Program Introduction and Overview

Assessment Needs for Salmon Recovery & Watershed Protection

The Big River Basin Assessment began as a project of the North Coast Watershed Assessment Program (NCWAP). That program was established by the state Legislature in July 2000 and was managed by the California Resources Agency and the California Environmental Protection Agency. Participating Resource Agency departments included Fish and Game (CDFG), Forestry and Fire Protection (CDF), Conservation/California Geologic Survey (DOC/CGS), and Water Resources (DWR), in conjunction with the North Coast Regional Water Quality Control Board (NCRWQCB) and State Water Resources Control Board.

In July 2003, after conducting large scale assessments on the Mattole and Gualala rivers, and Redwood Creek, the program was eliminated because of reductions in the state budget. However, large-scale watershed assessment efforts are ongoing by the CDFGs Coastal Watershed Planning and Assessment Program (CWPAP), with input from other Resources Agency departments as budgets allow.

Program Assessment Region

The original NCWAP was to provide baseline environmental and biological information for approximately 6.5 million acres of public and private lands over a several-year period. This area was to include all coastal drainages from Sonoma County north to Oregon, corresponding with the North Coast Region Water Quality Control board's region (Figure 1). The Big River Basin assessment is one of five watershed assessments initiated by NCWAP. Three of them, the Albion River, Redwood Creek, and Big River, were completed by CWPAP. The two NCWAP reports were for the Mattole and Gualala rivers.

Figure 1. Original NCWAP basin assessment area.

Program Guiding Questions

The program's work intends to provide answers to the following assessment questions at the basin and subbasin scales in California's North Coast watersheds:

- What are the history and trends of the size, distribution, and relative health and diversity of salmonid populations?
- What are the current salmonid habitat conditions? How do these conditions compare to desired conditions?

- What are the impacts of geologic, vegetative, fluvial, and other natural processes on watershed and stream conditions?
- How has land use affected these natural processes?
- Based upon these conditions, trends, and relationships, are there elements that could be considered to be limiting factors for salmon and steelhead production?
- What watershed and habitat improvement activities would most likely lead toward more desirable conditions in a timely, cost effective manner?

Program Goals

The program was developed to improve decision-making by landowners, watershed groups, agencies, and other stakeholders with respect to restoration projects and management practices to protect and improve salmonid habitat. It was therefore essential that the program took steps to ensure its assessment methods and products would be understandable, relevant, and scientifically credible. As a result, the interagency team developed the following 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 assist landowners, local watershed groups, and individuals to develop successful projects. This will help guide programs, like the CDFG Fishery Restoration Grants Program, toward those watersheds and project types that can efficiently and effectively improve freshwater habitat and support recovery of salmonid populations;
- Provide assessment information to help focus cooperative interagency, nonprofit and private sector approaches to protect the best watersheds and streams through watershed stewardship, conservation easements, and other incentive programs; and
- 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. 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. 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. These life requirements must be provided by diverse and complex instream habitats as the fish move through their life cycles. If any life requirements are missing or in poor condition at the time a fish or stock requires it, fish survival can be impacted. 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.

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 (Bjorn 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. 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 pools riffles and flatwater habitats.

Two important watershed goals are the protection and maintenance of high quality fish habitats. In addition to preservation of high quality habitat, reparation of streams damaged by poor resource management practices of the past is important for anadromous salmonids. 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 judge 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, such as the 1955 and 1964 north coast floods, which were system reset events. 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. Thus, it is important to understand the critical, interdependent relationships of salmon and steelhead with their natal streams during their freshwater life phases, and 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 181 square mile Big River 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 in 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; Leider 1989).

Human disturbance sites, although individually small in comparison to natural disturbance events, usually are spatially distributed widely 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 forty-acre landslide or wildfire covering several square miles. However, when all the roads in a basin the size of the Big 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 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.

Human disturbances are often concentrated in time because of newly developed technology or market forces such as the California Gold Rush or the post-WWII logging boom in Northern California. 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 the basin and regional scales. The result of these recent combined disruptions has overlain the pre-European disturbance regime process and conditions.

Consequently, stream habitat quality and quantity are generally depressed across most of the North Coast region. It is within this widely impacted environment that both human and natural disturbances continue to occur, but with vastly fewer habitat refugia lifeboats 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.

Although no long-term fish counts exist for the Big River Basin, Department of Fish and Game fish ladder counts at Benbow Dam and Cape Horn Dam, in the Eel River system, reflect an over 80% decline in coho salmon, Chinook salmon, and steelhead trout populations over the span of the last century (Figure 2, Figure 3). The Eel River, especially the South Fork Eel River, which is the location of Benbow Dam, although much larger, has similar watershed conditions and land use history to the Big River Basin. Anecdotal evidence from anglers and longtime local residents supports the likelihood of a similar decline in Big River fisheries (see Big River Basin Profile).

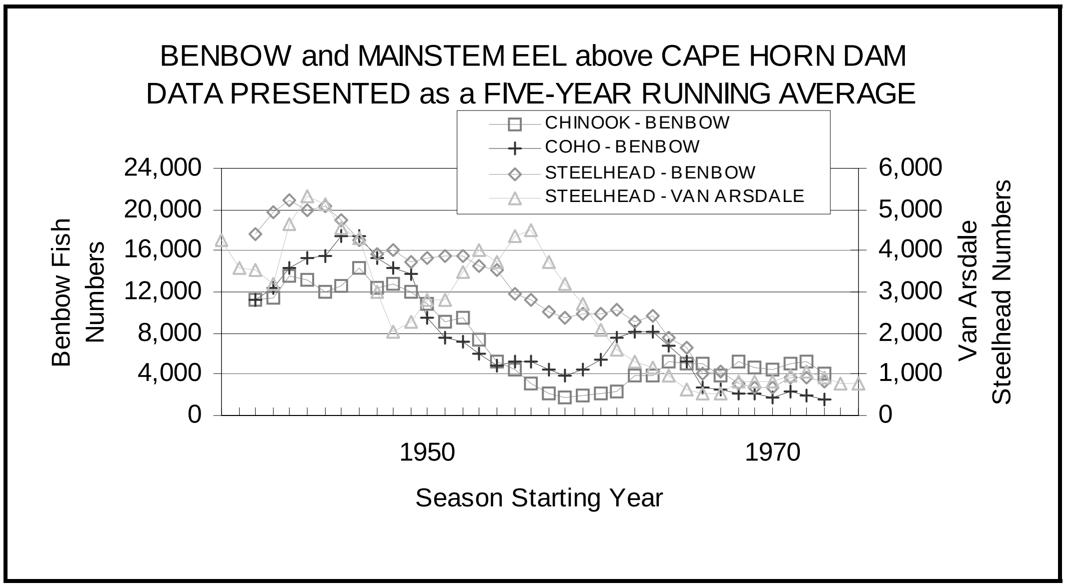

Figure 2. Five-year running average of salmonids at Benbow Dam, South Fork Eel River, and mainstem Eel River above Cape Horn Dam.

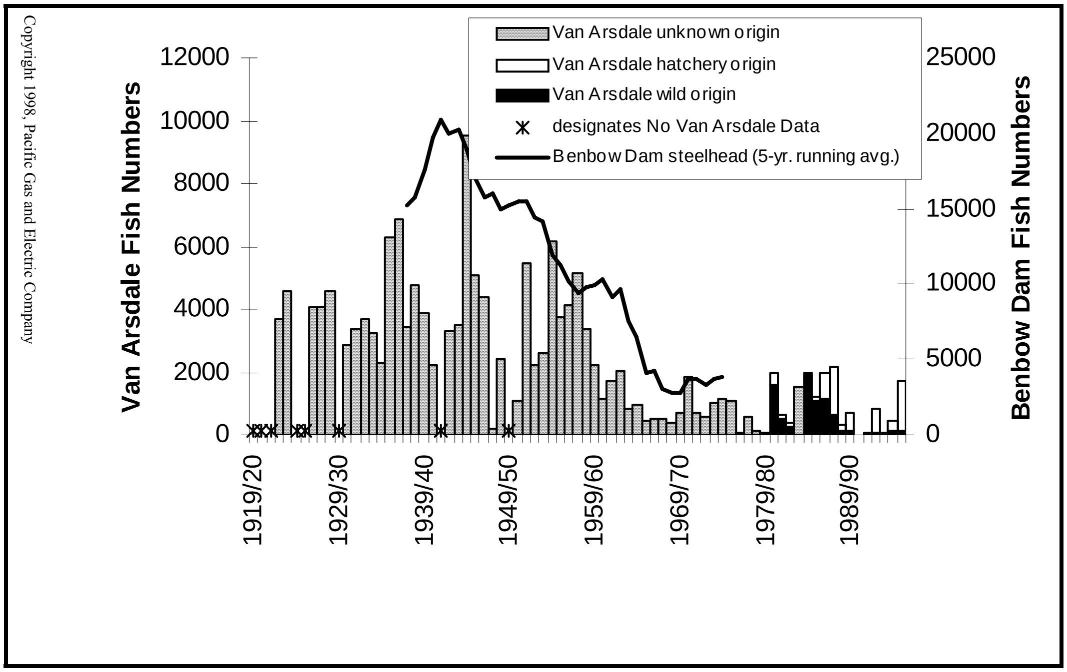

Figure 3. Historical steelhead trout ladder counts at Van Arsdale Fisheries Station, mainstem Eel River, and Benbow Dam, South Fork Eel River.

