.

**Groundwater**

There is monitoring well data from the Ca. Department of Water Resources (CASGEM) program that measures groundwater levels in the spring and fall. Some of these well records date to the 1970s, but the number of measurements per year limits the use of the data. There are some well done USGS groundwater studies in the Russian River basin (Niskikawa 2013, Farrar 1986, Metzger et al. 2006, Cardwell 1965). Another study (Jackson and Marcus

2004) documented changes in shallow groundwater levels with changes in river stage in the entrenched river channel and dewatering of valley tributaries in the Ukiah/Hopland subareas. The new Sustainable Groundwater Management Act (SGMA) will require additional groundwater monitoring in medium and high priority basins including Redwood/Ukiah Valley. As of 2016, the USGS is working with the State Water Resources Control Board and SCWA to create a GSFLOW model of the main stem Russian River and some tributaries. These models have to be calibrated with high quality data to produce realistic and useful results. Current data does not characterize surface and groundwater interactions, the effects of groundwater withdrawals, or the effects of river stage on groundwater levels in the alluvial valleys.

The questions new groundwater monitoring needs to answer include:

- In selected alluvial channel types (semiconfined, confined, unconfined alluvial and dissected alluvium) how do groundwater levels change over the seasons, with changes in surface flow and with groundwater extraction?
- In the alluvial valleys (Redwood, Ukiah, Hopland and Alexander) how does the groundwater table change with changes in flow in the entrenched Russian River channel? How does surface flow in unconfined alluvial tributaries on the valley floor change with changes in flow in the Russian River channel?
- In the alluvial valleys, do dry season releases from Lake Mendocino recharge the groundwater level in the adjacent valley?

For the valley aquifers in Redwood/Ukiah, Hopland and Alexander Valleys, a series of 30-40 existing wells/valley distributed over each valley need to be identified for installation of continuous monitoring pressure transducers. The selection of wells should also take into account the depth and use of the well. Supply wells can be used as long as detailed pumping records are maintained. Since the primary interest is in the interaction of surface and groundwater, the unconfined aquifers in the Quaternary Alluvium should be the primary location for selected wells. The depth of the Quaternary Alluvium varies by location in each valley; evaluation of drilling log information would provide an indication of alluvial depth and thereby guide well selection. Each well included in the network needs to be surveyed to a benchmark of known elevation so the data from different wells can be compared. Data can be collected on hourly intervals. The depth of the screens in each well needs to be documented. For the alluvial channel types (confined alluvial, semiconfined alluvial, unconfined alluvial, dissected alluvium and alluvial fan) in each subarea one, or more, existing wells should be monitored using pressure transducers.

**Stream Flow**

Compared to many watersheds, the Russian River basin has numerous stream flow gages. The main stem river channel is the primary focus of stream gaging efforts, but a few tributaries also have gages. Additional gaging is needed to characterize flows in tributaries particularly in bedrock channels important for steelhead rearing. The alluvial channel types (confined, semiconfined, unconfined alluvial and dissected alluvium) in various tributaries should be gaged for a few years to determine flow patterns and determine if dry, or intermittent, conditions are due to water diversions, or natural processes.

The questions stream flow gaging needs to answer include:

- In tributaries nested systems of stream flow gages can be used to detect the effect of diversions and determine if there are serious impacts to flow and at what season.
- Tributary gaging can be coordinated with groundwater monitoring to determine if changes in water use could improve flow conditions.
- Due to the expense of stream flow gaging, only 5 tributaries would be gaged at one time. This gaging should be coordinated with local gaging efforts under the State Water Board’s Frost Regulation.

