California Coastal Watershed Planning and Assessment Program Introduction and Overview

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California Coastal Watershed Planning and Assessment Program Introduction and Overview

The Coastal Watershed Planning and Assessment Program (CWPAP) is a program of the California Department of Fish and Wildlife (CDFW) based in Fortuna, CA. CDFW's large scale assessment efforts began in 2001 as a component of the North Coast Watershed Assessment Program (NCWAP), an interagency effort between the following agencies: California Resources Agency, CA Environmental Protection Agency, CDFW, CA Department of Forestry and Fire Protection, CA Geological Survey, CA Department of Water Resources, and North Coast Regional Water Quality Control Board. Due to budget constraints, the NCWAP was discontinued in 2003. At that time, CDFW established the CWPAP to continue large-scale watershed assessments along California's coast to facilitate fishery improvement and recovery efforts. The 690 square mile South Fork (SF) Eel River Basin, which is located in southern Humboldt County and northern Mendocino County, was selected as a CWPAP assessment area because of its high fishery value to anadromous salmonids, including coho salmon that are listed as threatened by both state and federal agencies. This report was guided by following the outlines, methods, and protocols detailed in the NCWAP Methods Manual (Bleier et al. 2003). The program's assessment is intended to provide answers to six guiding assessment questions at the basin, subbasin, and tributary scales.

Program Guiding Questions

- What are the history and trends of the size, distribution, and relative health and diversity of salmonid coastal populations?
- What are the current salmonid habitat conditions, and how do these conditions compare to desired conditions?
- What are the effects of geologic, vegetative, fluvial, and other endemic watershed attributes on natural processes and watershed and stream conditions?
- How has land use affected or disturbed these natural attributes, processes, and/or conditions?
- As a result of those attributes, natural processes, and land use disturbances, are there stream and habitat elements that could be considered to be factors currently limiting salmon and steelhead production?
- If so, what watershed management and habitat improvement activities would most likely lead toward more desirable conditions for salmon and steelhead in a timely, reasonable, and cost effective manner?

These questions systematically focus the assessment procedures and data gathering, and provide direction for syntheses, including the analysis of factors affecting anadromous salmonid production. The questions progress from the relative status of the salmon and steelhead resource, to an assessment of the watershed context by looking at processes and disturbances, and lastly to the resultant conditions encountered directly by the fish: flow, water quality, nutrients, and instream habitat elements, including free passage at all life stages. The watershed products delivered to streams shape the stream and create habitat conditions. Thus, watershed processes and human influences determine salmonid health and production and help identify what improvements could be made in the watershed and its streams.

CWPAP assessments do not address marine influences on the ocean life cycle phase of anadromous salmonid populations. While these important influences are outside of the scope of this program, we recognize their critical role upon sustainable salmonid populations and acknowledge that good quality fresh water habitat alone is not adequate to ensure sustainability. However, freshwater habitat improvements benefit their well-being and survival during their two freshwater life cycle phases and thus can create stronger year classes in the ocean.

Goals

- Organize and provide existing information, and develop limited baseline data to help evaluate the effectiveness of various resource protection programs over time;
- Provide assessment information to help focus watershed improvement programs, and to assist landowners, local watershed groups, and individuals in developing successful projects. This will help guide support programs, such as the CDFW Fishery Restoration Grants Program (FRGP), toward those watersheds and project types that can efficiently and effectively improve freshwater habitat and lead to improved salmonid populations;
- Provide assessment information to help focus cooperative interagency, nonprofit, and private sector approaches to protect watersheds and streams through watershed stewardship, conservation easements, and other incentive programs;
- Provide assessment information to help landowners and agencies better implement laws that require specific assessments such as the State Forest Practice Act, Clean Water Act, and State Lake and Streambed Alteration Agreements.

North Coast Salmon, Stream, and Watershed Issues

Pacific coast anadromous salmonids hatch in freshwater, migrate to the ocean as juveniles where they grow and mature, and then return as adults to freshwater streams to spawn. This general anadromous salmonid life history pattern is dependent upon a high quality freshwater environment at the beginning and end of the cycle (Bjornn and Reiser 1991). Different salmonid species and stocks utilize diverse inter-specific and intra-specific life history strategies to reduce competition between species and increase the odds for survival of species encountering a wide range of environmental conditions in both the freshwater and marine environments (Groot and Margolis 1991). These strategies include the timing and locations for spawning, length of freshwater rearing, juvenile habitat partitioning, a variable estuarine rearing period, and different physiologic tolerances for water temperature and other water quality parameters.

Salmonids thrive or perish during their freshwater phases depending upon the availability of cool, clean water, free access to migrate up and down their natal streams, clean gravel suitable for successful spawning, adequate food supply, and protective cover to escape predators and ambush prey (*Figure 1*). These life requirements must be provided by diverse and complex instream habitats as the fish move through their life cycles (JNRC 2002). If any life requirements are missing or in poor condition at the time a fish or stock requires it, fish survival can be affected. These life requirement conditions can be identified and evaluated on a spatial and temporal basis at the stream reach and watershed levels. They comprise the factors that support or limit salmonid stock production.

Figure 1. Example of high quality spawning habitat in the SF Eel River Basin.

The specific combination of these factors in each stream sets the carrying capacity for salmonids of that stream. The carrying capacity can thus be changed if one or more of the factors are altered. The importance of individual factors in setting the carrying capacity

differs with the life stage of the fish and time of year. All of the important factors for salmonid health must be present in a suitable, though not always optimal, range in streams where fish live and reproduce (Bjornn and Reiser 1991).

Within the range of anadromous salmonid distribution, historic stream conditions varied at the regional, basin and watershed scales. Wild anadromous salmonids evolved with their streams shaped in accordance with the inherent, biophysical characteristics of their parental watersheds, and stochastic pulses of fires, landslides, and climatic events (Waples et al. 2008). In forested streams, large trees grew along the stream banks contributing shade, adding to bank stability, and moderating air and stream temperatures during hot summers and cold winter seasons. The streams contained fallen trees and boulders, which created instream habitat diversity and complexity. The large mass of wood in streams provided important nutrients to fuel the aquatic food web. During winter flows, sediments were scoured, routed, sorted, and stored around solitary pieces and accumulations of large wood, bedrock, and boulders, forming pool, riffle, and flatwater habitats.

Two important watershed goals are the protection and maintenance of high quality fish habitats. Preserving high quality habitat and restoring streams damaged by poor resource management practices of the past are both important for anadromous salmonid populations (Bisson et al. 1997). Science-based management has progressed significantly and "enough now is known about the habitat requirements of salmonids and about good management practices that further habitat degradation can be prevented, and habitat rehabilitation and enhancement programs can go forward successfully" (Meehan 1991).

Through the course of natural climatic events, hydrologic responses and erosion processes interact to shape freshwater salmonid habitats. These processes influence the kind and extent of a watershed's vegetative cover as well, and act to supply nutrients to the stream system. When there are no large disturbances, these natural processes continuously make small changes in a watershed. Managers must constantly evaluate these small natural changes as well as changes made by human activity. Habitat conditions can be drastically altered when major disruptions of these small interactions occur (Swanston 1991).

Major watershed disruptions can be caused by catastrophic events, or system reset events (Junk et al. 1989), such as the 1955 and 1964 north coast floods. They can also be created over time by multiple small natural or human disturbances. These disruptions can drastically alter instream habitat conditions and the aquatic communities that depend upon them (Lake 2000). Thus, it is important to understand the critical interdependent relationships of salmon and steelhead with their natal streams during their freshwater life phases, their streams' dependency upon the watersheds within which they are nested, and the energy of the watershed processes that binds them together.

In general, natural disturbance regimes like landslides and wildfires do not impact larger basins like the 690 square mile SF Eel River Basin in their entirety at any given time. Rather, they normally rotate episodically across the entire basin as a mosaic composed of the smaller subbasin, watershed, or sub-watershed units over long periods. This creates a dynamic variety of habitat conditions and quality over the larger basin (Reice 1994).

The rotating nature of these relatively large, isolated events at the regional or basin scale assures that at least some streams in the area will be in suitable condition for salmonid stocks. A dramatic, large-scale example occurred in May 1980 in the Toutle River, Washington, which was inundated with slurry when Mt. St. Helens erupted. The river rapidly became unsuitable for fish. In response, returning salmon runs avoided the river that year and used other nearby suitable streams on an opportunistic basis, but returned to the Toutle two years later as conditions improved. This return occurred much sooner than had been initially expected (Quinn et al. 1991).

Human disturbances, although individually small in comparison to natural disturbance events, are usually widely distributed across basin level watersheds (Reeves et al. 1995). For example, a rural road or building site is an extremely small land disturbance compared to a 640-acre landslide or wildfire covering several square miles. However, when all the roads in a basin the size of the SF Eel River are looked at collectively, their disturbance effects are much more widely distributed than a single large, isolated landslide that has a high, but relatively localized impact to a single sub-watershed.

Human disturbance regimes collectively extend across basins and even regional scales and have cumulative,

lingering effects. Examples include water diversions, conversion of near stream areas to urban usage, removal of large mature vegetation, widespread soil disturbance leading to increased erosion rates, construction of levees or armored banks that can disconnect the stream from its floodplain, and the installation of dams and reservoirs that disrupt normal flow regimes and prevent free movement of salmonids and other fish. These disruptions often develop in concert and in an extremely short period of time on the natural, geologic scale. One of the biggest challenges to sustainable resource management is understanding and developing management strategies that minimize the cumulative effects of human disturbances on fish populations and ecological communities (Scrimgeour et al. 2003).

Human disturbances are often temporally concentrated due to newly developed technology or market forces such as the California Gold Rush, the post- WWII logging boom in Northern California, or the new "Green Rush" of industrial marijuana production (Evers 2010, Easthouse 2013). The intense human land use of the last century, combined with the transport energy of two mid-century record floods on the North Coast, created stream habitat impacts at basin and regional scales. The result of these recent combined disruptions has overlain the pre-European disturbance regime process and conditions within the region.

Consequently, stream habitat quality and quantity are generally reduced throughout most of the North Coast region. It is within this heavily impacted environment that both human and natural disturbances continue to occur, but with vastly fewer habitat refugia than were historically available to salmon and steelhead. Thus, a general reduction in salmonid stocks can at least partially be attributed to this impacted freshwater environment.

Factors Affecting Anadromous Salmonid Production

The concept that fish production is limited by a single factor or by interactions between discrete factors is fundamental to stream habitat management (Meehan 1991). A limiting factor can be anything that constrains, impedes, or limits the growth and survival of a population.

Identifying freshwater factors that are currently at a level that limits production of anadromous salmonids in North Coast basins is a key component of CWPAP watershed assessment. This limiting factors analysis (LFA) provides a means to evaluate the status of a suite of key environmental factors that affect anadromous salmonid life history, and is an important tool for developing management actions to conserve and recover salmonid populations (Trask 2003). LFAs are based on comparing measures of habitat components such as water temperature and pool complexity to a range of reference conditions determined from empirical studies and/or peer reviewed literature. If a component's condition does not fit within the range of reference values, it may be viewed as a limiting factor. This information is useful when identifying underlying causes of stream habitat deficiencies, and it helps reveal links between watershed processes and land use activities.

Chinook salmon, coho salmon, and steelhead trout all utilize headwater streams, larger rivers, estuaries, and the ocean during parts of their life history cycles. In the freshwater phase in salmonid life history, adequate flow, free passage, suitable stream conditions, suitable water quality (such as low water temperatures and low turbidity levels), and functioning riparian areas are essential for successful completion of their anadromous lifecycle (Barnhart 1986, Healy 1991, Sandercock 1991).

Water Quantity

Stream flow can be a significant limiting factor for salmonids, affecting fish passage, and quantity and quality of spawning, rearing, and habitat refugia areas. For successful salmonid production, stream flows should follow the natural hydrologic regime of the basin (Poff et al. 1997). A natural regime minimizes the frequency and magnitude of storm flows and promotes better base flows during dry periods of the water year. Salmonids evolved with the natural hydrograph of coastal watersheds, and changes to the timing, magnitude, and duration of low flows and storm flows can disrupt the ability of fish to follow life history cues. Adequate instream flow during low flow periods is essential for fish passage in the summer time, and is necessary to provide juvenile salmonids free forage range, cover from predation, and utilization of localized temperature refugia from seeps, springs, and cool tributaries. Adequate flow is also required for smolts migrating downstream to the estuary while they are still physiologically adapted to make the transition from freshwater to salt water habitats (Berggren and Filardo 1993).