Factors Affecting Anadromous Salmonid Production

A main component of the program is the analyses of the freshwater factors in order to identify whether any of these factors are at a level that limits production of anadromous salmonids in North Coast basins. 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.[1] These analyses 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 will be useful to identify underlying causes of stream habitat deficiencies and help reveal if there is a linkage to watershed processes and land use activities.

Chinook salmon, coho salmon, and steelhead trout all utilize headwater streams, larger rivers, estuaries, and the ocean for parts of their life history cycles. There are several factors necessary for the successful completion of an anadromous salmonid life history.

In the freshwater phase in salmonid life history, adequate flow, free passage, good stream conditions, and functioning riparian areas are essential for survival. 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.

Free passage describes the absence of barriers to the free 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. Temporary or permanent dams, poorly constructed road crossings, landslides, debris jams, or other natural and/or man-caused channel disturbances can disrupt.

Stream condition includes several factors: adequate stream flow, suitable water quality, suitable stream temperature, and complex habitat. For successful salmonid production, stream flows should follow the natural hydrologic regime of the basin. A natural regime minimizes the frequency and magnitude of storm flows and promotes better flows during dry periods of the water year. Salmonids evolved with the natural hydrograph of

---

[1] 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.

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.

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 adult resting areas. A high level of fine sediment fills pools and flatwater habitats. This reduces depths and can bury complex niches created by large substrate and woody debris. Riffles provide clean spawning gravels and oxygenate water as it tumbles across them. 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.

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. 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. This eventually reverberates through the food chain and affects salmonid food availability. Additionally, high levels of turbidity interfere with a juvenile salmonids' ability to feed and can lead to reduced growth rates and survival (Bill Trush, Trush & Associates; personal communication).

A third important aspect of water quality is stream sediment load. Salmonids cannot successfully reproduce when forced to spawn in streambeds with excessive silt, clays, and other fine sediment. Eggs and embryos suffocate under excessive fine sediment conditions because oxygenated water is prevented from passing through the egg nest, or redd. Additionally, high sediment loads can cap the redd and prevent emergent fry from escaping the gravel into the stream at the end of incubation. 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. Additionally, materials toxic to salmonids can cling to sediment and be transported through downstream areas.

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. Larval and adult macro-invertebrates are important to the salmonid diet and are dependent upon nutrient contributions from the riparian zone. 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).

Therefore, excessive natural or man-caused disturbances to the riparian zone, as well as directly to the stream and/or the basin itself can have serious impacts to the aquatic community, including anadromous salmonids. Generally, this seems to be the case in streams and watersheds in the North Coast of California. This is borne out by the recent decision to list many North Coast Chinook and coho salmon, and steelhead trout stocks under the Endangered Species Act.

Disturbance and Recovery of Stream and Watershed Conditions

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 streams away from their equilibrium or 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 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 from a natural landslide can fill instream pools providing salmon habitat just as readily as sediment from a road failure. On the recovery side, natural processes (such as small stream-side 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 occurred in 1955 and 1964 (Lisle 1981a) and 1974 (GMA 2001a) ground shaking and related tectonic uplift associated with the 1992 Cape Mendocino earthquake (Carver et al. 1994).

Major human disturbances (e.g., post-European development, dam construction, agricultural and residential conversions, and the methods of timber harvesting practices used particularly before the implementation of the 1973 Z'Berg-Nejedly Forest Practice Act) have occurred over the past 150 years (Ice 2000). 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 (Ice 1990). 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 a suitable and stable fish population. 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 can. 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). 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; Koehler et al. 2001), for widened stream channels to narrow, for aggraded streambeds to return to pre-disturbance level, and for streambanks to fully revegetate 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 rate of timber harvest on California's north coast has slowed during this period, with declining submissions of timber harvesting plans (THPs) and smaller average THPs (T. Spittler, pers. comm. in Downie 2003). However, in the Big River Basin, the amount of acreage harvested has increased sharply since 1990 as timber stands mature into merchantable second-growth timber and as selection and other partial harvest silvicultural prescriptions are widely implemented.

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. Cafferata and Spittler (1998) found that almost all recent landslides occurring in an area logged in the early 1970s were related to legacy logging roads. In contrast, in a neighboring watershed logged in the late 1980s to early 1990s, landslides to date have occurred with about equal frequency in the logged areas as in unlogged areas.

Further, most north coast streams have not recently experienced another large event on the scale of 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 important contributions.

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, it is not surprising that 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 (BOF 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;
- 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 on 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 deliberate 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 grapes. 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 increasing withdrawal of water, both directly from streams and groundwater sources connected to streams, for human uses. Water withdrawals pose a chronic disturbance to streams and aquatic habitat. Such withdrawals can result in lowered summer stream flows that impede the movement of salmonids and reduce 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 salmonids to recover their populations in an acceptable time frame. Clearly, the potential exists for new impacts from both human activities and natural disturbance processes to compromise recovery rates to a degree that threatens future salmonid recovery. To predict those cumulative effects will likely require additional site-specific information on sediment generation and delivery rates and additional risk analyses of other major disturbances. Also, 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 good quality freshwater habitat alone is not adequate to ensure sustainability.

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 or plans prepared by federal agencies or funded by them 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 least impacting alternative be chosen, only that the impacts be 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 (US EPA) or its state counterpart (locally, the North Coast Regional Water Quality Control Board and the State Water Resources Control Board) must set targets for Total Maximum Daily Loads (TMDLs) of the pollutants that are causing the impairment. Section 404 deals with the alterations of wetlands and streams through filling or other modifications, and requires the issuance of federal permits for most such 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. A take of a species listed as threatened may be allowed where specially permitted through the completion and approval of a Habitat Conservation Plan (HCP). 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 salmon runs are listed under the ESA, including the Chinook and coho salmon found in the Big River Basin (NMFS 2001). Steelhead trout, which are also found in the Big River Basin, have been proposed for listing.

State Statutes

The state analogue of NEPA is the **California Environmental Quality Act (CEQA)**. CEQA goes beyond NEPA in that it requires the project or plan proponent to select for implementation the least environmentally impacting alternative considered. When the least impacting 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 US EPA under the federal Clean Water Act. For example, the US 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 Game. 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 & Game Code §§ 2050, *et seq.*) generally parallels the main provisions of the Federal Endangered Species Act and is administered by the California Department of Fish and Game (CDFG). Coho salmon in the Big River Basin are listed as endangered under CESA.

The **Z'Berg-Nejedly Forest Practice Act (FPA)** and associated **Forest Practice Rules** establish extensive permitting, review, and management practice requirements for commercial timber harvesting. Evolving in part in 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 by each of the program's participating departments, and an introduction to methods for analyzing data across departments and disciplines. While the information contained in the report is extensive, more detail is included the appendices to this report:

- California Department of Forestry
- Ecological Management Decision Support
- Department of Water Resources
- North Coast Regional Water Quality Control Board
- California Department of Fish & Game

The reader is referred to these appendices for more detail on methods, data used in the assessment, and assessments of the data.

Basin Assessment Approach

The steps in the large-scale assessment include:

Form multi-disciplinary team. In order to assess watershed conditions and processes, several specialists were needed: geologists, fluvial geo-morphologists, foresters, water quality analysts, fisheries biologists, habitat specialists, and planners;

Conduct scoping and outreach workshops. In the Big River Basin assessment, a series of meetings with landowners and interested parties provided the team with local, historic knowledge and valuable critical discussion with which to establish the value of the information in hand;

Determine logical assessment scales. The Big River assessment team used the California Watershed Map (CalWater version 2.2.1) to delineate the Big River Basin into three subbasins (Coastal, Middle, and Inland) for assessment and analyses purposes (Figure 4);

Discover and organize existing data and information according to discipline. This information was used to form the basis of the disciplinary appendices to the assessment report;

Identify data gaps needed to develop the assessment. Working with limited time and resources constrained the amount of fieldwork that was performed. Fortunately, some data existed prior to this effort in the Big River Basin;

Collect field data. Over 79 miles of new stream data and 58 fishery surveys were performed for this assessment. Water Quality data were collected for this assessment at several locations in the basin, and additional data were provided by private and agency cooperators;

Amass and analyze information. Each agency (except California Geological Survey, which contributed limited information and maps) assembled, interpreted, and summarized data to create various specific reports for inclusion into the Assessment Report;