With the variation in geology and topography in each tributary, gaging is needed in all major creeks to characterize stream flows. Stream flow gaging should include continuous measurement of the stage of the stream with a pressure transducer, or similar instrument, as well as completion of discharge measurements at various flow levels near each gage. Both types of data, continuous stage measurement and discharge measurements, are needed to determine stream flows in cubic feet per second (cfs), the most common unit in hydrology. Developing complete hydrologic data sets allows for analysis of the effects of water diversions. Stream flow is difficult to measure accurately. Choosing a good location for a gage is the most important step. A fairly straight reach of channel with no major tributaries, a stable hydraulic control downstream that creates a suitable pool in which to place the gage are needed. The reach should be fairly stable so that scour and deposition at the control, and thus fluctuations of the gage pool, are minimized. Flow measurements are made at a nearby cross section with conditions most favorable for accurate measurement of discharge, typically a different location from that chosen for the gage. The recording gage should also have an "outside staff gage" from which stage can be manually read which provides a quality check on the readings of the pressure transducer.

**Climate Change**

Climate change predictions for the Russian River indicate fewer, but more intense, storm events and longer droughts. Temperatures will increase leading to less frost, but hotter conditions in the summer. These changes will not likely improve cold water habitats and could result in few creeks and areas of the Russian River remaining suitable for salmonid rearing (Moyle et al. 2013, Wenger et al. 2011).

The questions important to answer for future climate change studies include:

- What will future water temperatures be in specific tributary locations under various climate change scenarios? Can we prioritize restoration efforts in tributaries where cold water may be more prevalent?
- How will increased future water demands for urban, rural residential and agricultural land use fare under predicted future climate scenarios? Will there be adequate flows for human uses and fish and aquatic life?

**Water Demand and Use**

Water supply in the Russian River is largely distributed over numerous private parcels and diverted as surface, or groundwater. Lake Mendocino provides a large centralized water supply for municipalities in Sonoma County and some agricultural areas in Mendocino County. In the tributaries, water may be stored from winter runoff in off-stream, or on-stream, reservoirs largely for agricultural uses, or be diverted from groundwater, or creeks, for domestic uses. Most of these diversions are not metered, or reported, so actual water demand in a particular tributary basin cannot be determined without collaboration with users; only land use based demand estimates can be made and these are often higher than actual use numbers.

Records of water use for permitted appropriative and riparian rights are reported to the State Water Resources Control Board, but our analysis found incomplete reporting records. Another law (Senate Bill 88) was passed in 2015 and requires additional measurement and reporting beginning in January 2017. All diverters of 10 AF or more per year have to install and maintain a device on their diversion that monitors the rate and quantity of diverted water. The interval for measurements varies with the amount of water diverted. These changes should provide improved data on permitted surface water diversions.

Groundwater is diverted from the aquifers in the Ukiah, Hopland and Alexander Valleys for municipal, domestic, and agricultural uses and may affect river flow levels. Groundwater diversions are currently not reported, or required to be metered, so this portion of total water use cannot be documented. As the Sustainable Groundwater Management Act (SGMA) is implemented a reporting system may be developed for some of the medium priority groundwater basins in the Russian River watershed (Redwood/Ukiah Valleys, Santa Rosa Plain).

Rural residential water use is not reported. Recently the SWRCB implemented reporting requirements for rural residents in the Mark West, Dutch Bill, Mill and Green Valley Creek watersheds. This reporting could provide the information needed to more accurately calculate water demand numbers basin-wide for this land use.
By their nature, illegal diversions for marijuana cultivation are not reported and few have water rights. According to a study by CDFW marijuana uses 7-14 times more water than winegrapes. The largest demand for water for marijuana is during the driest period of the year. Because of this timing, use of water for marijuana production may have the largest

effect on rearing salmonids in tributaries. The 2015 Medical Marijuana Regulation and Safety Act regulates many aspects of the production of medical marijuana and is a start towards addressing this illegal use of water. However there are also marijuana plantations that are not associated with medical marijuana. An estimate of water demand for marijuana growing is needed to identify causes of impairment in tributary streams. A combination of remote sensing to detect growing areas and stream flow gaging may be able to quantify impacts of water diversions for marijuana.

The questions important to answer for future water demand and use include:

- What are the volumes of surface water and groundwater used by each type of diverter (vineyards, marijuana, rural residential, municipal) as well as the timing, volume and locations of diversions?
- How are these volumes likely to change with forecasted increases in population or changes in crops grown in the watershed?