Water Quality

Important aspects of water quality for anadromous salmonids are water temperature, turbidity, water chemistry, and sediment load. In general, suitable water temperatures for salmonids are between 48-56°F for successful spawning and incubation, and between 50-52°F and 60-64°F, depending on species, for growth and rearing (Bell 1986, Armour 1991, Carter 2005). Additionally, cool water holds more oxygen, and salmonids require high levels of dissolved oxygen in all stages of their life cycle.

A second important aspect of water quality is turbidity. Fine suspended sediments (turbidity) affect nutrient levels in streams that in turn affect primary productivity of aquatic vegetation and insect life (Power 2003). This eventually reverberates through the food chain and affects salmonid food availability. Additionally, high levels of turbidity interfere with juvenile salmonids' ability to feed and can lead to reduced growth rates and survival due to an impaired ability to find food and food assemblage changes (Suttle et al. 2004, NOAA Restoration Center 2011).

A third important aspect of water quality is stream sediment load. Salmonids cannot successfully reproduce when forced to spawn in streambeds with excessive silt, clay, and other fine sediments. Eggs and embryos suffocate under excessive fine sediment conditions because oxygenated water is prevented from passing through the egg nest, or redd (Gibbons and Salo 1973). Additionally, high sediment loads can cap the redd and prevent emergent fry from escaping the gravel into the stream at the end of incubation (Chapman 1988). High sediment loads can also cause abrasions on fish gills, which may increase susceptibility to infection. At extreme levels, sediment can clog the gills, causing death (Gibbons and Salo 1973). High sediment loads also fill in pool habitats, resulting in reduced cover and shelter for juveniles and adults, and, materials toxic to salmonids can cling to sediment and be transported to downstream areas.

Fish Passage

Free passage describes the absence of barriers to the instream movement of adult and juvenile salmonids. Free movement in streams allows salmonids to find food, escape from high water temperatures, escape from predation, and migrate to and from their stream of origin as juveniles and adults. Connectivity of habitats is an important consideration in salmonid restoration for all species and life stages (Roni et al. 2002). Temporary or permanent dams, poorly constructed road crossings, landslides, debris jams, or other natural and/or man-caused channel disturbances can disrupt or prevent free passage.

Instream Habitat Conditions

Complex instream habitat is important for all lifecycle stages of salmonids. Habitat diversity for salmonids is created by a combination of deep pools, riffles, and flatwater habitat types. Pools, and to some degree flatwater habitats, provide escape cover from high velocity flows, hiding areas from predators, and ambush sites for taking prey. Pools are also important juvenile rearing areas, particularly for young coho salmon. They are also necessary for providing adult resting areas. A high level of fine sediment can fill pool and flatwater habitats, reducing pool depth and burying complex niches created by large substrate and woody debris. Riffles provide clean spawning gravels and oxygenated water. Steelhead fry use riffles during rearing. Flatwater areas often provide spatially divided pocket water units (Flosi et al. 1998) that separate individual juveniles, which helps promote reduced competition and successful foraging.

The ratio of pool, riffle, and flatwater units is a measure of habitat diversity, and in habitats where complexity has been reduced by natural or anthropogenic degradation, restoration actions can be developed to restore habitat ratios and invertebrate biodiversity (Ebersole et al. 1997)

Riparian Zone

A functional riparian zone helps to control the amount of sunlight reaching the stream, provides vegetative litter, and contributes invertebrates to the local salmonid diet. These contribute to the production of food for the aquatic community, including salmonids. Tree roots and other vegetative cover provide stream bank cohesion and buffer impacts from adjacent uplands. Near-stream vegetation eventually provides large woody debris and complexity to the stream (Flosi et al. 1998).

Riparian zone functions are important to anadromous salmonids for numerous reasons. Riparian vegetation helps keep stream temperatures in the range that is suitable for salmonids by maintaining cool stream temperatures in the summer and insulating streams from heat loss in the winter (Poole et al. 2001, Poole and Berman 2001). Larval and adult macroinvertebrates are important to the salmonid diet and are dependent upon nutrient contributions from the riparian zone (Gregory et al. 1991). Additionally,

stream bank cohesion and maintenance of undercut banks provided by riparian zones in good condition maintain diverse salmonid habitat, and help reduce bank failure and fine sediment yield to the stream. Lastly, the large woody debris provided by riparian zones shapes channel morphology, helps retain organic matter and provides essential cover for salmonids (Murphy and Meehan 1991).

Excessive natural or human-caused disturbances to the riparian zone, as well as directly to the stream and/or the basin itself can have serious impacts on the aquatic community, including anadromous salmonids. This habitat loss and damage occurring in most Northern California coastal streams and watersheds is a primary factor in the listing of Chinook salmon, coho salmon, and steelhead trout stocks under the Endangered Species Act (Levin and Schiewe 2001, Nehlsen et al. 2001).

Disturbance and Recovery of Stream and Watershed Condition

Natural and Human Disturbances

The forces shaping streams and watersheds are numerous and complex. Streams and watersheds change through dynamic processes of disturbance and recovery (Madej 1999). In general, disturbance events alter stream equilibrium and average conditions, while recovery occurs as stream conditions return towards equilibrium after disturbance events.

Given the program's focus on anadromous salmonids, an important goal is to determine the degree to which current stream and watershed conditions in the region are providing salmonid habitat capable of supporting sustainable populations of anadromous salmonids. To do this, we must consider the habitat requirements for all species and life stages of salmonids. We must look at the disturbance history and recovery of stream systems, including riparian and upslope areas, which affect the streams through multiple biophysical processes.

Disturbance and recovery processes can be influenced by both natural and human events. A disturbance event such as sediment input from a natural landslide can fill instream pools, destroying salmon habitat just as readily as sediment from a road failure. During recovery, natural processes (such as small streamside landslides) that replace instream large woody debris washed out by a flood flow help to restore salmonid habitat, as does large woody debris placed in a stream by a landowner as a part of a restoration project.

Natural disturbance and recovery processes, at scales from small to very large, have been at work on north coast watersheds since their formation millions of years ago. Recent major natural disturbance events have included large flood events such as those that occurred in 1955, 1964 (Lisle 1981a), as well as ground shaking and related tectonic uplift associated with the 1992 Cape Mendocino earthquake (Carver et al. 1994).

Major anthropogenic disturbances (e.g., post-European development, dam construction, agricultural and residential conversions, and timber harvest methods used before the implementation of the 1973 Z'Berg-Nejedly Forest Practice Act) have occurred over the past 160 years (Cafferata and Spittler 1998, Yoshiyama and Moyle 2010). Salmonid habitat also was degraded during parts of the last century by well-intentioned but misguided restoration actions such as removing large woody debris from streams (Spence et al. 1996, Stillwater Sciences 1997). More recently, efforts at watershed restoration have been made, generally at the local level. For example, in California and the Pacific Northwest, minor dams from some streams have been removed to clear barriers to spawning and juvenile anadromous fish. For a thorough treatment of stream and watershed recovery processes, see the publication by the Federal Interagency Stream Restoration Working Group (FISRWG 1998).

Defining Recovered

There is general agreement that improvements in a condition or set of conditions constitute recovery. In that context, recovery is a process. One can determine a simple rate of recovery by the degree of improvement over some time period, and from only two points in time. One can also discuss recovery and rates of recovery in a general sense. However, a simple rate of recovery is not very useful until put into the context of its position on a scale to the endpoint of recovered.

In general, recovered fish habitat supports diverse and stable fish populations. Recovered not only implies, but necessitates, knowledge of an endpoint. In the case of a recovered watershed, the endpoint is a set of conditions deemed appropriate for a watershed with its processes in balance and able to withstand perturbations without large fluctuations in those processes and conditions. However, the endpoint of recovered for one condition or function may be on a different time and geographic scale than for another condition or function.

Some types and locations of stream recovery for salmonids can occur more readily than others. For example, in headwater areas where steeper source reaches predominate, suspended sediment such as that generated by a streamside landslide or a road fill failure may start clearing immediately, while coarser sediments carried as bedload tend to flush after a few years (Lisle 1981a; Madej and Ozaki 1996) or from large flood events, after many decades.

Broadleaf riparian vegetation can return to create shading, stabilize banks, and improve fish habitat within a decade or so. In contrast, in areas lower in the watershed where lower-gradient response reaches predominate, it can take several decades for deposited sediment to be transported out (Madej 1982), for widened stream channels to narrow, for aggraded streambeds to return to pre-disturbance level, and for streambanks to fully re-vegetate and stabilize (Lisle 1981b). Lower reach streams will require a similar period for the near-stream trees to attain the girth needed for recruitment into the stream as large woody debris to help create adequate habitat complexity and shelter for fish, or for deep pools to be re-scoured in the larger mainstems (Lisle and Napolitano 1998).

Factors and Rates of Recovery

Over the past quarter-century, several changes have allowed the streams and aquatic ecosystems to move generally towards recovery. The general rate of timber harvest on California's north coast has slowed during this period (Morgan et al. 2012). This is due to a declining number of timber harvesting plan (THP) submissions, but larger average harvest sizes per plan. The increased cost of timber sale preparation has led to reduced profitability from small harvests (Thompson and Dicus 2005). Timber harvesting practices have greatly improved over those of the post-war era, due to increased knowledge of forest ecosystem functions, changing public values, advances in road building and yarding techniques, and regulation changes such as mandated streamside buffers that limit equipment operations and removal of timber. Further, most north coast streams have not recently experienced a large event comparable to the 1964 flood. Therefore, we would expect most north coast streams to show signs of recovery (i.e., passive restoration [FISRWG 1998]). However, the rates and degrees of stream and watershed recovery will likely vary across a given watershed and among different north coast drainages.

In addition to the contributions made to recovery through better land management practices and natural recovery processes, increasing levels of stream and watershed restoration efforts are also contributing to recovery. Examples of these efforts include road upgrades and decommissioning, removal of road related fish passage barriers, installation of instream fish habitat structures, etc. While little formal evaluation or quantification of the contributions of these efforts to recovery has been made, there is a general consensus that many of these efforts have made significant contributions (Whiteway et al. 2010, Roni et al. 2010).

Continuing Challenges to Recovery

Given improvements in timber harvesting practices in the last 30 years, the time elapsed since the last major flood event, and the implementation of stream and watershed restoration projects, many north coast streams show indications of trends towards recovery (Madej and Ozaki 1996). Ongoing challenges associated with past activities that are slowing this trend include:

- Chronic sediment delivery from legacy (pre-1975) roads due to inadequate crossing design, construction and maintenance (Stillwater Sciences 1999);
- Skid trails and landings (Cafferata and Spittler 1998);
- A lack of improvements in stream habitat complexity, largely from a dearth of large woody debris for successful fish rearing (Dominguez and Cederholm 2000);
- The continuing aggradation of sediments in low-gradient reaches that were deposited as the result of activities and flooding in past decades (Koehler et al. 2001).

Increasing subdivision in several north coast watersheds raises concerns about new stream and

watershed disturbances. Private road systems associated with rural development have historically been built and maintained in a fashion that does little to mitigate risks of chronic and catastrophic sediment inputs to streams. While more north coast counties are adopting grading ordinances that will help with this problem, there is a significant legacy of older residential roads that pose an ongoing risk for sediment inputs to streams. Other issues appropriate to north coast streams include potential failures of roads during catastrophic events, erosion from house pads and impermeable surfaces, removal of water from streams for domestic uses, effluent leakages, and the potential for dumping of toxic chemicals used in illicit drug labs.

Some areas of the north coast have seen rapidly increasing agricultural activity, particularly conversion of grasslands or woodlands to marijuana cultivation. Such agricultural activities have typically been subject to little agency review or regulation and can pose significant risk of chronic sediment, chemical, and nutrient inputs to streams.

Associated with development and increased agriculture, some north coast river systems are seeing an increase in water diversion, from both streams and groundwater sources connected to streams, for human uses. Water withdrawals pose a cumulative chronic disturbance to streams and aquatic habitat (SWRCB 2010). Such withdrawals can result in reduced summer stream flows that impede the movement of salmonids and fewer important habitat elements such as pools. Further, the withdrawals can contribute to elevated stream water temperatures that are harmful to salmonids.

Key questions for landowners, agencies, and other stakeholders revolve around whether the trends toward stream recovery will continue at their current rates, and whether those rates will be adequate to allow salmonid populations to recover in an acceptable time frame. The potential exists for new impacts from both human activities and natural disturbance processes to compromise recovery rates, and complex biological and environmental systems make establishment of an exact timeline for recovery difficult (CDFG 2004). Predicting the direct effects and any cumulative effects of those impacts will require additional site-specific information on sediment generation and delivery rates, and additional risk analyses of other major disturbances. Our discussion here does not address marine influences on anadromous salmonid populations. While these important influences are outside of the scope of this program, we recognize their importance for sustainable salmonid populations and acknowledge that high quality freshwater habitat alone is not adequate to ensure sustainability.