Construct Integrated Analysis Tables (IA). Through the use of IA Tables the information from various disciplines were compared to one another. These comparisons were used to respond to the Assessment Questions. The IA process also helped to identify watershed conditions;

Conduct limiting factors analysis (LFA). The Ecological Management Decision Support system (EMDS) was used, along with expert analysis and local input, to evaluate factors at the tributary scale. These factors were rated to be either beneficial or restrictive to the well being of fisheries. The CDFG Restoration Manual (Flosi et al. 1998), and other literature, provided habitat condition values to help set EMDS reference curves;

Conduct refugia rating analysis. The assessment team created worksheets for rating refugia at the tributary scale (page 43). The worksheets have multiple condition factors rated on a sliding scale from high to low quality. Tributary ratings are determined by combining the results of air photo analyses, EMDS, Water Quality data, data in the CDFG tributary reports, and by a multi-disciplinary team of expert analysts. Ratings of various factors are combined to determine an overall refugia rating on a scale from high to low quality. The tributary ratings are subsequently aggregated at the subbasin scale and expressed as a general estimate of subbasin refugia conditions. Factors with limited or missing data are noted and discussed in the comments section as needed. In most cases, there are data limitations on one to three factors. A discussion of the rating system is located at the end of this summary;

Develop conclusions and recommendations. Recommendation tables for watershed and stream improvement activities were developed at the tributary scale based upon stream inventory information, air photo analysis, field verification samples, workshop inputs, and other information. The recommendations are presented at the end of each Profile chapter as answers to the sixth assessment question;

Facilitate monitoring of conditions. CDFG is developing a monitoring program and will facilitate it in the Big River and other assessed watersheds.

Guiding Assessment Questions and Responses

The NCWAP assessment team developed lists of questions that they considered important to understanding and implementing watershed assessments. From those lists, a short list of guiding assessment questions evolved and was adopted to provide focus for the assessments and subsequent analyses, conclusions, and recommendations.

- What are the history and trends of the sizes, distribution, and relative health and diversity of salmonid populations within this?
- What are the current salmonid habitat conditions in this subbasin? How do these conditions compare to desired conditions?
- What are the impacts of geologic, vegetative, fluvial, and other natural processes on watershed and stream conditions?
- How has land use affected these natural processes?
- Based upon these conditions, trends, and relationships, are there elements that could be considered to be limiting factors for salmon and steelhead production?
- What habitat improvement activities would most likely lead toward more desirable conditions in a timely, cost effective manner?

These six questions focus the assessment procedures and data gathering within the individual disciplines and also provide direction for those areas of analyses that require more interagency, interdisciplinary syntheses, including the analysis of factors limiting anadromous salmonid production. The questions systematically progress from the relative status of the salmon and steelhead resource, to the focus of the assessment effort, and lastly to the watershed components encountered directly by the fish – flow, water quality, nutrients, and instream habitat elements, including free passage at all life stages. The products delivered to streams by watershed processes and the influence of human activities on those processes shape these habitat elements. The watershed processes and human influences determine what factors might be limiting fishery production and what can be done to make improvements for the streams and fish.

The first two assessment questions point out the importance of salmonid population information for validating the assessment and predicting habitat conditions. In many watersheds, robust population data may not be available, implying a need for future monitoring efforts. In some watersheds, a need for additional physical habitat sampling may be indicated.

The third and fourth assessment questions consider the past and present conditions of the watersheds and their natural and man-caused watershed processes. The answers to these questions provide us with insights into the future of assessed watersheds and streams, and the feasibility of different management techniques for salmon and steelhead in each watershed.

The last two assessment questions consider factors directly encountered by fish that could be limiting salmonid production. These questions seek to identify opportunities and locations for prudent management practices and pro-active salmonid habitat improvement activities.

These six guiding assessment questions are presented and answered in the overall basin section and in each of the subbasin sections of the assessment report. They are also considered in the DFG Refugia Rating process at the subbasin and tributary scales. The responses become more specific as the assessment focuses from the course to the finer scales.

Report Utility and Usage

This report is intended to be useful to landowners, watershed groups, agencies, and individuals to help guide restoration, land use, and management decisions. As noted above, the assessment operates 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 general at the basin scale.

A goal of this program is to help guide, and therefore accelerate the recovery process, by focusing stewardship and improvement activities where they will be most effective. Scaling down through finer levels guided by the recommendations should help accomplish this focus.

To do so, the report is constructed to help provide guidance for that focus of effort. A user can scale down from the general basin finding and recommendation concerning high sediment levels, for example, to the subbasin sections, to the stream reach level information to determine which streams in the subbasin may be most affected by sediment.

There is a list of surveyed streams in each subbasin section. In the general recommendation section, a tributary finding and recommendation summary table indicates the findings and recommendations for the surveyed streams within the subbasin. If indicated, field investigations at the stream reach or project site level can be conducted to make an informed decision on a land use project, or to design improvement activities.

Program Products

The program will produce and make available to the public a set of products for each basin assessed.

These products include:

- A basin level Synthesis Report that includes:
    - Collection of Big River Basin historical and sociological information;
    - Description of historic and current vegetation cover and change, land use, geology, and water quality, stream flow, water use, and instream habitat conditions;
    - List of issues developed by agency team members and constituents;
    - An interdisciplinary 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 productivity;
    - Monitoring recommendations to improve the adaptive management efforts.
- Ecological Management Decision Support system (EMDS) models to help analyze data;
- Databases of information used and collected;
- A data catalogue and bibliography;
- Web based access to the Program's products: http://coastalwatersheds.ca.gov/, and http://imaps.dfg.ca.gov/, and ArcIMS site.

Assessment Report Conventions

Subbasins

In order to be more specific and useful to planners, managers, and landowners, it is useful to subdivide the larger Big River Basin into smaller subbasin units whose size is determined by the commonality of many distinguishing traits. Variation among subbasins is at least partially a product of natural and human disturbances. Other variables that can distinguish areas, or subbasins, in larger basins include differences in elevation, geology, soil types, aspect, climate, vegetation, fauna, human population, land use and other social-economic considerations.

The Big River assessment team subdivided the Big River Basin into three subbasins for assessment and analyses purposes (Figure 4). These are the Coastal, Middle, and Inland subbasins. In general, these subbasins have distinguishing attributes common to the CalWater 2.2.1 Planning Watersheds (PWs) contained within them.

CalWater 2.2.1 Planning Watersheds

The California Watershed Map (CalWater Version 2.2.1) is used to delineate planning watershed units (Figure 4). 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). CalWater version 2.2a is the third version of CalWater (after versions 1.2 and 2.0) and is a descendent of the 1:500,000-scale State Water Resources Control Board Basin Plan Maps drawn in the late 1970s.

The PW level of specificity is used in many analyses. PWs generally range from 3,000-10,000 acres in size and each PW consists of a specific watershed polygon, which is assigned a single unique code. The program used PWs for mapping, reporting, EMDS, and statistical analysis of geology, vegetation, land use, and fluvial geomorphology.

An important aspect of CalWater 2.2a PWs is that individual PWs often do not represent true watersheds. In other words, PWs often cut across streams and ridgelines and do not cover the true catchment of a stream or stream system. Streams, such as the mainstem Big River, can flow through multiple PWs. In addition, a stream may serve as a border between two CalWater 2.2a PWs. This disconnect with hydrologic stream drainage systems is an artifact of the creation of CalWater 2.2.1 as a tool for managing forest lands in fairly consistent sized units.

Figure 4. Big River subbasins and CalWater 2.2.1 planning watersheds.

Hydrology Hierarchy

Watershed terminology often becomes confusing when discussing different scales of watersheds involved in planning and assessment activities. The conventions used in the Big River Basin assessment follow guidelines established by the Pacific Rivers Council. The descending order of scale is from *basin* level (e.g., Big River Basin) – *subbasin* level (e.g., Coastal Subbasin) – *watershed* level (e.g., Little North Fork Big River) – *sub-watershed* level (e.g., Berry Gulch) (Figure 5).

The subbasin is the assessment and planning scale used in this report as a summary framework; subbasin findings and recommendations are based upon the more specific watershed and sub-watershed level findings. Therefore, there are usually exceptions at the finer scales to subbasin findings and recommendations. Thus, findings and recommendations at the subbasin level are somewhat more generalized than at the watershed and sub-watershed scales. In like manner, subbasin findings and recommendations are somewhat more specific than the even more generalized, larger scale basin level findings and recommendations that are based upon a group of subbasins.

The term watershed is used in both the generic sense, as to describe watershed conditions at any scale and as a particular term to describe the *watershed* scale introduced above, which contains, and is made up from multiple, smaller sub-watersheds. The watershed scale is often approximately 20 - 40 square miles in area; its sub-watersheds can be much smaller in area, but for our purposes contain at least one perennial, un-branched stream. Please be aware of this multiple usage of the term watershed, and consider the context of the term's usage to reduce confusion.