**Geomorphology**

The geomorphic changes in the main stem Russian River have been significant with up to 20 ft. of channel entrenchment. There have not been any channel topographic surveys in the Upper Russian River for many years. The analysis completed to determine the effects of flood operations on salmonid habitat in the Upper Russian River for the Biological Opinion (BO) completed no channel measurements and used 30-year old cross sections to develop a hydraulic model of the river. This report came to highly questionable conclusions regarding geomorphic processes in the Upper Russian River.

The questions geomorphic surveys and analyses need to answer include:

- How much and where has the main stem river channel aggraded (built-up) or degraded (downcut) since the last survey was done?
- Predicted climate change will result in fewer, but more intensive large storm events, which will initiate further adjustments in the river channel. It is expected that these storms will generate greater volumes of sediment and flood flows. Is the incision process continuing and at what rate under changed climate conditions?
- How are tributary streams in the alluvial valleys adjusting to the incision of the main stem?
- Using a hydraulic model calibrated with up-to-date geomorphic data analyze the effects of Coyote Dam flood releases on channel erosion and geomorphology under numerous different flow scenarios.

A topographic survey of the river channel would allow for comparisons with the 1990s and earlier topographic data to evaluate the ongoing entrenchment of the channel. If possible, the locations of previously surveyed cross sections should be re-occupied so the two data sets can be directly compared. The cross sections should be 500 feet apart or less, capture topographic details of the channel from top of bank to top of bank and be tied to an established benchmark. Major tributary channels should also be included to monitor the upstream propagation of incision into the tributaries and effects on infrastructure.

**<u>Development of a Numerical Model of the Watershed</u>**

The limited stream flow and groundwater monitoring data, water use data as well as the lack of salmonid population and distribution data severely limits identification of priority streams for salmonids and of needed water management actions. For example, the significance of a dry channel, or intermittent pools, cannot be determined if we do not know what areas of the tributary salmonids use for rearing. If the one reach of good rearing habitat dries up, this would be a significant problem. But if that reach is a migration corridor where water is only needed in the winter and spring, a summer dry channel is not a problem for salmonids.

In California’s Mediterranean climate seasonally-dry channels are a natural part of the watershed and not necessarily the result of water diversions. The channel typology developed by the ISRP provides a system to define where summer stream flows are likely to occur. A bedrock channel is likely to have flow in the summer while an alluvial fan, or valley unconfined alluvial channel are likely to be dry. The suggested stream flow and groundwater monitoring of confined alluvial, semiconfined alluvial, dissected alluvium channels in various tributaries can further define summer time flow locations and allow for the effect of water diversions to be determined.

The development of the conceptual model of stream flow presented here provides a basis for the development of a quantitative numeric model. The ISRP strongly recommends the development of a physically-based, numeric hydrologic model capable of simulating surface water/groundwater interactions coupled with a rainfall-runoff model to simulate stream flow processes in the Russian River basin. A numeric model has to be calibrated with stream flow gaging data, stream channel topographic data and groundwater level data and can use the typology developed by the ISRP. The numeric model can be developed in stages as data are collected for each tributary. As the model is developed, more detail for each tributary can be added. Through the calibration process any additional data gaps can be identified. After calibration the model would be capable of evaluating the effects of surface/groundwater diversions, or the effects on stream flow, groundwater elevations and water temperatures of various restoration concepts. In addition in the Mendocino County portion of the Russian River the relationship of river stage to tributary stream flow/groundwater levels needs to be evaluated. This information could be used to refine reservoir operations and coordinate connected flows for smolt outmigration. The model could also evaluate the downscaled climate change data to determine the locations of critical future changes in water availability.

The development of a numeric model should be coordinated with other models in the watershed especially for standardizing data inputs. In 2016, the USGS began working with the State Water Resources Control Board and Sonoma County Water Agency to develop a GSFLOW model of the main stem Russian River from the Potter Valley Project to the ocean. Some tributary basins will also be included. Currently there is a Basin Characterization Model developed by the USGS and SCWA and a Research Distributed Hydrologic Model (RDHM) developed by the NOAA National Weather Service Office of Hydrologic Development. The GSFLOW model simulates surface and groundwater interactions. All models require accurate monitoring data for calibration in order to produce realistic and useful results.