Climate Change

Anthropogenic climate change is altering ecosystems worldwide, with the average global temperature increasing 1.4˚F over the past century (USEPA 2013). Increased global temperatures have been accompanied by warmer ocean temperatures and increased acidification, rising sea levels, and changes in local weather patterns resulting in intense rainfall and flooding, drought, and heat waves. Climate change is modifying the volume, timing, and quality of water resources, which directly affect salmonid populations in freshwater habitats by increasing stream temperatures and altering flow regimes. Mote and Salathè (2010) reviewed 21 global climate change models used by the Intergovernmental Panel on Climate Change (IPCC) in their Fourth Assessment Report and summarized projected changes in the Pacific Northwest, including:

- Average annual air temperature increases of 1.1˚C (2.0˚F) by the 2020s, 1.8˚C (3.2˚F) by the 2040s, and 3.0˚C (5.3˚F) by the 2080s (compared to the average annual temperature from 1970-1999);
- Small (1-2%) changes in annual precipitation, with some models predicting a shift toward wetter fall and winter conditions, with drier summers;
- Nearshore sea surface temperatures substantially exceeding interannual variability;
- Little change in coastal upwelling; and
- Highly variable sea level rise estimates, depending on factors such as polar ice sheet instability and local tectonic activity, ranging from 20 cm (8”) to 1.3 m (50”).

Chinook salmon, coho salmon, and steelhead trout occupy a variety of instream habitats and have variable life history event timing. Therefore, individuals of each species will encounter a different suite of stream flow and temperature changes resulting from climate change at each life stage (Beechie et al. 2012). These changes will have significant impacts on both SF Eel River salmonid populations and the food webs that sustain them, especially if predicted changes in rainfall and temperature are realized.

Wetter fall and winter conditions will result in higher than normal flows and possibly flooding. This could wash away nests, especially those of Chinook and coho salmon that spawn in the beginning of the winter storm season.

In relation to salmonid life cycle requirements, current stream temperatures in the SF Eel River Basin are generally good in Western Subbasin streams, but poor to fair in Eastern and Northern Subbasin streams. Increases in stream temperature resulting from projected increases in air temperature in areas where current stream temperatures are poor or near lethal for salmonids will pose a high threat to salmonids (Beechie et al. 2012), especially in the late summer and early fall months when stream temperatures are highest. In the SF Eel River Basin, areas with high stream temperatures are located in sampled locations in the mainstem downstream from the confluence of Rattlesnake Creek (RM 75), to below Miranda (RM 4) (Friedrichsen 1998 and 2003, Higgins 2012). Salmonids in these habitats may be less affected by increasing stream temperatures due to climate change if they can access cooler habitat in tributaries, or if there are cool water refugia from groundwater seeps nearby, but the location and stability of these seeps are spatially and temporally unpredictable.

Madej (2011) reported that over the last century, summer temperatures have increased and summer low flows have decreased in north coastal California streams. Increasingly drier summer conditions will be especially problematic for SF Eel River Basin salmonids, due to the already low flows and associated warm temperatures resulting from diversion and reduced flow in late summer months. Reduced flows would result in more juvenile stranding and a decrease in the limited amount of rearing habitat currently available throughout the Basin. Purchasing water rights or implementing water conservation measures that leave more water in streams in areas where withdrawals or diversions have already led to reduced flow can ameliorate predicted decreases in low flows due to climate change (Beechie et al. 2012).

Reduced rainfall and drier conditions resulting from climate change may also affect the natural fire regime in many areas (Flannigan et al. 2000, Fry and Stephens 2006). In Humboldt County, fire behavior in the future will be less predictable due to changes in temperatures, precipitation, fire frequency and fire severity (Tetra Tech 2013). Changes in the natural fire regime are a concern in all three subbasins, particularly in the drier Eastern Subbasin. Grassland habitat is more prevalent, air temperatures are higher, and slope gradients are greater in the Eastern Subbasin compared to the Northern and Western subbasins, where fuel potential is high but the climate is damp (Tetra Tech 2013).

Snowpack is a key component of the hydrologic cycle (Hamlet et al. 2005, Mote et al. 2005). The current warming trend is causing an increase in the amount of precipitation falling as rain, or an earlier melting of snow, or a combination of both in snowmelt basins (Barnett et al. 2005). In the Klamath River Basin in Northern California, warmer winter temperatures have caused earlier runoff peaks in both snowmelt and groundwater basins (Mayer and Naman 2011). Although snowmelt provides runoff to some SF Eel River tributaries, it is not the primary flow source for SF Eel River Basin streams.

Moyle et al. (2012) outlined methods to determine the baseline vulnerability of native salmonids and to assess the likely impact of climate change on these species. Based on predicted effects from climate change on freshwater fish in California, they stated that the future distribution of most native fish will become more restricted, and some populations may go extinct. Small populations are less resilient than larger populations, and will be affected more by variations in natural conditions due to climate change, especially if there is an increase in the frequency of stochastic events such as extreme floods or prolonged droughts. Invasive species (e.g. pikeminnow, with a higher tolerance for elevated water temperatures) will not be affected as much as native species, and may become dominant in diminished freshwater ecosystems as conditions change.

Fisheries management practices will need address localized environmental issues resulting from projected climate change. Rieman and Isaak (2010) suggested that fisheries managers will need to prioritize limited resources if enhanced resistance and resilience of existing species or communities is key. Management plans should include:

- Development of a local information base, including climate change projections and current conditions;
- Facilitation of transitions to new conditions;
- Coordination of efforts between resource managers to ameliorate the effects of climate change; and

- Creation of an iterative process to reevaluate and revise plans, including assumptions, as progress is monitored (Tillmann and Siemann 2011).

Recovery actions and restoration projects must also be adapted in the context of natural resource management and conservation to address environmental variations associated with climate change. In order to help ecosystems withstand and adapt to new climate conditions, managers will need to identify conservation targets, consider their vulnerability, evaluate management options, assess the effectiveness of proposed restoration efforts, and develop and implement management and monitoring strategies (Battin et al. 2007, Glick et al. 2009).

Habitat deterioration associated with climate change will make recovery targets much more difficult to attain, and managers and regulators will need to anticipate and track multiple environmental changes and species trajectories (Battin et al. 2007, Barbour and Kueppers 2012). Recovery actions are currently being developed by NOAA Fisheries for SONCC coho salmon, which are listed as threatened in the SF Eel River Basin. The draft recovery plan is available at: http://www.westcoast.fisheries.noaa.gov/protected_species/salmon_steelhead/recovery_planning_and_implementation/southern_oregon_northern_california_coast/southern_oregon_northern_california_coast_recovery_plan_documents.html. Recovery actions that are designed to enhance lower elevation habitats (e.g. SF Eel River streams) are more likely to be successful in protecting salmonids than those in higher elevation basins where the snow-rain transition will be greatest (Battin et al. 2007).

Climate change will dramatically alter ocean conditions and productivity, which directly affect salmonid populations (Behrenfeld et al. 2006), but CWPAP assessments do not address marine influences on the ocean life cycle phase of anadromous salmonid populations. We recognize the critical role of ocean conditions upon sustainable salmonid populations and acknowledge that good quality freshwater habitat alone is not adequate to ensure sustainability. However, in this assessment, we will concentrate on how potential changes to freshwater habitats may affect the well-being and survival of salmonids during their two freshwater life cycle phases.

Policies, Acts, and Listings

Several federal and state statutes have significant implications for watersheds, streams, fisheries, and their management. Here, we present only a brief listing and description of some of the laws.

Federal Statutes

One of the most fundamental of federal environmental statutes is the National Environmental Policy Act (NEPA). NEPA is essentially an environmental impact assessment and disclosure law. Projects contemplated, prepared, or funded by federal agencies must have an environmental assessment completed and released for public review and comment, including the consideration of more than one alternative. The law does not require that the alternative with the lowest impact be chosen, only that the impacts are disclosed.

The Federal Clean Water Act has a number of sections relevant for watersheds and water quality. Section 208 deals with non-point source pollutants arising from silvicultural activities, including cumulative impacts. Section 303 deals with water bodies that are impaired to the extent that their water quality is not suitable for the beneficial uses identified for those waters. For water bodies identified as impaired, the US Environmental Protection Agency (EPA) or its state counterpart (locally, the North Coast Regional Water Quality Control Board (NCRWQCB) and the State Water Resources Control Board (SWRCB)) must set targets for Total Maximum Daily Loads (TMDLs) of the pollutants that are causing the impairment. Section 404 addresses the alterations of wetlands and streams through filling or other modifications, and requires the issuance of federal permits for similar activities.

The Federal Endangered Species Act (ESA) addresses the protection of animal species whose populations are dwindling to critical levels. Two levels of species risk are defined. A threatened species is any species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range. An endangered species is any species that is in danger of extinction throughout all or a significant portion of its range. In general, the law forbids the take of listed species. Taking is defined as harassing, harming, pursuing, hunting, shooting, wounding, killing, trapping, capturing, or collecting a species or attempting to engage in any such conduct. Section 4(d) of the ESA prohibits any take of species

listed as endangered, but some take of threatened species that does not interfere with salmon survival and recovery can be allowed. Section 10 of the ESA allows NMFS to issue a permit for take of threatened species for scientific research, habitat conservation plans (HCPs), artificial propagation programs, and harvest management programs. An HCP is a document that describes how an agency or landowner will manage their activities to reduce effects on vulnerable species. An HCP discusses the applicant's proposed activities and describes the steps that will be taken to avoid, minimize, or mitigate the take of species that are covered by the plan.

Many of California's salmonids are listed under the ESA, including three species found in the SF Eel River Basin (*Table 1*). SONCC coho salmon were originally listed by the National Marine Fisheries Service (NMFS) in 1997, CC Chinook salmon in 1999, and NC steelhead Distinct Population Segment (DPS) in 2000. Five-year status reviews were completed by NMFS in 2011 for these listed species, with recommendations that the status remain "threatened" for all three. NMFS determined that the biological status of SONCC coho salmon has worsened due in part to ocean survival conditions, drought effects, and small population size since the previous status review in 2005, and recommended careful monitoring and re-evaluation of the status of this species in 2-3 years (NMFS 2011a).

Table 1. ESA listed salmonids in the SF Eel River Basin.

Common Name	Scientific Name	Status
Coho Salmon (Southern Oregon/Northern California)	*Oncorhynchus kisutch*	Threatened (Federal and State)
Chinook Salmon (California Coastal)	*Oncorhynchus tshawytscha*	Threatened (Federal)
Steelhead Trout (Northern California)	*Oncorhynchus mykiss*	Threatened (Federal)

State Statutes

The state equivalent of NEPA is the California Environmental Quality Act (CEQA). CEQA goes beyond NEPA in that it requires the project or plan proponent to select and implement the proposed alternative with the lowest environmental impact. When the selected alternative would still cause significant adverse environmental impacts, a statement of overriding considerations must be prepared.

The Porter-Cologne Water Quality Control Act establishes state water quality law and defines how the state will implement the federal authorities that have been delegated to it by the EPA under the federal Clean Water Act. For example, the EPA has delegated to the state certain authorities and responsibilities to implement TMDLs for impaired water bodies and NPDES (national pollution discharge elimination system) permits to point-source dischargers to water bodies.

Sections 1600 et seq. of the Fish and Game Code are implemented by the Department of Fish and Wildlife. These agreements are required for any activities that alter the beds or banks of streams or lakes. A 1600 agreement typically would be involved in a road project where a stream crossing was constructed. While treated as ministerial in the past, the courts have more recently indicated that these agreements constitute discretionary permits and thus must be accompanied by an environmental impact review per CEQA.

The California Endangered Species Act (CESA) (Fish and Game Code §§ 2050, et seq.) generally parallels the main provisions of the Federal Endangered Species Act and is administered by the CDFW. SONCC Coho salmon in the SF Eel River Basin are listed as threatened under CESA.

From a recovery and management perspective, the State of CA emphasizes natural, as opposed to hatchery, spawning and rearing in natural habitats. Hatchery production may be appropriate to protect and expand populations in specific situations (e.g. rescue rearing efforts in the Mattole River Basin), but natural production should take preference when both alternatives are feasible. Recovery and protection of native salmonids should be accomplished primarily through stream habitat improvement efforts (CDFG 2002).