Another important watershed term is river mile (RM). River mile refers to a point that is a specific number of miles upstream from the mouth of a river. In this report, RM is used to locate points along the Big River Basin.

Electronic Data Conventions

The program 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 four remaining partner departments required establishing standards for data format, storage, management, and dissemination. Early in the assessment process, we held a series of meetings designed to gain consensus on a common format for the often widely disparate data systems within each department. Our objective was to establish standards which could be used easily by each department, that were most useful and powerful for selected analysis, and would be most compatible with standards used by potential private and public sector stakeholders.

As a result, we agreed that spatial data used in the program and base information disseminated to the public through the program would be in the following format (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 coverage (Environmental System Research Institute, Inc. © [ESRI]). Data were organized by watershed and distributed among watershed synthesis teams. 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) 1927 and Universal Transverse Mercator (UTM), Zone 10, NAD 1983. Both formats were used in data analysis and synthesis.

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]).

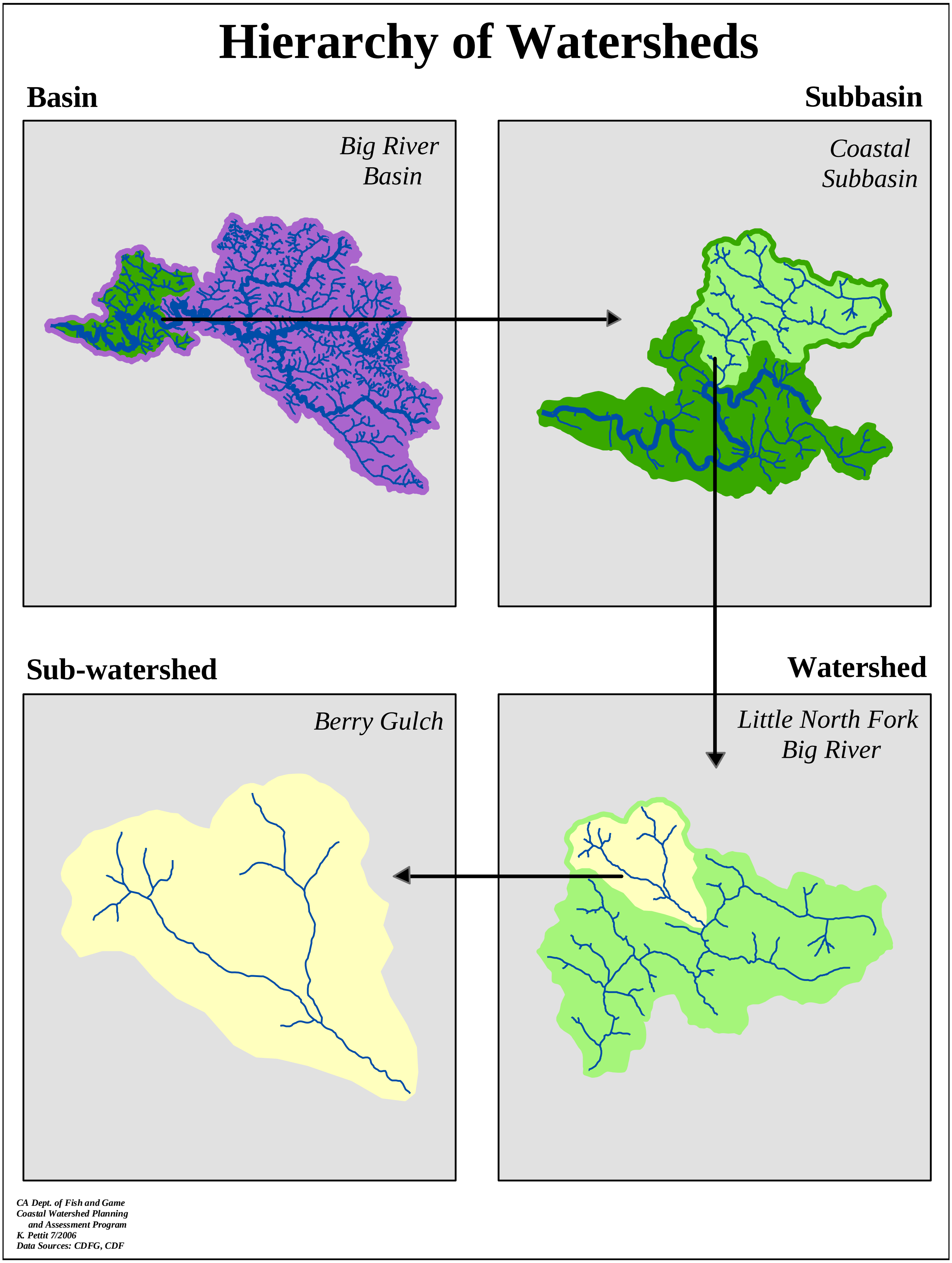

Figure 5. Hydrography hierarchy.

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, please see http://arconline.esri.com/arconline/whitepapers/ao/ArcGIS8.1.pdf). 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 from base contour data obtained from the USGS 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.

Methods by Department

Geology and Fluvial Geomorphology

A geologic map was compiled from numerous sources including published maps and reports, unpublished mapping by CGS, United States Geological Survey, California Department of Forestry, aerial photographic mapping, and field reconnaissance geologic mapping. Geologic features were compiled through the previous work of Durham, 1979, Kilbourne, et al, 1982, 1983, and 1984, and Short and Spittler, 2002, stereoscopic evaluation of aerial photos, and limited geologic and geomorphic reconnaissance mapping. Aerial photographs and compilation of existing data represent the primary information sources for this product.

Three sets of aerial photographs (1947, 1984, and 2000) were stereoscopically evaluated for geomorphic features related to landsliding in the watershed. All photos were black and white, with scales ranging from 1:12,000 to 1:36,000. Fluvial geomorphic features were evaluated using two sets of aerial photos (1984, 2000). Geomorphic features were digitized using ArcView GIS. Limited field assessment was completed of the landslide features mapped. The information was then incorporated into a GIS, with associated data attributes compiled into a spatial database with metadata.

The scale of the geologic map for this watershed limits the delineation of some features, and the map should not be substituted for site-specific studies. Information on the geologic map is not sufficient to serve as a substitute for the geologic and geotechnical site investigations required under Chapters 7.5 and 7.8 of Division 2 of the California Public Resources Code.

Landslides and geomorphic features were mapped from historical aerial photographs (see map references) as follows: 1947 (CDF), 1984 (WAC), 2000 (WAC). Field verification of landslide and geomorphic features was very limited and mapping relied primarily on interpretation of aerial photographs.

Fluvial geomorphic features were mapped from aerial photographs flown in April of 1984 and April of 2000 (WAC Corporation, see map references). Features were not verified in the field.

The bedrock geology depicted on the geologic map was modified from 1:24,000 and 1:62,500-scale non-digital source data (see "Index to Geologic and Geomorphic Mapping References" and References). Although the geologic information has been represented on this map at a scale of 1:24,000, the detail and accuracy of the bedrock and structural data are limited by the spatial resolution of the original source maps.

Landslides shown on the geologic map have been divided into groups based on the clarity of their morphology and inferred type of movement. The landslides are also classified according to the certainty of their existence as determined by analysis of aerial photographs. The various landslide designations are not intended to imply, nor should they be interpreted to imply, the relative stability of slopes involved.

Previous mapping by CGS was reviewed and incorporated using current interpretive protocols for identifying and classifying geomorphic features and/or landslides. Previous map data that were added directly to the Big River Watershed database are referred to in that electronic database with an appropriate citation.

Landslide features locally overlap stream-channel deposits, labeled Qsc2 thru 4. However, landslides do not generally overlie stream-channel deposits. This is a misleading relationship caused by GIS compilation and it has minimal geological significance at the coarse scale of this assessment.

Digital landslide and fluvial geomorphology data are available from the following sources: on the CGS website at www.conservation.ca.gov/cgs, on compact disc from CGS, or on the North Coast Watershed Assessment Program website at http://coastalwatersheds.ca.gov/.

In addition to the study conducted by CGS, geological information for the Big River Basin was obtained from Graham Matthews and Associates' (GMA) Sediment Source Analysis (2001), the Big River Total Maximum Daily Load (EPA 2001), CGSs Engineering Geologic Resource Assessment for the Big River State Park (2004), and the Mendocino Redwood Company's (MRC) Watershed Analysis for their ownership in the Big River Basin.

Hydrology

Data Collection

Only two stream flow gaging stations have operated within the Big River Basin. One gage, South Fork Big River near Comptche (USGS station #11468070), has continuous historical flow records. This gage is located on the South Fork Big River at Orr Springs Road, downstream of the confluence of the South Fork Big River and Daugherty Creek. The gage measures streamflow from 36.14 square miles. It is expected that unit peak discharges (cubic feet per second/square mile) for the entire watershed would be lower than from those recorded at the gaging site because of generally lower rainfall in the lower basin (GMA 2001a). The South Fork gage has continuous records from October 1, 1960 through September 30, 1971, and was reinstalled February 2001 at the same site.