The numeric model can evaluate changes from Lake Mendocino and various diversions of surface and groundwater in the adjacent valleys if groundwater diversion data can be collected. This would provide a basis for improved coordination of diversions in dry years.

The aquatic communities studies can be used with the model to determine how best to preserve critical rearing habitat from the effects of surface and groundwater diversions. The numeric model can also be used to determine where unaccounted for diversions, such as those for marijuana plantations, are occurring.

The development of the numeric model should include a stakeholder group made up of agricultural, rural residential, municipal, and environmental interests to assure understanding and acceptance of the results. Under SGMA, a Groundwater Sustainability Agency has to prepare a plan for the Redwood/Ukiah Valley groundwater basin. A varied stakeholder group could inform both the numeric model and SGMA process.

**Economic Incentives**

Management of water issues within the basin will inevitably involve tradeoffs. Economic information can provide guidance on the nature and efficacy of tradeoffs by identifying least cost alternatives to meet a given goal or objective. Facilitating changes in user behavior necessary to achieve these alternatives can be enhanced through use of economic incentives that encourage such changes in behavior. Subsidies are commonly used to encourage changes in private behavior and are widely used in environmental regulation. Within the Russian River basin subsidies may be effective in some settings, such as construction of off-stream water storage facilities for use in frost protection. Use of public funds to voluntarily change private behavior is justified when the benefits that accrue to society exceed the costs of alternative approaches to obtain a desired outcome.

An economic mechanism that is specifically aimed at water issues is the creation of water markets. Water markets have been used widely to facilitate alternative water allocations in the arid west. Water markets have the advantage of being voluntary exchanges between sellers of water and potential buyers, usually a public agency. There is a large literature on the necessary conditions to implement a water market, but in general such markets tend to work best when water rights are well defined, water can be easily moved throughout the system and the value of water varies spatially. The State of California has employed forms of water markets to address drought by moving water from the northern portions of the state to areas of higher demand in the south via the state's extensive system of canals, dams, diversions and other infrastructure.

With the decentralized water supply system in the Russian River water may be stored in one location and be needed in another location for instream flows. For example, conserving water in cities reduces the water demand from Lake Mendocino or Lake Sonoma, but will not directly benefit steelhead trout rearing in a bedrock channel in a tributary. However, water markets may be possible within the tributaries. Specifically, if additional water is needed in a tributary stream for fishery benefits, there may be a diverter who would voluntarily sell/supply the needed water from ponds or a well. The price of such water would be negotiated by the seller and the public agency. The water must be sufficiently cold for salmonids, so groundwater wells could be the best source. Currently there is no system for trading or selling water within the Russian River basin. The numerical model will be essential in determining how to set up a Russian River water market.

A variant on water markets is creation of temporary water markets. Temporary water markets tend to encourage wider participation because a seller does not permanently lose his/her water right. Under certain conditions, these temporary water markets have been effective in obtaining water for instream flows during critical drought periods. Such temporary markets have been created in the California Delta, in the Klamath Basin in southern Oregon and northern California. Similar examples have occurred in the Deschutes and John Day River basins of Oregon. Where and when water markets may be used in the Russian River basin can be informed by the conceptual model developed in this report and the proposed numeric model. Use of these and other incentive-based mechanisms should be encouraged.

**Restoration Recommendations**

Table 3 outlines restoration recommendations for each channel type. For most channel types there will be a need to analyze the current water use with the numerical model to determine the best method for changing water use if needed.