The Z'Berg-Nejedly Forest Practice Act (FPA) and associated Forest Practice Rules (CalFire 2012) establish extensive permitting, review, and management practice requirements for commercial timber harvesting. Evolving in part as a response to water quality protection requirements established by the 1972 amendments to the federal Clean Water Act, the FPA and Rules provide for significant measures to protect watersheds, watershed function, water quality, and fishery habitat.

Assessment Strategy and General Methods

The NCWAP developed a Methods Manual (Bleier et al. 2003) that identified a general approach to conducting a watershed assessment, described or referenced methods for collecting and developing new watershed data, and provided a preliminary explanation of analytical methods for integrating interdisciplinary data to assess watershed conditions. This chapter provides brief descriptions of data collection and analysis methods used in the SF Eel River Assessment. See the Methods Manual and Analysis Appendix for a more detailed description of the assessment methods, data, and analysis.

Watershed Assessment Approach in the SF Eel River Basin

The steps in a large-scale assessment include:

- Conduct external scoping and outreach. Receive public input from agencies, private entities, and individuals. Compile, analyze, and report input to identify issues and promote cooperation;
- Determine logical assessment scales. The SF Eel River Basin assessment delineated the basin into three subbasins (Northern, Eastern, and Western) for assessment and analyses purposes;
- Discover and organize existing data and information;
- Identify data gaps needed to develop the assessment;
- Collect field data. CDFW habitat typing crews surveyed more than 300 miles of habitat in 118 streams in the SF Eel River Basin between 1990 and 2010. These data, along with information from CDFW spawner surveys, and historical field notes and stream survey documents were compiled for this assessment. Additional data were provided by private and agency cooperators;
- Conduct limiting factors analysis (LFA). An analysis based on the Ecological Management Decision Support system (EMDS) was used to evaluate factors at the tributary scale. These factors were rated to be either beneficial or restrictive to the well-being of fisheries;
- Conduct refugia rating analysis. Watershed, stream, habitat, and fishery information were combined and evaluated in terms of their importance to salmon and steelhead;
- Develop conclusions and recommendations;
- Facilitate monitoring of conditions.

CWPAP Products and Utility

CWPAP assessment reports and their appendices are intended to be useful to landowners, watershed groups, agencies, and individuals to help guide restoration, land use, watershed, and salmonid management decisions. The assessments operate on multiple scales ranging from the detailed and specific stream reach level to the very general basin level. Therefore, findings and recommendations also vary in specificity from being particular at the finer scales, and more general at the basin scale.

Assessment products include:

- A basin level report that includes:
  - A collection of the SF Eel River Basin's historical information;
  - A description of historic and current hydrology, geology, land use, water quality, salmonid distribution, and instream habitat conditions;
  - An evaluation of watershed processes and conditions affecting salmonid habitat;
  - A list of issues developed by landowners, agency staff, and the public;
  - An analysis of the suitability of stream reaches and the watershed for salmonid production and refugia areas;
  - Tributary and watershed recommendations for management, refugia protection, and restoration activities to address limiting factors and improve conditions for salmonid health and productivity;
  - Monitoring recommendations to improve the adaptive management efforts;
- Ecological Management Decision Support system (EMDS) based models to help analyze instream conditions;
- Databases of information used and collected;
- A data catalog and bibliography;
- Web based access to the Program's products:
  - http://www.coastalwatersheds.ca.gov/,
  - http://www.calfish.org, http://bios.dfg.ca.gov,
  - http://www.dfg.ca.gov/biogeodata/gis/imaps.asp

Assessment Report Conventions CalWater 2.2.1 Planning Watersheds and CWPAP Subbasins

The California Watershed Map (CalWater Version 2.2.1) is used to delineate planning watershed units (*Figure 2*). This hierarchy of watershed designations consists of six levels of increasing specificity: Hydrologic Region, Hydrologic Unit, Hydrologic Area, Hydrologic Sub-Area, Super Planning Watershed, and Planning Watershed (PW). PWs are used by CWPAP to delineate basins, subbasins, and drainages.

CalWater 2.2.1 PWs may not represent true watersheds. Because PWs were created using elevation data rather than flow models, PWs may cut across streams and ridgelines, especially in less mountainous areas. Streams, such as the mainstem SF Eel River, can flow through multiple PWs. In addition, a stream, or administrative boundary, such as the California state border, may serve as a division between two PWs. For these and other reasons, PWs may not depict the true catchment of a stream or stream system. Despite these potential drawbacks, the use of a common watershed map has proven helpful in the delineation of basins and subbasins.

The assessment team subdivided the SF Eel River Basin into three subbasins for assessment and analyses purposes (*Figure 3*). These are the Northern, Eastern, and Western subbasins. In general, these subbasins have distinguishing attributes common to the CalWater 2.2.1 Planning Watersheds (PWs) contained within them.

Variation among subbasins is a product of natural and human disturbances. Characteristics that can distinguish subbasins within larger basins include differences in elevation, geology, soil types, aspect, climate, vegetation, fauna, human population, land use and other social-economic considerations.

Demarcation in this logical manner provides a uniform methodology for conducting large scale assessment. It provides a framework for the reporting of specific findings as well as assisting in developing recommendations for watershed improvement activities that are generally applicable across the relatively homogeneous subbasin area.

CalWater was created by the California Interagency Watershed Mapping Committee (IWMC), a collaboration of nine state and federal agencies. Since 2000, the IWMC has supported the development of a new dataset known as the Watershed Boundary Dataset (WBD). This new dataset is nationally consistent, and is delineated and geo-referenced to the USGS 1:24,000 scale. The WBD is now part of the USGS National Hydrography Dataset (NHD), and will eventually replace CalWater (T. Christy, CDFW, personal communication). Future CWPAP watershed assessments may use WBD to delineate planning watershed units. For additional information on WBD and the transition from CalWater, see: http://nhd.usgs.gov/wbd.html.

Hydrologic Hierarchy

Watershed terminology often becomes confusing when discussing different scales of watersheds involved in planning and assessment activities. The conventions used in the SF Eel River Basin assessment follow guidelines established by the Pacific Rivers Council. The descending order of scale is from basin level (e.g., SF Eel River Basin) to subbasin level (e.g., Northern Subbasin) to watershed level (e.g., Bull Creek) to sub-watershed level (e.g., Upper Bull Creek) (*Figure 4*).

The subbasin is the assessment and planning scale used in this report as a summary framework. In the watershed hierarchy, findings and recommendations are broader at the basin level and more specific at the sub-watershed level. Subbasin findings and recommendations are based on more specific watershed and sub-watershed level findings; therefore, there may be exceptions or modifications to recommendations when applied at different levels within the hydrologic hierarchy.

Terminology

The term “watershed” is used in both the generic sense, to describe watershed conditions at any scale and as a particular term to describe the watershed hierarchy introduced above. It is important to consider

Figure 2. SF Eel River Basin - CalWater 2.2.1 planning watersheds

Figure 3. SF Eel River Basin and Northern, Eastern, and Western Subbasin boundaries.

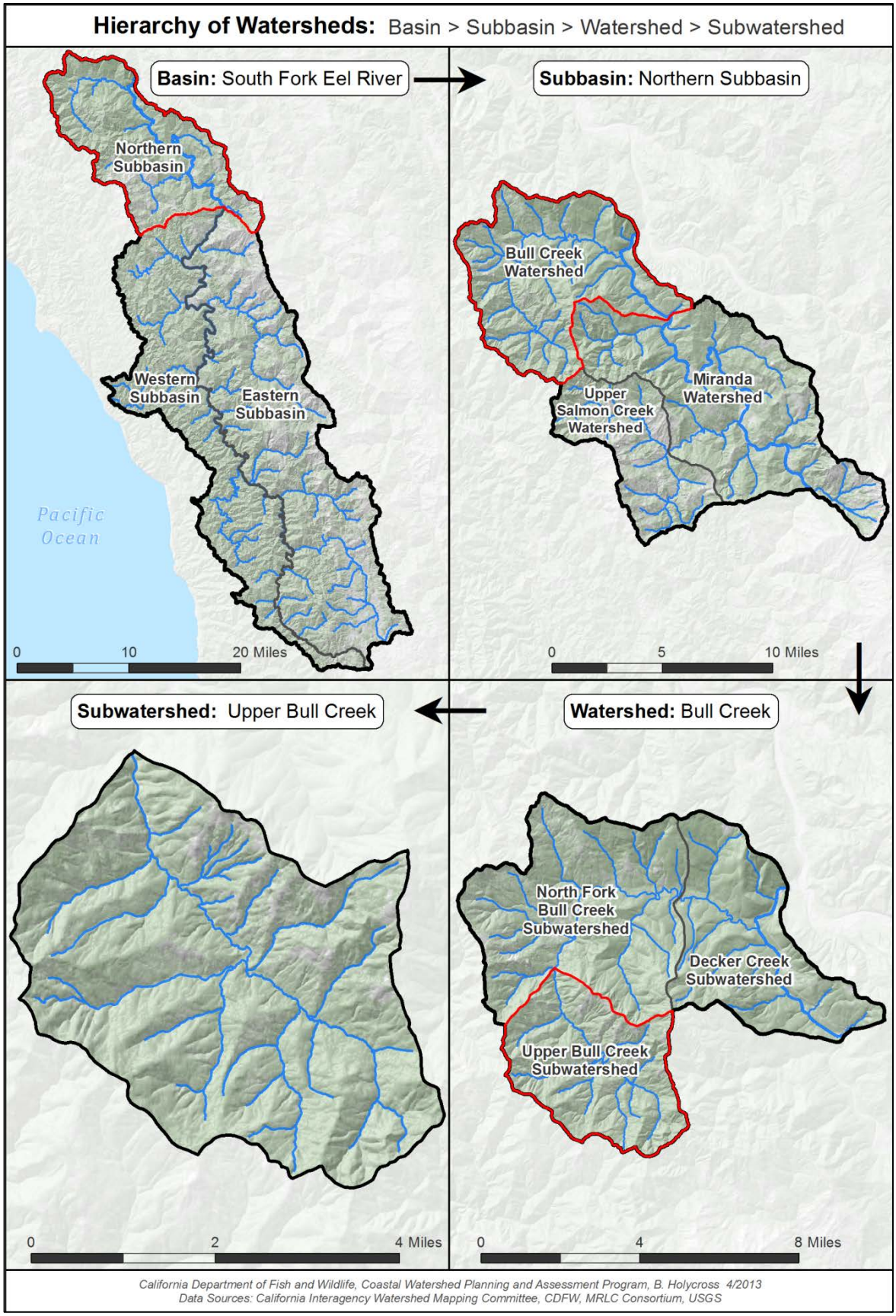

Figure 4. Hydrography Hierarchy in Bull Creek watershed, SF Eel River Basin.

the context of the term when used to reduce confusion. A watershed area is often approximately 20–40 square miles; sub-watersheds can be much smaller, but for assessment purposes must contain at least one perennial, un-branched stream.

Another important term is "river mile," indicated as RM. RM is used to assign a specific, measured distance upstream from the mouth of a river or stream to a point or feature upstream. In this report, RM is used to locate points along the SF Eel River and/or its tributaries (e.g. Benbow Dam is at RM 40).

Electronic Data Conventions

Members of the CWPAP collected or created hundreds of data records for synthesis and analysis purposes and most of these data were either created in a spatial context or converted to a spatial format. Effective use of these data between the partner departments required establishing standards for data format, storage, management, and dissemination. Early in the assessment process, the CWPAP held a series of meetings designed to gain consensus on a common format for the often widely disparate data systems within each department. The objective of these meetings was to establish standards which could be used easily by each department, were most useful and powerful for selected analysis, and would be most compatible with standards used by potential private and public sector stakeholders. Participants agreed on the following standardized format for spatial data used in the program and base information disseminated to the public through the program (see the data catalog at the end of this report for a complete description of data sources and scale):

Data form: standard database format usually associated with a Geographic Information System (GIS) shapefile or personal geodatabase (Environmental System Research Institute, Inc. © [ESRI]). Data were organized by watershed. Electronic images were retained in their current format.

Spatial Data Projection: spatial data were projected from their native format to Teale Albers, North American Datum (NAD) 1983.

Scale: most data were created and analyzed at 1:24,000 scale to (1) match the minimum analysis scale for planning watersheds, and (2) coincide with base information (e.g., stream networks) on USGS quadrangle maps (used as Digital Raster Graphics [DRG]).

Data Sources: data were obtained from a variety of sources including spatial data libraries with partner departments or were created by manually digitizing from 1:24,000 DRG.