A second gage was installed in May 2001 on the Big River below the confluence with Two Log Creek, near Comptche. Data from these two gages were obtained from the USGS website.

GMA (2001) extended this short streamflow record using a correlation process with the longer record of data available from the adjacent Noyo River Basin. GMA also operated several monitoring stations from November 2000 through April 2001 to gather additional stream flow information.

Mean Discharge

USGS discharge records were used to construct tables and graphs of mean monthly flows; mean, maximum, and minimum daily flows; annual yield or runoff volume in acre-feet; and daily flow duration.

The USGS publishes mean daily discharge records for each of its gages on an annual basis. These values are typically used to construct annual streamflow hydrographs and perform flow duration analyses. Due to the extremely short period of record for the South Fork Big River (eleven years), GMA (2001) used modeling to extend or create a mean daily discharge record for each Big River subbasin and the entire Big River Basin. GMA scaled mean daily discharge measurements from the Noyo Watershed using watershed area and mean annual precipitation as the scaling factors.

Flow Duration and Annual Runoff

GMA (2001) performed a flow duration analysis using a combination of historic data from the USGS gage on the South Fork Big River and synthetic mean daily discharge data calculated as described above. They also calculated annual runoff for the South Fork Subbasin using the USGS streamflow gage records for the period of record and computed from the synthetic data generated for the rest of the basin.

Peak Discharge

USGS peak discharge records are available for eleven years, 1961-1971, and 1974. In addition, synthetic peak discharges for the South Fork Big River were developed by GMA (2001) using peak correlation analysis between the Noyo River and the Big River basins in order to extend the record. GMA estimated peak discharges back to 1952 and forward to 1999, based on the record available from the Noyo River. In addition, GMA measured peak discharge for Water Year 2001 at the South Fork Big River USGS gage during streamflow data collection. GMA also estimated peak discharges for the Big River Basin based on a correlation with the Noyo record adjusted by drainage area and mean annual precipitation ratios.

Flood Frequency

Flood frequency analysis is a method used to predict the magnitude of a flood that would be expected to occur, on average, in a given number of years (recurrence interval) or have a specific probability of occurrence in any one year (a 100-year flood has a 1% chance of occurring in any given year, for example).

A frequency analysis for annual peak and low-flow was completed using the techniques from the USGS Bulletin number 17B, Techniques of Water-Resources Investigation of the USGS (HSIACWD 1981) and Ven Te Chow's Handbook of Hydrology (1964). The data used for the peak flow frequency were the annual instantaneous values. For this analysis the Gringorten plotting position equation was used, as it tended to give better results when using the normal distribution.

The low flow frequency analysis is similar to the peak-flow analysis except that the discharge values were found by calculating the minimum seven-day running average of the mean daily flows for each water year. These values were then used to complete the frequency analysis described above.

Water Rights

A search of the State Water Resources Control Board Water Right Information System (WRIMS) was performed to determine the number and types of water rights within the Big River watershed. The WRIMS database is under development and may not contain all post-1914 appropriative water right applications that are on file with the SWRCB at this time. Some pre-1914 and riparian water rights are also contained in the WRIMS database for those water rights whose users have filed a "Statement of Water Diversion and Use."

Vegetation and Land Use

Vegetation

Analysis of the tree size and density was accomplished utilizing CDFs CALVEG 2000 data. Because crown diameter and tree diameter are highly correlated, measuring the tree crowns can make estimates of tree size. Tree size values within the Big River represent the average visible crown diameter bases on the following information outlined in Table 1. The tree size classification is rated on a scale of one to five based on the crown diameter and cross-walked to a tree diameter size. Canopy density is a percent scale reflecting the percent of canopy closure detected within a stand.

Table 1. Comparison chart of the tree size classes.

Size Class	Class Name	Breast Height Tree Diameter (inches)	Conifer Crown Diameter Class	Hardwood Crown Diameter Class
N	Non-stocked	---	---	---
0	Seedlings	---	Derived From Plantation Age	---
1	Saplings	< 6 inches	Derived From Plantation Age	< 15 feet
2	Poles	6 to 11 inches	< 12 feet	15 to 30 feet
3	Small	12 to 24 inches	12 to 24 feet	30 to 45 feet
4	Medium	24 to 40 inches	24 to 40 feet	> 45 feet
5	Large	> 40 inches	> 40 feet	---

Note: Breast height tree diameter classes derived from crosswalk to WHR vegetation size classes.

Fire and Fuels

CDFG personnel analyzed CDF fire data available from the CDF Fire and Resource Assessment Program (FRAP). A statewide GIS layer of large fire history, 300-acre minimum for CDF fires since 1950 and 10-acre minimum for USFS fires since 1910, and a statewide GIS layer of fire threat, combining expected fire frequency with potential fire behavior to create four threat classes were used.

Population

CDFG analyzed year 2000 census data to provide population estimates for each Big River subbasin. The 2000 data were available from FRAP. The Census Bureau statistics are organized at several levels including: State, County, Census County Division (CCD), Census Tract, Block Group, and Block. The Big River Basin straddles the Mendocino-Anderson, Willits, Redwood-Potter, and Fort Bragg CCDs. Additionally, the basin contains sections of six census tracts (010300, 010600, 010900, 011000, 011200, and 011300). Census Tracts are made up of blocks. Block population totals were compiled to determine the estimated population of each Big River subbasin. Blocks that crossed the Big River Basin boundary or subbasin boundaries were examined more closely and population values were allocated by estimated fraction of area.

Land Use

Land use was delineated by placing transparent plastic sleeves directly over the photos and classifying land use change while viewing through a stereoscope. Categories that were delineated were fire, timber harvest, pasture, irrigated crops, orchard, buildings, and urban. Since this is a land use change classification, not all grassland or timberland was delineated or typed. While the full extent of many areas burned by fire could not be estimated, if the fire created a change in vegetation, it was recorded. For example, in 1937 aerial photographs the area of the 1931 Comptche wildfire was evident by the amount of grassy understory, open canopies, and areas of brush. The area of the wildfire itself was derived from an existing electronic database but portions of the burned area were recorded as a permanent conversion, usually subjectively determined by evidence of continued burning, proximity to existing grasslands, barns or other buildings, and roads.

Timber harvest activity was broken into silviculture and logging system categories using the closest approximation to the standard definitions. There is no way of knowing from air photos whether the trees removed were old- growth stands that were present prior to European-American settlement or if these were trees that had grown in due to changes in land-use practices between 1860 and 1937. In some instances, trees had been removed or killed and the closest silvicultural category was used. In many of the earliest photographs, there were no roads or skid trails visible and no logging system was recorded.

Minimum acreage mapped varied by land use classification. Crops and orchards were mapped when seen. It was assumed that fenced grassland was grazed. Silvicultural treatments were difficult to categorize. The large proportion of hardwood and brush was very apparent because there was often a lot of vegetative cover remaining after a harvest that removed most of the conifer. The resultant silviculture was highly variable in many instances. Seed tree removal step was delineated as the silvicultural system used when it appeared that the dominant conifer cover was removed, but considerable hardwood and/or brush remained. When the excluded areas were large relative to the adjacent harvested areas, they were also excluded from the harvest land use polygon.

Disturbance categories were broadly grouped into low, medium and high. Disturbance was based on potential sediment delivery to watercourses. High intensity fire areas, cultivated land and grazed areas immediately adjacent to streams or on steep slopes, and virtually all tractor logging during this time period were classified as high disturbance potential areas. Slides were not mapped although sometimes included as a comment.

The information from the Mylar sleeves was input as polygon features into the ArcView GIS system by onscreen or "heads-up" digitizing using 1993 black and white orthographic quadrangles as the background. Distortion was corrected by using watercourses, ridges, and roads as reference indicators. The scale distortion apparent in the aerial photographs compared to the orthoquads during the heads-up digitizing was manually corrected by changing the scale of the orthoquad to match the area near the polygon to provide the best fit.

These data are similar to other aerial photograph interpretations of various types of land use. The aerial photos used appeared to be of the same age as the flight date. Many were faded and had hand-drawn line work on them from past projects. When using the data, it is important to note that timber harvesting is often used as a surrogate for a change in vegetation type, size, or density. In a general sense, this is true, but early harvesting did not follow the classic silvicultural methodology and even-aged harvests in particular varied widely in the application on the ground. Disturbance was based on potential sediment delivery to watercourses and was evaluated on the project level.