**Table 3. Restoration recommendations by channel type**

| Chanel Type | Months of continuous flow from gaging records | Salmonid use | Human developments | Restoration recommendations |
|---|---|---|---|---|
| Colluvial | <6 | Low to no use, important to aquatic invertebrates | Housing and hillside vineyards, on-stream reservoirs | Design developments to infiltrate storm water, maintain creeks fully vegetated to reduce channel erosion and sediment into downstream habitats |
| Bedrock canyon | 12 | Spawning, egg incubation, rearing, adult and smolt migration | On-stream reservoirs, diversions into off-stream reservoirs, near channel wells and direct diversions for rural residential, illegal diversions for marijuana production | Protect existing habitat quality, revise summertime direct diversions to winter only with storage. Revegetate stream banks with native trees. Remove migration barriers. Possibly install large wood in channel. Artificial instream structures are not recommended. |
| Confined alluvial | 6-12 | Spawning, egg incubation, rearing, adult and smolt migration | On-stream reservoirs, diversions into off-stream reservoirs, near channel wells and direct diversions for rural production | Check depth of screens in wells, need to be screened in deeper bedrock to avoid affecting stream flow. Revise summertime diversions to winter only with storage. Revegetate stream banks with native trees. Remove migration barriers. Possibly install large wood in channel. Artificial instream structures are not recommended. |
| Semiconfined alluvial | 10-12 | Spawning, egg incubation, rearing, adult and smolt migration | Wells in floodplain, floodplain development, direct diversions and diversion into off stream storage | Wells and direct diversions may need to be changed to avoid dewatering stream habitats. Numeric model can be used to evaluate surface and groundwater interactions and determine action to coordinate/change diversions. Revegetate stream banks with native trees. Remove migration barriers. Possibly install large wood in channel. If channel is incised bank setbacks and grade control may be needed. Artificial instream structures are not recommended. |
| Dissected alluvium | 8-12 | Spawning, egg incubation, rearing, adult and smolt migration | On-stream reservoirs, direct diversions into off-stream reservoirs, wells | Wells and direct diversions may need to be changed to avoid dewatering stream habitats. Numeric model can be used to evaluate surface and groundwater interactions and determine actions to coordinate/change diversions. Revegetate stream banks with native trees. Remove migration barriers. Possibly install large wood in channel. If channel is incised bank setbacks and grade control may be needed. Artificial instream structures are not recommended. |

**Table 3. Restoration recommendations by channel type (cont.)**

| Chanel Type | Months of continuous flow from gaging records | Salmonid use | Human developments | Restoration recommendations |
|---|---|---|---|---|
| Alluvial fan | 5-9 | Adult and smolt migration | Wells, direct diversions into off stream reservoirs | Naturally dry water levels can be affected by main stem river flow stage. Revegetate with oak savannah. Remove migration barriers. Artificial instream structures are not recommended. |
| Unconfined alluvial | 3-6 estimated, no gage records | Adult and smolt migration, spawning and rearing in limited locations | Highly altered from gravel mining, channelization, flood plain development, on-stream reservoirs, direct diversion into off-stream reservoirs, wells | Flow affected by incision of main stem river and lowered groundwater levels. Evaluate effects of diversions and wells and lowered groundwater levels in alluvial valleys using numerical model. Revegetate stream banks with native trees. Remove migration barriers. Possibly install large wood in channel. If channel is incised bank setbacks and grade control may be needed. Artificial instream structures are not recommended. |
| Regulated river | 12 | Adult and smolt migration, spawning and rearing in limited locations | Highly changed by large on-stream reservoirs, gravel mining, channelization, floodplain development, wells | Two reaches of the Russian River have restoration potential for salmonids. Just downstream of Coyote Dam extending to where summer water temperatures exceed 70°F. Restoration should evaluate surface and groundwater interactions, widening river channel and riparian corridor through work with willing landowners, augmentation of gravel.<br>Narrows reach of Russian River also has cold water.<br>Need evaluation of river stage and groundwater levels in alluvial valleys and unconfined alluvial tributaries with numeric model in order to coordinate flows for salmonid migrations.<br>Manage the remaining reaches of the Russian River to improve riparian habitats, warm water aquatic habitats and for winter and spring spawning and rearing for Chinook salmon.<br>Minimize gravel mining in river channel as channel is already highly entrenched and sediment starved. |