The metadata available for each spatial data set contain a complete description of how data were collected and attributed for use in the program. Spatial data sets that formed the foundation of most analysis included the 1:24,000 hydrography and the 10-meter scale Digital Elevation Models (DEM). Hydrography data were created by manually digitizing from a series of 1:24,000 DRG then attributing with direction, routing, and distance information using a dynamic segmentation process (for more information, see Cadkin 2002). The resulting routed hydrography allowed for precise alignment and display of stream habitat data and other information along the stream network. The DEM was created by USGS from base contour data for the entire study region.

Source spatial data were often clipped to watershed, planning watershed, and subbasin units prior to use in analysis. Analysis often included creation of summary tables, tabulating areas, intersecting data based on selected attributes, or creation of derivative data based on analytical criteria. For more information regarding the approach to analysis and basis for selected analytical methods, see Chapter 2, Assessment Strategy and General Methods, and Chapter 4, Interdisciplinary Synthesis and Findings.

Assessment Methods

Hydrology

There are three United States Geological Survey (USGS) river gages located within the basin: at Bull Creek (USGS ID 1147660), Miranda (USGS ID 11476500), and Leggett (USGS ID 11475800). There are also historic records from five additional, discontinued USGS river gages: at Branscomb (USGS ID 1145500), Laytonville (USGS ID 1145700), Garberville (USGS ID 1146000, 11475940), and Dyerville (USGS ID 1146620) (*Table 2*).

Table 2. USGS gages within the SF Eel River Basin.

Continuous:	Catchment miles^2	Years of record
11476500 SF Eel River near Miranda	537	1940 - 2012
11476600 Bull Creek	28.1	1960 - 2012
11475800 SF Eel River at Leggett	248	1964 - 2012
Discontinued:		
11475500 SF Eel River near Branscomb	43.9	1947-70
11475700 Tenmile Creek near Laytonville	50.3	1958-74
11475940 East Branch SF Eel River near Garberville	74.3	1966-72
11476000 SF Eel River at Garberville	468	1912-13, 1940
Partial records:		
11476620 SF Eel River at Dyerville	689	1963 - 1964

An approximation of likely historic flows occurring at the mouth of the SF Eel River (Dyerville Gage) was generated using nearby, existing gage records, basin area, and available precipitation data.

Geology and Fluvial Geomorphology

A generalized geologic map was compiled for use in this report using published USGS maps and limited, geologic field and aerial photo reconnaissance mapping. This map was then simplified by combining rock types of similar age, composition, and geologic history. Landslides depicted on the map are derived from McLaughlin et al (2000) and represent only large Quaternary landslide features as of 2000. Calculations of area occupied by each rock type were based on GIS interpretation. Limited field reconnaissance as well as a review of aerial photos (Humboldt County) from years 1941, 1963, 1967 and 1996 and recent images from Google-Earth was conducted to gather specific geologic information relevant to the report. A review of the available literature, published and unpublished, pertinent to the geology of the local area was used to gather information presented in this report.

Stream profiles were constructed primarily from USGS topographic 7.5 minute quadrangle coverage of the basin. Profile topography was combined with geologic information and maps from McLaughlin et al (2000), Kilbourne (1983 and 1984) and Spittler (1983 and 1984), and available GIS maps and data. Subsurface geology was extended from the surface vertically and does not reflect the actual inclination of subsurface geologic units, contacts, or faults.

Vegetation and Land Use

The USDA Forest Service (USFS) CALVEG vegetation data were used to describe basin-wide vegetation. This classification breaks down vegetation into major “vegetation cover types”. These are further broken down into a number of “vegetation types”.

A literature search was conducted to obtain all available historic land use data. More recent land use data was obtained from the Humboldt County Planning Department. Additionally, more detailed records of logging activity (THPs and NTOs) from 1991 to present were obtained from California Department of Forestry (CDF) in digital format.

Year 2010 census data were analyzed to provide population estimates for each SF Eel subbasin. The 2010 data were available from the CDF’s Fire and Resource Assessment Program (FRAP). The Census Bureau statistics are organized at several levels including: State, County, Census County Division (CCD), Census Tract, Block Group, and Block. The SF Eel River basin contains sections of census tracts, which are made up of individual blocks. Block population totals were compiled to determine the estimated population of each SF Eel River subbasin. Blocks that crossed the basin or subbasin boundaries were examined more closely and population values were weighted based on the percentage of block area within the basin or subbasin boundary.

Fish Habitat and Populations Data Compilation and Collection

CDFW compiled existing available data and gathered anecdotal information pertaining to salmonids and the instream habitat on the SF Eel River and its tributaries. Anecdotal and historic information was cross-referenced with other existing data whenever possible. Where data gaps were identified, access was sought from landowners to conduct habitat inventory and fisheries surveys. Habitat inventories and biological data were collected following the protocol presented in the California Salmonid Stream Habitat Restoration Manual (Flosi et al. 1998).

Fish Passage Barriers

A total of 133 structures considered potential barriers to fish passage were evaluated between 1980 and 2012 in the SF Eel River Basin. Barriers were identified using a variety of sources, including DFW habitat and spawner survey reports, the CalFish Passage Assessment Database, profile analysis, NMFS' SONCC coho intrinsic potential map, field validation, and expert professional judgment. There are many types of barriers in the SF Eel River watershed including but not limited to: steep gradients, cascades, woody debris jams, landslides, and culverts. These barriers can be classified as temporary, partial, and total, and each type has different impacts on salmonid species and life stages (*Table 3*).

The most frequently encountered man-made barrier is culverts. Culverts often create temporary, partial, or complete barriers for adult and/or juvenile salmonids during their freshwater migration activities, and the cumulative effect of blocked habitat in Northern California streams is likely significant (Bates 1999, Taylor and Associates 2005).

Table 3. Definitions of barrier types and their potential impacts to salmonids (Taylor 2000).

Barrier Category	Definition	Potential Impact
Temporary	Impassable to all fish some of the time.	Delay in movement beyond the barrier for some period of time.
Partial	Impassable to some fish at all times.	Exclusion of certain species and life stages from portions of a watershed.
Total	Impassable to all fish at all times.	Exclusion of all species from portions of a watershed.

Target Values from Habitat Inventory Surveys

Beginning in 1991, habitat inventory surveys were used as a standard method to determine the quality of the stream environment in relation to conditions necessary for salmonid health and production. In the *California Salmonid Stream Habitat Restoration Manual* (Flosi et al. 2010) target values were given for canopy density, primary pool frequency, and pool shelter/cover (*Table 4*). Target values for embeddedness were established by the NCWAP team, using a modification of Flosi et al.'s (2010) consideration of category 1 cobble embeddedness as the highest quality spawning habitat. Because of the incompetent Franciscan geology found throughout the SF Eel River Basin, many streams contain large amounts of fine sediment in streams. The NCWAP team determined that streams with a preponderance of habitat with categories 1 and 2 embeddedness would be suitable for spawning salmonids, and set a value of >50% category 1 and 2 embeddedness as the target for this factor. When habitat conditions fall below the target values, restoration projects may be proposed in an attempt to meet critical habitat needs for salmonids.

Table 4. Habitat inventory target values.

Habitat Element	Canopy Density	Embeddedness	Primary Pool* Frequency	Shelter/Cover
Range of Values	0-100%	0-100%	0-100%	0-300 Rating
Target Values	>80%	>50% of the pool tails surveyed with category 1 & 2 embeddedness values	>40% of stream length	>100
*Primary pools are pools >2 feet deep in 1st and 2nd order streams, >3 feet deep in 3rd order streams, or >4 feet deep in 4th order streams				

Canopy Density - Eighty Percent or More of the Stream Should be Covered by Canopy

Near-stream forest density and composition contribute to microclimate conditions. These conditions help regulate air temperature and humidity, which are important factors in determining stream water temperature. Along with the insulating capacity of the stream and riparian areas during winter and summer, canopy density levels provide an indication of the potential present and future recruitment of large woody debris to the stream channel. Re-vegetation projects should be considered when canopy density is less than the target value of 80%.

Good Spawning Substrate - Fifty Percent or More of the Pool Tails Sampled Should be Fifty Percent or Less Embedded

Cobble embeddedness is the percentage of an average sized cobble piece, embedded in fine substrate at the pool tail. The best coho salmon and steelhead trout spawning substrate is classified as Category 1 cobble embeddedness or 0-25% embedded. Category 2 is defined by the substrate being 26-50% embedded.

Cobble embedded deeper than 51% is not within the range for successful spawning. The target value is for 50% or more of the pool tails sampled to be 50% or less embedded (categories 1 and 2). Streams with less than 50% of their length greater than 51% embedded do not meet the target value and do not provide adequate spawning substrate conditions.

Pool Depth/Frequency - Forty Percent or More of the Stream Should Provide Pool Habitat

During their life history, salmonids require access to pools, flatwater, and riffles. Pool enhancement projects are considered when pools comprise less than 40% of the length of total stream habitat. The target values for pool depth are related to the stream order. First and second order streams are required to have 40% or more of the pools 2 feet or deeper to meet the target values. Third and fourth order streams are required to have 40% or more of the pools 3 feet or deeper or 4 feet or deeper, respectively, to meet the target values. A frequency of less than 40% or inadequate depth related to stream order indicates that the stream provides insufficient pool habitat.

Shelter/Cover - Scores of One Hundred or More Means That the Stream Provides Sufficient Shelter/Cover

Pool shelter/cover provides protection from predation and rest areas from high velocity flows for salmonids. Shelter/cover elements include undercut banks, small woody debris, large woody debris, root masses, terrestrial vegetation, aquatic vegetation, bubble curtains (whitewater), boulders, and bedrock ledges. All elements present are measured and scored. Shelter/cover values of 100 or less indicate that shelter/cover enhancement should be considered.

Water Quality

The maximum weekly average temperature (MWAT) is the maximum value of the seven day moving average temperatures. The CWPAP staff created suitability ranges for habitat based on MWATs, considering the effect of temperature on salmonid viability, growth, and habitat fitness (*Table 5*). This metric was calculated from a seven-day moving average of daily average temperatures. The maximum daily average was used to illustrate possible stressful conditions for salmonids. The instantaneous maximum temperature that may lead to salmonid lethality is ≥75°F.

Table 5. CWPAP-defined salmonid habitat quality ratings for MWATs.

MWAT Range	Description
50-62°F	Good habitat
63-65°F	Fair habitat
≥66°F	Poor habitat

Ecological Management Decision Support System

The Ecological Management Decision Support (EMDS) system software was developed at the USDA Forest Service, Pacific Northwest Research Station (Reynolds 1999). It employs a linked set of software that includes MS Excel, NetWeaver, EMDS and ArcGIS™. The NetWeaver software, developed at Pennsylvania State University, helps scientists model linked frameworks of various environmental factors called knowledge base networks (Reynolds et al. 1996).

These networks specify how various environmental factors will be incorporated into an overall stream or watershed assessment. The networks resemble branching tree-like flow charts, graphically showing the assessment's logic and assumptions, and are used in conjunction with spatial data stored in a Geographic Information System (GIS) to perform assessments and render the results into maps.

EMDS was used as an analysis tool in previous NCWAP and CWPAP watershed assessments. However, due to changes in EMDS 4.2 software and compatibility issues with ArcMap 10.0, CWPAP staff created a program in Visual Basic to synthesize information on stream reach condition using instream habitat data for 4 factors: canopy density, pool depth, pool shelter, and cobble embeddedness. Our analysis used similar logic, factors, and assumptions, but a more simplified model framework compared to the EMDS analysis used in previous CWPAP watershed assessments. Habitat suitability maps were designed by importing model output data into ArcMap 10, and the analysis was referred to throughout the assessment report as an "EMDS based analysis". A brief introduction to EMDS is presented below in order to describe the logic and assumptions used in the SF Eel River Basin analysis; for a more detailed explanation, see Appendix A.

Development of the North Coast California EMDS Model

NCWPAP staff began development of EMDS knowledge base models with a three-day workshop in June of 2001 organized by the University of California, Berkeley. In addition to the assessment program staff, model developer Dr. Keith Reynolds and several outside scientists also participated. As a starting point, analysts used an EMDS knowledge base model developed by the Northwest Forest Plan for use in coastal Oregon. Based upon the workshop, subsequent discussions among staff and other scientists, examination of the literature, and consideration of localized California conditions, the assessment team scientists then developed preliminary versions of the EMDS models.