CDF Northern Region Forest Practice GIS Timber Harvesting Plan Data

Spatial timber harvesting plan data are digitized into the GIS at a scale of 1:12,000 or better using the onscreen or "heads-up" digitizing method. Digital USGS 1:24,000 topographic quadrangles and USGS 1:24,000 DLGs (Digital Line Graphs) serve as base data layer. Timber harvesting plan data (THP) are derived from THP maps, amendments, and completion reports contained in the THP of record on file with the California of Forestry and Fire Protection in Santa Rosa, California. The USGS 1:24,000 DLG data are augmented with features derived from the THP of record.

The State of California and the Department of Forestry and Fire Protection make no representations or warranties regarding the accuracy of data or maps. Neither the State nor the Department shall be liable under any circumstances for any direct, special, incidental, or consequential damages with respect to any claim by any user or third party on account of or arising from the use of data or maps.

These records are not fitted to aerial photographs or digital ortho-photo quads and may not be precise in location, but timber harvesting plan boundaries appeared to fit pretty well when qualitatively viewed with 1993 digital ortho photo quads and 2000 aerial photographs. As mentioned previously, one should be cautious about using silviculture as a surrogate for vegetative cover descriptions; some of the rehabilitation and seed tree removal step prescriptions were almost indistinguishable from the pre-harvest condition when viewing aerial photographs. The files are organized by the date of THP submittal. The time between plan submittal and actual harvest varies, often by several years. This time delay occurs for a variety of reasons including long THP review periods for controversial plans, litigation, and landowner attempts to harvest when the market is most favorable. In addition, Non-industrial Timber Management Plans (NTMPs) are only included in the database when a Notice of Operations is filed. The current policy is to digitize all newly submitted NTMPs as they arrive and to retroactively digitize older NTMPs as resources allow.

Roads

Roads data for the Big River Basin are from a compendium of sources compiled by Graham Matthews and Associates (GMA) for the Total Maximum Daily Load (TMDL) report for Environmental Protection Agency (EPA). It includes digitized data based on United States Geologic Survey (USGS) 7.5 minute quadrangle maps, upgraded and added to by CDF Santa Rosa GIS using Timber Harvest Plan (THP) documents, integrated with Mendocino Redwood Company data and finally roads were added based on aerial photos by GMA.

Stream Buffer Vegetation

Stream buffers were established on Class I / Perennial streams at 150 feet from the bank of the watercourse on both sides and 75 feet for Class II / Intermittent streams. Data used for analysis are the USGS 1:24,000 hydrography GIS data layer, upgraded with in field watercourse designation from THPs digitized by CDF Santa Rosa GIS.

Disturbance

Activities and methods are presented here in the form of a relative combined factor as a form of analysis called the Disturbance Level. For the Big River, this includes wildland fires, timber harvesting, and permanent conversions of forest land to other uses such as development and agriculture. Disturbance level is a relative ranking of the inferred overall effect on the landscape due to activities and the method of activity since 1852 when timber harvesting in the Big River began, with a primary focus on the potential for sediment production and transport. It is based on disturbed ground as interpreted from aerial photos and qualitative field checking with consideration for:

- Density of skid roads or overall amount of exposed soil area;
- Skid road proximity to watercourses;
- Direction of yarding-cable: downhill vs. uphill and skidding down to and into watercourses;
- Era/method—stream yarder worst, then tractor pre 1973, tractor post 1973, skyline yarder, and helicopter least impactive;
- Size of equipment and logs yarded which have a direct impact on the amount of soil displaced; these have become progressively smaller and lighter;

- Crown canopy reduction;
- Forest Practice Rules as they apply to logging practices, i.e. skid road, waterbar and crossing construction, standard improvement over time.

Each area of activity was rated low, moderate, or high. Low is minimal ground disturbance such as a commercial thinning logged by yarder, uphill, with full suspension, in later years. A high rating is the most impactive and is typified by an area that was clearcut prior to 1972 by tractor or groundlead cable, no waterbars installed, large logs harvested often downhill with no regard for watercourse protections. Moderate is in between.

Water Quality

Water Quality Criteria

The criteria used for the assessment of the Big River Basin are a compilation of criteria from the Basin Plan, the Big River TMDL, EMDS, and other literature sources discussed in more detail in the Water Quality Appendix (Table 2). Therefore, the water quality assessment discusses the state of the watershed according to comparisons of the appropriate water quality objective or target as noted in the following table. With the exception of the Basin Plan objectives, these ranges and thresholds are not enforceable. Rather, they are criteria based on information available at the time of this assessment and may change as new data, analyses, and research becomes available.

It is worth noting that the criteria for fine sediment are based on wet sieve (percent by volume) determinations. In some cases, stream substrate cores are dry sieved, resulting in a percent by weight determination. The percent of fine sediment arrived at by wet sieving and dry sieving are sufficiently different so that the dry sieve results are not directly comparable to the target values. In those instances where the percent fine sediment was arrived at through dry sieving, it is explicitly noted.

Table 2. Criteria used in the assessment of water quality data

<table>
<tr><th>Water Quality Parameter</th><th colspan="2">Range or Threshold</th><th>Reference</th></tr>
<tr><th colspan="4">Water Column Chemistry</th></tr>
<tr><td>pH</td><td colspan="2">6.5 - 8.5</td><td>Basin Plan, Table 3-1, p 3-7.00</td></tr>
<tr><td>Dissolved Oxygen</td><td colspan="2">7.0 mg/L</td><td>Basin Plan, Table 3-1, p 3-7.00</td></tr>
<tr><td rowspan="2">Specific Conductance</td><td colspan="2">< 90% of upper limit at 300 micromhos</td><td>Basin Plan, Table 3-1, p 3-7.00</td></tr>
<tr><td colspan="2">< 50% of upper limit at 195 micromhos</td><td>Basin Plan, Table 3-1, p 3-7.00</td></tr>
<tr><td>Nutrients
(Biostimulatory Substances)</td><td colspan="2">No increase in concentrations that promote growths and cause nuisance or adversely affect beneficial uses</td><td>Basin Plan, p 3-3.00</td></tr>
<tr><td>General Inorganic & Organic Compounds</td><td colspan="2">Various numeric and narrative Basin Plan objectives.</td><td>Basin Plan, Table 3-2
Various numeric criteria to implement Basin Plan narrative objectives as found in Marshack (2000). The numeric criteria used are also described in the Water Column Chemistry section beginning on page 28.</td></tr>
<tr><th colspan="4">Temperature</th></tr>
<tr><td rowspan="6">Water Temperature</td><td colspan="2">No alteration that affects BUs1</td><td>Basin Plan, p 3-3.00</td></tr>
<tr><td colspan="2">No increase above natural > 5°F</td><td>Basin Plan, p 3-4.00</td></tr>
<tr><th>MWAT[2] Range</th><th>Description</th><td rowspan="2">EMDS[3]</td></tr>
<tr><td>50-60°F
61-62°F
63°F
64°F
65°F
66-67°F
≥ 68°F</td><td>Fully Suitable
Moderately Suitable
Somewhat Suitable
Undetermined
Somewhat Unsuitable
Moderately Unsuitable
Fully Unsuitable</td></tr>
<tr><th>Daily Maximum</th><th>Description</th><td rowspan="2">Cold water fish rearing, RWQCB (2000), p. 37</td></tr>
<tr><td>75°F</td><td>Lethal</td></tr>
<tr><th colspan="4">SEDIMENT</th></tr>
<tr><td>Settleable Material</td><td colspan="2">Cannot cause nuisance or adversely affect BUs[1]</td><td>Basin Plan, p 3-2.00</td></tr>
<tr><td>Suspended Material/Load</td><td colspan="2">Cannot cause nuisance or adversely affect BUs[1]</td><td>Basin Plan, p 3-2.00, 3-3.00</td></tr>
<tr><td>Turbidity</td><td colspan="2">No more than 20 percent increase above natural occurring background levels</td><td>Basin Plan, p 3-3.00</td></tr>
<tr><td>V* in 3rd order streams with</td><td colspan="2">≤0.21 (mean)</td><td>Big River TMDL, US EPA (2001)</td></tr>
</table>

Water Quality Parameter	Range or Threshold	Reference
slopes 1-4 %	<0.45 (max)	Knopp (1993)
Median particle size (D50) in 3rd order streams of slopes 1-4 %	69 mm mean (for index yes/no streams) 38 mm mean (for highly disturbed streams)	Knopp (1993)
Percent fines <0.85 mm	<14% in fish-bearing streams[4] ≤10% - fully suitable	Big River TMDL, US EPA (2001)
Percent fines <6.4 mm	<30% in fish-bearing streams[4] ≤15% - fully suitable	Big River TMDL, US EPA (2001)

1 BUs = Basin Plan beneficial uses

2 MWAT= maximum average weekly temperature, to be compared to a 7-day moving average of daily average temperature

3 EMDS = Ecological Management Decision Support model used as a tool in the fisheries limiting factors analysis. These ranges and thresholds were derived from the literature and agreed upon by a panel of NCWAP experts.