The Knowledge Base Network

For California's north coast watersheds, the assessment team constructed a knowledge base network, the Stream Reach Condition Model. The model was reviewed in April 2002 by an independent nine-member science panel, which provided suggestions for model improvements. According to their suggestions, the team revised the original model. The Stream Reach Condition model addresses conditions for salmonids on individual stream reaches and is largely based on data collected using CDFW stream survey protocols found in the *California Salmonid Stream Habitat Restoration Manual*, (Flosi et al. 2010).

In creating these models, the team used what is termed a tiered, top-down approach. For example, the Stream Reach Condition model tested the truth of the proposition: The overall condition of the stream reach is suitable for maintaining healthy populations of native Chinook, coho, and steelhead trout. A knowledge base network was then designed to evaluate the truth of that proposition, based upon existing data from each stream reach. The model design and contents reflected the specific data and information analysts believed were necessary, and the manner in which they should be combined, to test the proposition.

In evaluating stream reach conditions for salmonids, the model uses data from several environmental factors. The first branching tier of the knowledge base network shows the data based summary nodes on: 1) in-channel condition; 2) stream flow; 3) riparian vegetation and: 4) water temperature (*Figure 5*). These nodes are combined into a single value to test the validity of the stream reach condition suitability proposition. In turn, each of the four summary branch node values is formed from the combination of its more basic data components. The process is repeated until the knowledge base network incorporates all information believed to be important to the evaluation (*Figure 6*).

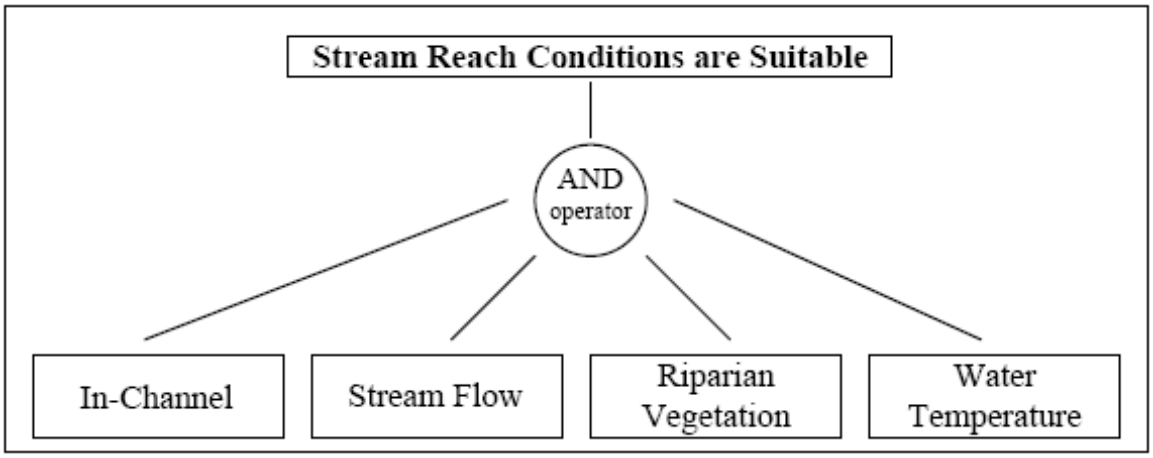

Figure 5. Tier one of the stream reach knowledge base network.

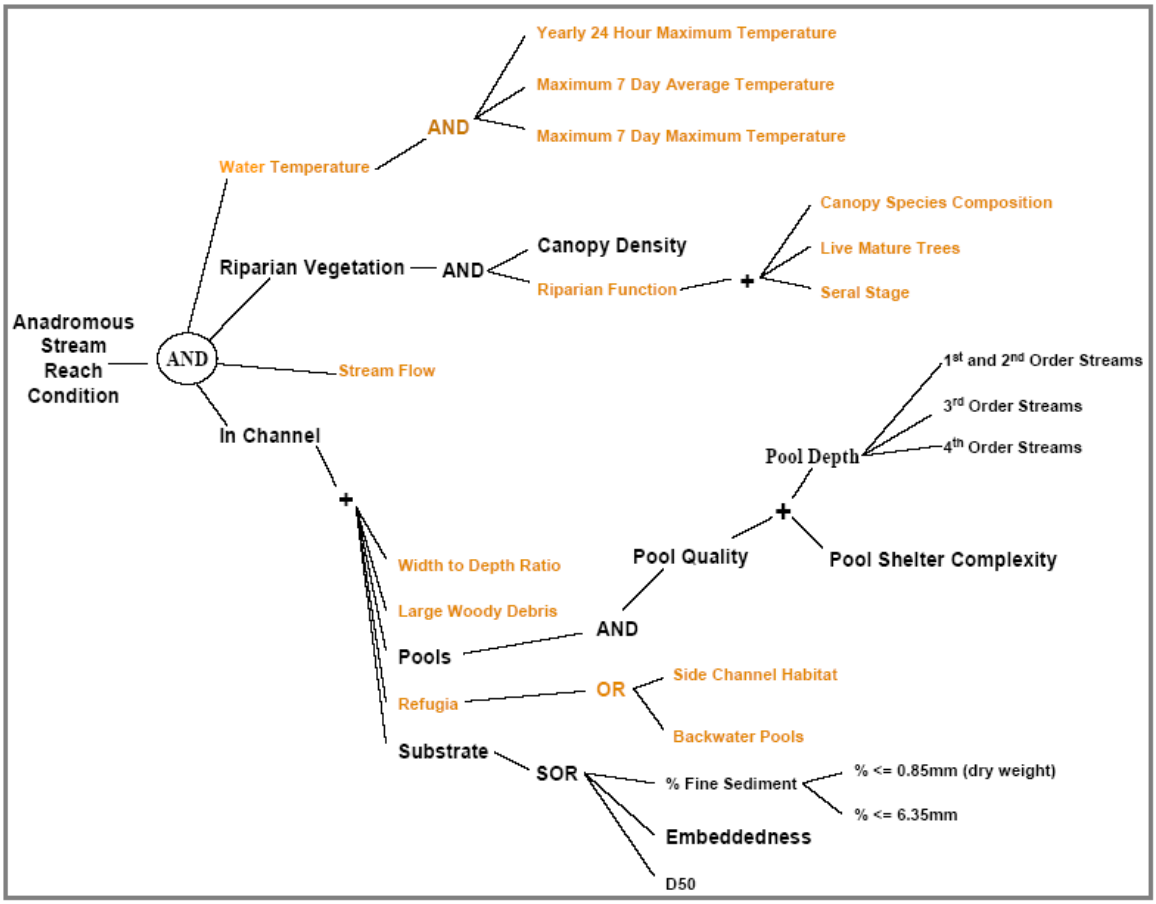

Figure 6. Graphic representation of the stream reach condition model.

Habitat factors populated with data in the SF Eel River Basin assessment model are shown in black. Other habitat factors considered important for stream habitat condition evaluation, but data limited in the SF Eel River assessment, are shown in orange.

In *Figure 5*, the *AND operator* indicates a decision node that means that the lowest, most limiting value of the four general factors determined by the model will be passed on to indicate the potential of the stream reach to sustain salmonid populations. In that sense, the model mimics nature. For example, if summertime low flow is reduced to a level deleterious to fish survival or well-being, regardless of a favorable temperature regime, instream habitat, and/or riparian conditions, the overall stream condition is not suitable to support salmonids.

Although model construction is typically done top-down, models are run in an EMDS type analysis from the bottom up. That is, stream reach data are usually entered at the lowest and most detailed level of the several branches of the network tree (the leaves). The data from the leaves are combined progressively with other related attribute information as the analysis proceeds up the network. Decision nodes are intersections in the model networks where two or more factors are combined before the resultant information moves up the network (*Figure 6*).

The model assesses the degree of truth (or falsehood) of each proposition. Each proposition is evaluated in reference to simple graphs called reference curves that determine the degree of truth/falsehood, according to implications of the data for salmon. *Figure 7* shows an example reference curve for the proposition that stream temperature is suitable for salmon. The horizontal axis shows temperature ranging from 30-80° F, while the vertical axis is labeled Truth Value and ranges from values of +1 to -1. The upper horizontal line arrays the fully suitable temperatures from 50-60°F (+1). The fully unsuitable temperatures are arrayed at the bottom (-1). Those in between range from fully suitable to fully unsuitable and are rated accordingly. A similar numeric relation is determined for all attributes evaluated with reference curves in the models.

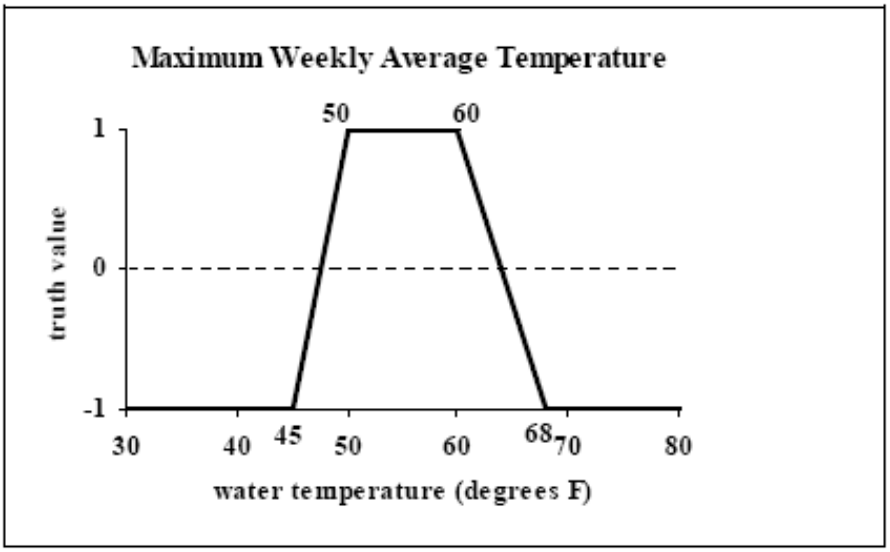

Figure 7. Reference curve for stream temperature.

This type of reference curve is used in conjunction with data specific to a stream reach. This example reference curve evaluates the proposition that instream water temperature is suitable for salmonids. Break points on the curve can be set for individual species, life stages, or seasons of the year. Curves are dependent on the availability of data to be included in an analysis.

For each evaluated proposition in the model network, the result is a number between –1 and +1. The number relates to the degree to which the data support or refute the proposition. In all cases a value of +1 means that the proposition is completely true, and –1 implies that it is completely false, while in-between values indicate degrees of truth (i.e. values approaching +1 are closer to true and those approaching –1 are closer to completely untrue). A zero value means that the proposition cannot be evaluated based upon the data available. Breakpoints occur where the slope of the reference curve changes. For example, in *Figure 7*, breakpoints occur at 45, 50, 60, and 68°F.

CWPAP staff used a four-class system for depicting truth-values. Values ranged between +1 (highest suitability) and –1 (lowest suitability). Between 0 and 1 are two classes which, although unlabeled in the legend, indicate intermediate values of better suitability (0 to 0.5, and 0.5 to 1). Symmetrically, between 0 and –1 are two similar classes which are intermediate values of worse suitability (< 0 to –0.5, and –0.5 to –1). These ranking values are assigned based upon condition findings in relation to the criteria in the reference curves. *Table 6* summarizes Stream Reach Condition model information and parameters.

Table 6. Reference curve metrics for the stream reach condition model.

Stream Reach Condition Factor	Definition and Reference Curve Metrics
Aquatic / Riparian Conditions	
Summer MWAT	• Maximum 7-day average summer water temperature • < 45°F fully unsuitable, 50-60°F fully suitable, > 68°F fully unsuitable. • Water temperature was not included in current evaluation.
Riparian Function	
Canopy Density	• Average percent of the thalweg within a stream reach influenced by tree canopy. • < 50% fully unsuitable, ≥ 85% fully suitable.
Seral Stage	Seral stage composition of near stream forest. Under development.
Vegetation Type	Forest composition Under development.
Stream Flow	Model parameters are in development; currently, stream flow is considered separately from EMDS based analysis in the assessment process.

Stream Reach Condition Factor	Definition and Reference Curve Metrics
In-Channel Conditions	
Pool Depth	• Percent of stream reach with pools of a maximum depth of 2.5, 3, and 4 feet deep for first and second, third, and fourth order streams respectively. • ≤ 15% fully unsuitable, 33 – 55% fully suitable, ≥ 85% fully unsuitable.
Pool Shelter Complexity	• Relative measure of quantity and composition of large woody debris, root wads, boulders, undercut banks, bubble curtain, overhanging and instream vegetation. • ≤ 30 fully unsuitable, ≥ 100 - 300 fully suitable.
Pool Frequency	Percent of pools by length in a stream reach. Under development.
Substrate Embeddedness	• Pool tail embeddedness is a measure of the percent of small cobbles (2.5" to 5" in diameter) buried in fine sediments. • The model calculates categorical embeddedness data to produce evaluation scores between –1 and +1. The proposition is fully true if evaluation scores are 0.8 or greater and -0.8 evaluate to fully false.
Percent Fines in Substrate <0.85mm (dry weight)	• Percent of fine sized particles <0.85 mm collected from McNeil type samples. • < 10% fully suitable, > 15% fully unsuitable. • There was not enough of percent fines data to use percent fines in evaluations
Percent Fines in Substrate <6.4 mm	• Percent of fine sized particles < 6.4 mm collected from McNeil type samples. • <15% fully suitable, >30% fully unsuitable. • There was not enough of percent fines data to use percent fines in evaluations.
Large Woody Debris (LWD)	• The reference values for frequency and volume are derived from Bilby and Ward (1989) and are dependent on channel size. • See Analysis Appendix for details. • Most watersheds do not have sufficient LWD survey data for use in the analysis.
Winter Refugia Habitat	• Winter refugia habitat is composed of backwater pools, side channel habitats, and deep pools (> 4 feet deep). • Not implemented at this time.
Pool to Riffle Ratio	Ratio of pools to riffle habitat units. Under development.
Width to Depth Ratio	Ratio of bankfull width to maximum depth at velocity crossovers. Under development.

Advantages Offered by EMDS Based Analysis

The EMDS based analysis offers a number of advantages for use in watershed assessments. Instead of being a hidden black box, each model has an open and intuitively understandable structure. The explicit nature of the model networks facilitates open communication among agency personnel and with the general public through simple graphics and easily understood flow diagrams. The models can be easily modified to incorporate alternative assumptions about the conditions of specific environmental factors (e.g., stream water temperature) required for suitable salmonid habitat.

Using model outputs, CWPAP staff used Geographic Information System (GIS) software, to map the factors affecting fish habitat and show how they vary across a basin. The models also provide a consistent and repeatable approach to evaluating watershed conditions for fish. In addition, the maps from supporting levels of the model show the specific factors that, taken together, determine overall watershed conditions. This latter feature can help identify what is most limiting to salmonids, and thus assist in prioritizing restoration projects or modifying land use practices.

Limitations of the EMDS Based Model and Data Input

While EMDS based syntheses are important tools for watershed assessment, they do not by themselves yield a course of action for restoration and land management. Analysis results require interpretation, and how they are employed depends upon other important issues, such as social and economic concerns. In addition to the accuracy of the model constructed, the dates and completeness of the data available for a stream or watershed will strongly influence the degree of confidence in the results. External validation of the model using fish population data and other information should be done.

One disadvantage of linguistically based models is that they do not provide results with readily quantifiable levels of error. Therefore, the EMDS model should only be used to indicate the quality of watershed or instream conditions based on available

data and the model structure. It is not intended to provide highly definitive answers, such as those obtained from a statistically based process model. The model does provide a reasonable first approximation of conditions through a robust information synthesis approach; however, its outputs need to be considered and interpreted using other information sources and with an understanding of the inherent limitations of the model and its data inputs. It also should be clearly noted that this model does not assess the marine phase of the salmonid life cycle, nor does it consider fishing pressures.

Program staff identified some model or data elements needing attention and improvement in future iterations. These currently include:

- Completion of quality control evaluation procedures;
- Adjust the model to better reflect differences between mainstem and tributary habitat, for example, the modification of canopy density standards for wide streams;
- Develop a suite of Stream Reach Model reference curves to better reflect the variation in expected conditions for different geographic watershed locations, depending on geology, vegetation, precipitation, and runoff patterns.

At this time, all of the recommendations made by peer reviewers have not been implemented into the models. Additionally, results should be used as valuable but not necessarily definitive products, and their validation with other observations is necessary. The *Analysis Appendix* provides additional detail concerning the system structure and operations.

Adaptive Application for EMDS Based Model and CDFW Stream Habitat Evaluations

CDFW has developed habitat evaluation standards, or target values, to help assess the condition of anadromous salmonid habitat in California streams (Flosi et al. 2010). These standards are based upon data analyses of over 1,500 tributary surveys, and considerable review of pertinent literature. The model reference curves have similar standards, adapted from CDFW, but following peer review and professional discussion, they have been modified slightly. As a result, slight differences occur between values found in Flosi et al. (2010) and those used in the model. Reference curves developed for the analysis are provided in the *Analysis Appendix* of this report.

Both habitat evaluation systems have similar but slightly different functions. Stream habitat standards developed by CDFW are used to identify habitat conditions and to establish priorities among streams considered for improvement projects based upon standard CDFW tributary reports. The EMDS based model compares select components of the stream habitat survey data to reference curve values and expresses degrees of habitat suitability for fish on a sliding scale. In addition, the model produces a combined estimate of overall stream condition by combining the results from several stream habitat components. In the fish habitat relationship section of this report, we utilize target values found in Flosi et al. (2010), field observations, and results from reference curve evaluations to help describe and evaluate stream habitat conditions.

Due to the wide range of geology, topography and diverse stream channel characteristics which occur within the North Coast region, there are streams that require more detailed interpretation and explanation of results than can be simply generated by suitability criteria or tributary survey target values. For example, pools are an important habitat component and a useful stream attribute to measure. However, some small fish-bearing stream channels may not have the stream power to scour pools of the depth and frequency considered to be high value “primary” pools by CDFW target values, or to be fully suitable according to the model. Often, these shallow pool conditions are found in low gradient stream reaches in small watersheds that lack sufficient discharge to deeply scour the channel. They also can exist in moderate to steep gradient reaches with bedrock/boulder dominated substrate highly resistant to scour, which also can result in few deep pools. Therefore, some streams may not have the inherent ability to attain conditions that meet the suitability criteria or target values for pool depth. These scenarios result in pool habitat conditions that are not considered highly suitable by either assessment standard. However, these streams may still be very important because of other desirable features that support valuable fishery resources. As such, they receive additional evaluation with our refugia rating system and expert professional judgment. Field validation of any modeling system results is a necessary component of watershed assessment and reporting.

Limiting Factors Analysis

A main objective of CDFW watershed assessment is to identify factors that limit production of anadromous salmonid populations in North Coast watersheds.

This process is known as a limiting factors analysis (LFA). The limiting factors concept is based upon the assumption that eventually every population must be limited by the availability of necessary support resources (Hilborn and Walters 1992) or that a population's potential may be constrained by an overabundance, deficiency, or absence of a watershed ecosystem component. Identifying stream habitat factors that limit or constrain anadromous salmonids is an important step towards setting priorities for habitat improvement projects and management strategies aimed at the recovery of declining fish stocks and protection of viable fish populations.

Although several factors have contributed to the decline of anadromous salmonid populations in the Northwest, habitat loss and modification are major determinants of their current status (FEMAT 1993, Yoshiyama and Moyle 2010). Our approach to a LFA integrates two habitat based methods to evaluate the status of key aspects of stream habitat that affect anadromous salmonid production - species life history diversity and the ability of a stream to support viable populations.

The first method uses priority ranking of habitat categories based on a CDFW team assessment of data collected during stream habitat inventories. The second method uses the EMDS based model to evaluate the suitability of key stream habitat components to support anadromous fish populations. These habitat-based methods assume that stream habitat quality and quantity play important roles in the ability of a watershed to produce viable salmonid populations.

The LFA assumes that poor habitat quality and a reduction in favorable habitat impairs fish production. LFA focuses primarily on those physical habitat factors in freshwater and estuarine ecosystems that affect spawning and subsequent juvenile life history requirements during low flow seasons. Two general categories of factors or mechanisms limit salmonid populations:

- Density independent mechanisms, which generally operate without regard to population density. These include factors related to habitat quality such as stream flow and water temperature or chemistry. In general, fish will die regardless of the population density if flow is inadequate, or if water temperatures or chemistry reach lethal levels; and
- Density dependent mechanisms, which generally operate according to population density and habitat carrying capacity. Competition for food, space, and shelter are examples of density dependent factors that affect growth and survival when populations reach or exceed the habitat carrying capacity.

The CWPAP approach considers these two types of habitat factors before prioritizing recommendations for habitat management strategies. Priority steps are given to preserve and increase the amount of high quality (density independent) habitat in a cost effective manner.

Restoration Needs/Tributary Recommendations Analysis

CDFW crews inventoried 118 tributaries to the SF Eel River between 1990 and 2010, using protocols in the *California Salmonid Stream Habitat Restoration Manual* (Flosi et al. 2010). The stream inventories are a combination of several stream reach surveys: habitat typing, channel typing, biological assessments, and in some reaches LWD and riparian zone recruitment assessments. An experienced Biologist and/or Habitat Specialist conducted quality assurance/quality control (QA/QC) on field crews and collected data, performed data analysis, and determined general areas of habitat deficiency based upon the analysis and synthesis of information.

CDFW biologists selected and ranked recommendations for each of the inventoried streams, based upon the results of these standard CDFW habitat inventories, and updated the recommendations with the results of the stream reach condition EMDS based synthesis and the refugia analysis (*Table 7*). These selections are made from stream reach conditions that were observed at the times of the surveys and do not include upslope watershed observations other than those that could be made from the streambed. They reflect a single point in time and do not anticipate future conditions. However, these general recommendation categories have proven to be useful as the basis for specific project development, and they provide focus for on-the-ground project design and implementation.

It is important to remember that stream and watershed conditions change over time and periodic survey updates and field verification are necessary if watershed improvement projects are being considered. In general, recommendations designed to reduce erosion and sediment input by treating roads and failing stream banks, and those that improve riparian and near stream vegetation, precede instream recommendations in reaches within watersheds with high levels of disturbance. Instream improvement recommendations are usually a high priority in streams that reflect watersheds in recovery or those in good health. Various project treatment recommendations can be made concurrently if watershed and stream conditions warrant.

Table 7. List of tributary recommendations in stream tributary reports.

Recommendation	Explanation
Water Surface Flows	Dry stream reaches were measured and analyzed to be a high percent of overall stream length surveyed and impacting the aquatic community.
Water Temperature	Summer water temperatures were measured to be above optimum for salmon and steelhead in survey reaches
Pool	Pools are below CDFW target values in quantity and/or quality
Cover	Escape cover is below CDFW target values
Bank	Stream banks are failing and yielding fine sediment into the stream
Roads	Fine sediment is entering the stream from the road system
Canopy	Shade canopy is below CDFW target values
Spawning Gravel	Spawning gravel is deficient in quantity and/or quality
LDA	Large debris accumulations are retaining large amounts of gravel and could need modification
Livestock	There is evidence that stock is impacting the stream or riparian area and exclusion should be considered
Fish passage	There are barriers to fish migration in the stream

Fish passage problems, especially in situations where favorable stream habitat reaches are being separated by a man-caused feature (e.g., culvert), are usually a treatment priority. Good examples of these are the recent and dramatically successful Humboldt County/CDFW culvert replacement projects in tributaries to Humboldt Bay. In these regards, the program's more general watershed scale upslope assessments can go a long way in helping determine the suitability of conducting instream improvements based upon watershed health. As such, there is an important relationship between the instream and upslope assessments.

Additional considerations must enter into the decision-making process before these general recommendations are further developed into improvement activities. In addition to watershed condition considerations as a context for these recommendations, there are certain logistic considerations involved in ranking recommendations for project development. These can include work party access limitations based upon lack of private party trespass permission and/or physically difficult or impossible locations of selected work sites. Biological considerations are made based upon the propensity for potential projects to benefit multiple or single fishery stocks or species. Cost benefit and project feasibility are also important factors in project design, development, and selection.

Potential Salmonid Refugia

Establishment and maintenance of salmonid refugia areas containing high quality habitat and sustaining fish populations are activities vital to the conservation of our anadromous salmonid resources (FEMAT 1993; Reeves et al. 1995). Protecting these areas will prevent the loss of remaining high quality salmon habitat and salmonid populations. Therefore, a refugia investigation project should focus on identifying areas found to have high salmonid productivity and diversity.

Identified areas should then be carefully managed for the following benefits:

- Protection of refugia areas to avoid loss of the last best salmon habitat and populations. The focus should be on protection for areas with high productivity and diversity;
- Refugia area populations which may provide a source for re-colonization of salmonids in nearby watersheds that have experienced local extinctions, or are at risk of local extinction due to small population size and stochastic effects;
- Refugia areas provide a hedge against the difficulty in restoring extensive, degraded habitat and recovering imperiled populations in a timely manner.