4 Fish-bearing streams are streams with cold water fish species

Data Analysis Methods

All of the available data were compiled into electronic formats appropriate for the information, such as spreadsheets, databases, etc. The exact method of data analysis is specific to the data type and its quality. However, in general, during the analysis of the water quality data, data were evaluated for exceedences of the criteria established in Table 2 and other patterns or abnormalities in the data. Based on this analysis and the quality of the data, broader hypotheses about potential causes for the exceedences, patterns, or abnormalities were developed. Often, these hypotheses concerned factors that the other NCWAP partners were assessing. Therefore, as the synthesis of the data from each of the NCWAP agencies proceeded, the water quality data were evaluated in the context of influencing factors such as canopy for temperature and land use and/or erosional features/fluvial geomorphology for sediment. These larger scope multi-media evaluations are presented in the synthesis report. Thus, the synthesis report is an interdisciplinary effort to recognize and hypothesize about the linkages, and understanding the data in a broader context.

To the extent possible, all monitoring sites are referenced using the contributors identification number prefaced by the contributors acronym. For example, MRC provided a water temperature data for a site that MRC refers to as “74-1.” In this assessment, that site is referenced as “MRC 74-1.” If no site identifier is provided by the data contributor, a unique identifier was created and assigned to the monitoring location. In those instances where a numbering sequence already exists, that numbering sequence was continued.

Channel Measurements & Sediment Sources

For sediment parameters, we used data available for pebble counts, bulk sediment sampling, suspended sediment sampling, and turbidity sampling. We also utilized values in the preliminary sediment budget for the Big River (GMA 2001a) to estimate the upslope contribution of sediment. This enabled us to draw some correlation with in-channel sediment conditions and upslope activities.

The primary metrics used to analyze percent of fine material in core samples was percent less than 0.85 mm and percent less than 6.5 mm as shown in Table 2. The thresholds are maximas of 14% and 30% by volume, respectively (US EPA 2001). We applied the TMDL targets where data were available in the appropriate size classes or where other size classes could be reasonably evaluated. For example, the target for fines less than 6.5 mm states that the fraction of this size class in the total sample of streambed material is less than 30% by volume. If the percentage of fines less than 4 mm was measured as 50%, then the target for the 6.5-mm size class was exceeded.

The data used for this analysis came primarily from bulk sediment sampling done by MRC, HTC, and GMA. Typically, after collecting a substrate core, it is “wet sieved” in the field to separate the material into its various size fractions. While the dry sieve technique can be more accurate, wet sieving avoids the need to carry out what is sometimes hundreds of pounds of wet gravel for the dry sieve technique. Therefore, wet sieving has become common practice when analyzing core samples in the field.

When using the wet sieve technique, the material retained on each of the sieves is measured volumetrically. This allows for the “percent less than values” to be calculated on a volumetric basis by using the volume retained on the sieve divided by the total volume of material sieved. With smaller size fractions, there can be significant error using the wet sieve method due to the amount of water retained by the particles (Shirazi, Seim, and Lewis, 1979). Therefore, for size fractions less than 4 mm, it is preferable to drain the material in the field or to collect a sample to determine density at a later date.

In the Big River Basin, streambed bulk sediment sampling occurred at 15 sites. In some cases, the same site was sampled by both MRC and GMA. However, the MRC and GMA sediment cores from 13 sites were dry sieved and the HTC sediment cores from two sites were wet sieved. Because the TMDL target values were developed based on research using the wet sieved technique, we were not able to compare the MRC and GMA data to the TMDL target values. Even the MRC and GMA values could not be directly compared to each other because the GMA values did not include the surface material. As a result, GMA bulk sediment data are not directly comparable to the MRC data, neither of which are comparable to the TMDL targets. In an attempt to describe the difference that removing the surface particles had on the size distribution, complete bulk sediment data sets for the Albion River were reviewed (GMA 2001b). One would expect that removing the surface armoring layer would remove the larger rocks from the size distribution, substantially reducing the total sample volume and thus increasing the relative percentages in each of the smaller size classes. However, there was no apparent pattern to indicate how the removal of the surface material shifted the percentages in the size distribution.

The HTC percent fine sediment values, because they were calculated using the wet sieve technique, were directly comparable to the TMDL targets for fine sediment in the sub 6.5 mm and 0.85 mm size classes. All of the data provided for this assessment were already reduced into the percent finer classes.

With streambed substrate samples, it is important to keep in mind that conditions in a riffle may vary considerably and large sample sizes are needed to describe the conditions for salmonids. Nevertheless, streambed substrate samples can provide a perspective on the composition and dynamics of the streambed and add validity to other observations such as the embeddedness and dominant particle size data from habitat surveys done by CDFG.

As discussed in the Water Quality Criteria section, other common techniques for measuring substrate particle size in streambeds include pebble counts and D50's. Unfortunately, there was no raw pebble count data and only one D50 data point calculated by Knopp (1993) in Berry Gulch and one D50 data point calculated by MRC at each of the stream cross-sections measured in 2000. In any case, because there is no D50 target or objective for the Big River and the D50 values for each site were only collected during one year, these values are only reported and not evaluated for salmonid suitability.

To be able to directly compare sediment input conditions from upslope activities, subbasins were compared against one another using the calculated relative disturbance index and sediment input values by activity. Generally, the estimated sediment input values were converted to tons/mi^2/yr to eliminate the factors of watershed size and the number of years in the discrete time period analyzed. This enabled direct comparisons across time periods and between different planning and superplanning watersheds, regardless of size.

For the analysis, the 1989-2000 time period was evaluated to determine the current source(s) of sediment. The sediment input values for this time period were further broken down into specific activities that contributed to the discharge to develop focused restoration and/or activity modification recommendations. If the subbasin being analyzed also had in-channel sediment data (e.g. bulk sediment data, pebble counts, etc.), the estimated sediment inputs were evaluated next to the in-channel sediment conditions in an attempt to draw associations.

It should be noted that in the preliminary sediment budget for the Big River (GMA 2001a), estimated background levels of sediment input were not reported by planning watershed. However, it was estimated over the entire watershed using several short discrete time periods within the overall study period (1921-2000). The long term background sediment input rate was estimated to be 315 tons/mi^2/yr, which consists of background landslides, surface erosion, and fluvial and bank erosion. It was further estimated that 175 tons/mi^2/yr of the total represents background landslides, 75 tons/mi^2/yr represents background surface erosion (soil creep), and 65 tons/mi^2/yr represents background fluvial and bank erosion. However, to discuss background sediment inputs over shorter time periods, these estimated values were adjusted with a factor that represented the hydrologic conditions of the shorter discrete time period. For example, during the 1989-2000 time period, the hydrologic conditions were such that a factor of 0.91 was applied to the input rates, yielding an adjusted background rate of 286 tons/mi^2/yr, an adjusted landslide rate of 159 tons/mi^2/yr, an adjusted soil creep rate of 68 tons/mi^2/yr, and an adjusted fluvial rate of 59 tons/mi^2/yr.

Finally, landslides picked up in the aerial photo analysis were assigned a mean thickness of 5.5 feet if road-related, and a mean thickness of 4.0 feet if non-road related. These values were based on field verified slides from an Albion River watershed analysis conducted by MRC (GMA 2001a). Earthflows were assigned a thickness of 10 feet, while rotation/translation slides were assigned a thickness of 25 feet. The resulting volumes were then converted to tons using a factor of 1.48 tons/yd^3 (GMA 2001a). In addition, the 1936 aerial photographs were not available for the eastern portion of the watershed (Upper Big River, North Fork Big River, and South Fork Big River). Therefore, the 1921-1936 time period was not available for analysis in these subbasins.

Water Temperature

Water temperature data were typically collected through one of two techniques: grab measurements with a thermometer or continuous measurement with a data logger. Most of the grab measurements taken in the Big River Basin were done by CDFG at every tenth habitat unit during stream surveys. However, for the purpose of evaluating the water temperature for suitability for anadromous fish, these data were not used. This is primarily because these measurements only represent a single point in time and are not useful for drawing any larger conclusions about the stream condition with respect to water temperature.

Continuous water temperature measurements were conducted by large landowners or government agencies. For this assessment, continuous water temperature measurements were available for various years and locations from 1990 to 2001. Because high water temperature can be a limiting factor with respect to cold water fisheries, summer data were evaluated to capture the highest temperatures during the year. No temperature data were available for other times of the year, as it was assumed that water temperatures during non-summer months are not limiting for salmonids.

Prior to using the data, raw temperature charts were created for each data set and checked for abnormalities as shown in Table 3, and to trim out any erroneous data at the beginning or end of the data sets where the data loggers were exposed to air. In no cases were the data trimmed or modified other than at either end of the data set.

Table 3. Continuous water temperature data review steps.