The concept of refugia is based on the premise that patches of aquatic habitat provide habitat that retains the natural capacity and ecologic functions to support wild anadromous salmonid spawning and rearing. Anadromous salmonids exhibit typical features of patchy populations; they exist in dynamic environments and have developed various dispersal strategies including juvenile movements, adult straying, and relatively high fecundity for an animal that exhibits some degree of parental care through nest building (Reeves et al. 1995).

Conservation of patchy populations requires conservation of multiple suitable habitat patches and maintenance of passage corridors between them. Potential refugia may exist in areas where the surrounding landscape is marginally suitable for salmonid production or altered to a point that stocks have shown dramatic population declines in traditional salmonid streams (Bartholow 2005, Sutton and Soto 2012). If altered streams or watersheds recover their historic natural productivity through either restoration efforts or natural processes, the abundant source populations from nearby refugia can potentially re-colonize these areas or help sustain existing salmonid populations in marginal habitat (May and Peterson 2003). Protection of refugia areas is noted as an essential component of conservation efforts to ensure long-term survival of viable stocks, and a critical element towards recovery of depressed populations (Sedell et al. 1990; FEMAT 1993; Frissell 1993, Frissell et al. 2000).

Refugia habitat elements include the following:

- Areas that provide shelter or protection during times of danger or distress;
- Locations and areas of high quality habitat that support populations limited to fragments of their former geographic range, and;
- A center from which dispersion may take place to re-colonize areas after a watershed and/or subwatershed level disturbance event and readjustment.

Spatial and Temporal Scales of Refugia

These refugia concepts become more complex in the context of the wide range of spatial and temporal habitat required for viable salmonid populations. Habitat can provide refuge at many scales from a single fish to groups of them, and finally to breeding populations. For example, refugia habitat may range from a piece of wood that provides instream shelter for a single fish, or individual pools that provide cool water for several rearing juveniles during hot summer months, to watersheds where conditions support sustaining populations of salmonid species. Refugia also include areas where critical life stage functions such as migrations and spawning occur, at both the stream reach and watershed scale (Feist et al. 2003). Although fragmented areas of suitable habitat are important, their connectivity is necessary to sustain the fisheries (May and Peterson 2003).

Today, watershed scale refugia are needed to recover and sustain aquatic species (Moyle and Sato 1991). For the purpose of this discussion, refugia are considered at the fish bearing tributary and subbasin scales. These scales of refugia are generally more resilient to the deleterious effects of landscape and riverine disturbances such as large floods, persistent droughts, and human activities than the smaller, habitat unit level scale (Sedell et al. 1990).

Standards for refugia conditions are based on reference curves from the literature and CDFW data collection at the regional scale. CWPAP staff used these values in EMDS models to formulate recommendations. Li et al. (1995) suggested three prioritized steps to use the refugia concept to conserve salmonid resources:

- Identify salmonid refugia and ensure that they are protected;
- Identify potential habitats that can be rehabilitated quickly;
- Determine how to connect dispersal corridors to patches of adequate habitat.

Refugia and Metapopulation Concept

The concept of anadromous salmonid metapopulations is important when discussing refugia. The classic metapopulation model proposed by Levins (1969) assumes that the environment is divided into discrete patches of suitable habitat. These patches include streams or stream reaches that are inhabited by different breeding populations or sub-populations (Barnhart 1994; McElhany et al. 2000). A metapopulation consists of a group of sub-populations which are geographically located such that over time, there is likely genetic exchange between the subpopulations (Barnhart 1994). Metapopulations are characterized by:

1) Relatively isolated, segregated breeding populations in a patchy environment that are connected to some degree by migration between them, and

2) A dynamic relationship between extinction and re-colonization of habitat patches.

Anadromous salmonids fit well into the subpopulation and metapopulation concept because they exhibit a strong homing behavior to natal streams forming sub-populations, and they have a tendency to stray into new areas. The straying or movement into nearby areas results in genetic exchange between subpopulations or seeding of other areas where populations are at low levels. This seeding comes from abundant or source populations supported by high quality habitat patches which may be considered refugia (May and Peterson 2003).

Habitat patches differ in suitability and population strength. In addition to the classic metapopulation model, other theoretical types of spatially structured populations have been proposed (Li et al. 1995; McElhany et al. 2000). For example, the core and satellite (Li et al. 1995) or island-mainland population (McElhany et al. 2000) model depicts a core or mainland population from which dispersal to satellites or islands results in smaller surrounding populations. Most straying occurs from the core or mainland to the satellites or islands. Satellite or island populations are more prone to extinction than the core or mainland populations (Li et al. 1995; McElhany et al. 2000).

Another model termed source-sink populations is similar to the core-satellite or mainland-island models, but straying is one way, only from the highly productive source towards the sink subpopulations. Sink populations are not self-sustaining and are highly dependent on migrants from the source population to survive (May and Peterson 2003). Sink populations may inhabit typically marginal or unsuitable habitat, but when environmental conditions strongly favor salmonid production, sink population areas may serve as important sites to buffer populations from disturbance events (Li et al. 1995) and increase basin population strength. In addition to testing new areas for potential suitable habitat, the source-sink strategy adds to the diversity of behavior patterns salmonids have adapted to maintain or expand into a dynamic aquatic environment.

The metapopulation and other spatially structured population models are important to consider when identifying refugia because in dynamic habitats, the location of suitable habitat changes (McElhany et al. 2000) over the long term from natural disturbance regimes (Reeves et al. 1995) and over the short term by human activities. Satellite, island/patch, and sink populations need to be considered in the refugia selection process because they are an integral component of the metapopulation concept. They also may become the source population or refugia areas of the future.

Methods to Identify Refugia

Currently there is no established methodology to designate refugia habitat for California's anadromous salmonids. This is mainly due to a lack of sufficient data describing fish populations, metapopulations, habitat conditions, and productivity across large areas. This lack of information is consistent across all study basins especially in terms of metapopulation dynamics. Studies are needed to determine population growth rates and straying rates of salmonid populations and sub-populations to better utilize spatial population structure to identify refugia habitat.

Classification systems, sets of criteria, and rating systems have been proposed to help identify refugia type habitat in north coast streams, particularly in Oregon and Washington (Moyle and Yoshiyama 1992; FEMAT 1993; Li et al. 1995; Frissell et al. 2000). Upon review of these works, several common themes emerge. A main theme is that refugia are not limited to areas of pristine habitat. While ecologically intact areas serve as dispersal centers for stock maintenance and potential recovery of depressed sub-populations, lower quality habitat areas also play important roles in long-term salmonid metapopulation maintenance. These areas may be considered the islands, satellites, or sinks in the metapopulation concept. Implementing ecosystem management strategies that are aimed at maintaining or restoring natural processes may result in improved habitat quality, increases in fish numbers, and stronger metapopulations.

A second common theme is that over time within the landscape mosaic of habitat patches, high quality habitat areas will suffer impacts and become less productive, while areas of low quality habitat will recover and become more productive. These processes can occur through either human caused or natural disturbances or through succession to new ecological states. Regardless, it is important that a balance be maintained in this alternating, patchwork dynamic to ensure that adequate high quality habitat is available to support viable anadromous salmonid populations (Reeves et al. 1995).

Approach to Identifying Refugia

The CWPAP interdisciplinary refugia identification team identified and characterized refugia habitat using expert professional judgment and criteria developed for North Coast watersheds. The criteria considered different values of watershed and stream ecosystem processes, the presence and status of fishery resources, water quality, and other factors that may affect refugia productivity. The expert refugia team encouraged other specialists with local knowledge to participate in the refugia identification and categorization process.

The team also used results from information processed by the EMDS at the stream reach and planning watershed/subbasin scales. Stream reach and watershed parameter evaluation scores were used to rank stream and watershed conditions based on field data. Stream reach scale parameters included pool shelter rating, pool depth, embeddedness, and canopy cover. Water temperature data were also used when available. The individual parameter scores identified which habitat factors currently support or limit fish production (see EMDS and limiting factors sections).

Professional judgment, field note analysis, local expert opinion, habitat inventory survey results, water quality data results, and EMDS scores determined potential locations of refugia. If a habitat component received a suitable ranking from the EMDS model, it was cross-referenced with survey results from that particular stream and with field notes from that survey. The components identified as potential refugia were then ranked according to their suitability to encourage and support salmonid health.

When identifying anadromous salmonid refugia, the program team considered several non-substitutable habitat needs for salmonids at various stages of their life cycle. According to NMFS (2001), these needs include:

- Adult migration pathways;
- Spawning and incubation habitat;
- Stream rearing habitat;
- Forage and migration pathways;
- Estuarine habitat.

The highest quality refugia areas are large, meet all of these life history needs, and therefore provide complete functionality to salmonid populations. These large, intact systems are scarce today and smaller refugia areas that provide only some of the requirements have become very important areas, but they cannot sustain large numbers of fish. These must operate in concert with other fragmented habitat areas for life history support, and refugia connectivity becomes very important for success (May and Peterson 2003). The refugia team considered relatively small areas in tributaries because they provide partial refuge values while contributing to the overall refugia rating of larger scale areas. Therefore, the team's analyses used the tributary scale as the fundamental refugia unit. CDFW created a tributary scale refugia-rating worksheet with 21 condition factors that were rated on a sliding scale from high quality to low quality.

The 21 condition factors were grouped into five categories:

- Stream condition;
- Riparian condition;
- Native salmonid status;
- Present salmonid abundance;
- Management impacts (disturbance impacts to terrain, vegetation, and the biological community).

Additionally, NCRWQCB created a worksheet specifically for rating water quality refugia. The worksheet has 13 condition factors that were rated on a sliding scale from high quality to low quality.

These 13 condition factors were grouped into three categories:

- In-stream sediment related;
- Stream temperature related;
- Water chemistry related.

Tributary ratings were determined by combining the results of NCRQCB water quality results, EMDS results, and data in CDFW tributary reports by a multidisciplinary, expert team of analysts. The various factors' ratings were combined to determine an overall tributary rating on a scale from high to low quality refugia. Tributary ratings were subsequently aggregated at the subbasin scale and expressed a general estimate of subbasin refugia conditions. Factors with limited or missing data were noted. In most cases there were data limitations on 1–3 factors. These were identified for further investigation and inclusion in future analyses.

The program has created a hierarchy of refugia categories that contain several general habitat

conditions. This descriptive system is used to rank areas by applying results of the analyses of stream and watershed conditions described above, and are used to determine the ecological integrity of the study area. A basic definition of ecological integrity is "the ability [of an ecosystem] to support and maintain a balanced, integrated, and functional organization comparable to that of the natural habitat of the region" (Karr and Dudley 1981).

Salmonid Refugia Categories and Criteria

High Quality Habitat, High Quality Refugia:

- Maintains a high level of watershed ecological integrity;
- Contains the range and variability of environmental conditions necessary to maintain community and species diversity and supports natural salmonid production;
- Contains relatively undisturbed and intact riparian corridor;
- All age classes of historically native salmonids present in good numbers, and a viable population of an ESA listed salmonid species is supported;
- Provides population seed sources for dispersion, gene flow and re-colonization of nearby habitats from straying local salmonids;
- Contains a high degree of protection from degradation of its native components.

High Potential Refugia

- Watershed ecological integrity is diminished but remains good;
- Instream habitat quality remains suitable for salmonid production and is in the early stages of recovery from past disturbance;
- Riparian corridor is disturbed, but remains in fair to good condition;
- All age classes of historically native salmonids are present including ESA listed species, although in diminished numbers;
- Salmonid populations are reduced from historic levels, but still are likely to provide straying individuals to neighboring streams;
- Currently is managed to protect natural resources and is resilient to degradation, which demonstrates a strong potential to become high quality refugia.

Medium Potential Refugia

- Watershed ecological integrity is degraded or fragmented;
- Components of instream habitat are degraded, but support some salmonid production;
- Riparian corridor components are somewhat disturbed and in degraded condition;
- Native anadromous salmonids are present, but in low densities; some life stages or year classes are missing or only occasionally represented;
- Relatively low numbers of salmonids make significant straying unlikely;
- Current management or recent natural events have caused impacts, but if positive change in either or both occurs, responsive habitat improvements should occur.

Low Quality Habitat, Low Potential Refugia

- Watershed ecological integrity is impaired;
- Most components of instream habitat are highly impaired;
- Riparian corridor components are degraded;
- Salmonids are poorly represented at all life stages and year classes, especially older year classes;
- Low numbers of salmonids make significant straying very unlikely;
- Current management and/or natural events have significantly altered the naturally functioning ecosystem and major changes in either of both are needed to improve conditions.