Review steps	Purpose
Plot raw data	Check data set for obvious abnormalities such as exposure to air. Check data irregularities against the same time period at other monitoring sites to determine if caused by climatological conditions.
Check data set for interruptions in the recording period.	Check if logger was removed from the water or stopped data collection, and if it would affect the quality of the summary data.
Record number of times that temperature exceeds 4°F (2.2°C) between measurements. Record the maximum of these fluctuations.	Check data for abnormalities such as exposure to air, stream withdrawals/discharges, and data logger errors. The value 4°F was arbitrarily chosen as a screening number because it is an unusually large change in water temperature between measurements, which are typically 96 to 144 minutes apart.
Record the number of measurements that did not change between consecutive readings.	Check for data logger errors, dead or dying batteries, thermally stratified or groundwater dominate pools.
Record the seasonal maximum temperature for each data set. Any data sets that recorded temperatures in excess of 70°F were reviewed in closer detail.	Check data for exposure to air, or other abnormal conditions. Any exceedences of the lethal limit (75°F) were also recorded.
Check period of record and raw data plot for time of peak temperature.	If the raw data plot indicated that the peak temperature may have been missed, the data are generally not used as it would not be representative or comparable to other years or sites.
Record maximum diurnal fluctuation.	Assist in understanding of flow/shading conditions and check for exposure to air.

Analysis of data quality involved plotting all of the raw temperature files and verifying that the warmest part of the year was captured with reasonable certainty. The raw data plots are also useful in that they clearly show how the temperature changes at a specific site, which can lead one to hypothesize about flow and shading conditions. In some cases, particularly where a temperature monitor was placed in a short stream or gulch, the raw temperature plots can clearly show an atypical flat data record. Assuming that the data logger is operating properly, a flat data record suggests that the data logger may be recording a predominately groundwater flow regime with little or no surface flow, or a thermally stratified pool. This situation can occur when the data logger is placed in what becomes a partially or entirely isolated pool, or placed in a deep pool that is thermally stratified. The fact that this behavior was seen primarily in short streams or gulches, it is speculated that the former is true. In any case, if the data logger still appeared to respond to area wide temperature changes (as seen in other nearby sites), or if there were multiple years of data at a flat site to confirm the characteristics of the site, it was assumed that the data logger was recording representative stream conditions and was therefore used in this assessment.

Across all of the available water temperature monitoring sites in the Big River Basin between 1990 and 2001, the maximum water temperatures occurred between May 31 and September 10. However, on average, the maximum water temperatures occurred between the last week of June and the second week of August. Therefore, all of the data sets were checked to ensure that data collection began by June 21 and continued until at least August 15. The data sets were also checked visually to ensure that the highest temperatures appeared to have been captured. If either one of these conditions were not met, the data were qualified or not used at all in those cases where the peak water temperatures were clearly missed. Potential data quality issues, including the resolution to the potential problem, are given in the Water Quality Appendix.

If the data did not exhibit any significant abnormalities, the summary values were then calculated. These summary values included: the maximum weekly average temperature (MWAT), the maximum weekly maximum temperature (MWMT), the seasonal maximum temperature, and the daily minimum, average, and maximum temperatures. The MWAT is the maximum value of a seven day moving average of the daily average temperatures. The MWMT is the maximum value of a seven day moving average of the daily maximum temperatures. Where we did not have the raw data set, we evaluated only the summary statistics provided to us by the contributor. Due to the large amount of data generated during the calculation of the daily minimum, maximum and average, these data are not presented in tabular form in this assessment. For the same reason, raw data are generally not included in either tabular or graphical form in this assessment. However, this raw data are made available to the public in the KRIS Big River database.

Other summary statistics were calculated for each data set, as described in Table 3, including the number of times the water temperature varied by more than 4°F between consecutive measurements and the maximum diurnal temperature fluctuations. If the water temperature did fluctuate more than 4°F between consecutive measurements, then the maximum fluctuation was recorded. These statistics were used to help identify potential problems with the data and to better understand the dynamics of a stream at a particular monitoring location. For example, large fluctuations between measurements could indicate that the data logger either came out of the water, was affected by discharges/withdrawals from the stream, or was exposed to short-term direct sunlight. In most cases where several large fluctuations were observed, they tended to be cyclical increases in temperature that occurred at the same time each day, primarily in the late morning or early afternoon. This type of repetitive, consistent temperature jump would suggest that the cause is not anthropogenic because the jumps happen at the same time for days or weeks in a row. This type of repetitive temperature effect is more likely climatological. It is speculated that it is due to rapid heating of the data logger by direct sunlight exposure or direct sunlight exposure to shallow water in the thermal reach, which then is recorded by the data logger. In the Big River Basin, no data loggers were placed in the estuary, where tidal fluctuations could be another influencing factor.

The maximum diurnal temperature fluctuation recorded at each site is related to climatological, flow (which is related to climatological conditions), and shading conditions. In many cases, the maximum diurnal fluctuations in water temperature tend to be similar between multiple years and can point to shading and/or flow conditions in that thermal reach. This parameter is useful in that it can assist in developing hypotheses about shading conditions at the various monitoring sites. In general, any diurnal fluctuations in the range of 0-6°F was considered good, >6-10 was considered moderate, and >10 was considered poor. These guidelines do not mean anything with respect to salmonids, but are used as a loose guide for interpreting flow and/or shading conditions in a thermal reach. In addition, large changes in diurnal fluctuations between years may indicate some change in shading conditions.

Once the summary statistics were obtained, these values were compared against the water quality criteria shown in Table 2. As indicated in this table, the calculated MWATs were compared against the EMDS targets. The seasonal maxima are also important to consider as they may reflect short-term thermal extremes that, unless salmonids are able to escape to cool water refugia, may be lethal to fish. The literature supports a critical peak lethal temperature threshold of 75°F (24°C), above which death is usually imminent for most Pacific Coast salmonid species (Brett 1952; Brungs and Jones 1977; RWQCB 2000; Sullivan, et al. 2000). As a rule, if the instantaneous maxima at any site exceeded 70°F, the data record was scrutinized in detail as an additional data quality check to ensure that the data logger remained submerged.

To quantify the trend in the MWATs for each site, an MWAT Trend was calculated. This simple calculation consisted of subtracting the MWAT value for the current year from the value from the previous year. These values are then added together to arrive at the MWAT Trend. For example, if there are MWAT values for 1993 (58.60°F), 1995 (57.30°F), and 1998 (60.40°F), the MWAT value for 1993 is subtracted from the 1995 value (-1.3°F). Then the MWAT value for 1995 is subtracted from the 1998 value (+3.1°F). These two numbers are then added together to get the MWAT Trend (+1.8°F). For this assessment, any MWAT trend greater than 2°F was considered a significant trend and discussed in the subbasin analysis sections.

To provide a visual aid in analysis, a chart was made for each subbasin that summarizes the range of MWATs at a given site. For each stream, the monitoring sites are plotted in order from upstream to downstream. In addition, all of the EMDS thresholds are plotted on the same charts as a point of reference.

USFWS Temperature Study

In 1973, the USFWS recorded water temperatures at six sites in the Big River Basin as part of a Fisheries Improvement Study (Perry 1973). Data were reported in the form of daily minimum, maximum, and mean temperatures. CDFG used this data to calculate MWATs, MWMTs, and maximum temperatures. These summary statistics were compared to recent water temperature data at the similar locations. Due to the nature of USFWS data, this data were not subjected to the same level of quality control as data examined by NCWQCB.

Suspended Sediment & Turbidity

Another common metric to measure in-stream sediment are turbidity and suspended sediment. While both of these parameters were sporadically monitored in the Big River Basin, the samples were typically only grab samples and were relatively infrequent. The data that are available are charted for the respective sub-basin sections. While the amount of data available is insufficient to assess the impacts to the cold-water fisheries and other beneficial uses in the Big River, the data did provide at least a preliminary look at the relationship between turbidity and suspended sediment in the Big River Basin. The existing turbidity data are also useful in that it provides the beginning of the data that will be needed to eventually establish a baseline for this parameter.

Water Column Chemistry

Water column chemistry samples were collected in the Big River Basin by the USGS, the Regional Water Board, and community drinking water system operators. In general, these samples were tested for basic water quality chemistry. Additional on-going sampling began after a tanker truck turned over on Highway 20 on February 27, 2001 and spilled approximately 7,000 gallons of recycled motor oil and diesel, some of which discharged to James Creek. The subsequent sampling consisted of testing for a variety of organic and inorganic compounds.

The analysis of water column chemistry is divided into parameters with numeric water quality objectives in the Basin Plan, parameters with narrative water quality objectives in the Basin Plan (which can be quantified using numeric criteria found in the literature), and other important parameters that may have applicable narrative water quality objectives, but no available numeric criteria. The applicable numeric water quality objectives found in the Basin Plan are contained in Table 2. When quantifying narrative water quality objectives, any number of criteria can apply, depending on the designated beneficial uses for the water body. Therefore, these are only incorporated by reference and discussed in detail when used in this assessment. However, to help clarify the process of selecting numeric criteria, Figure 6 from Marshack (2000) is included.

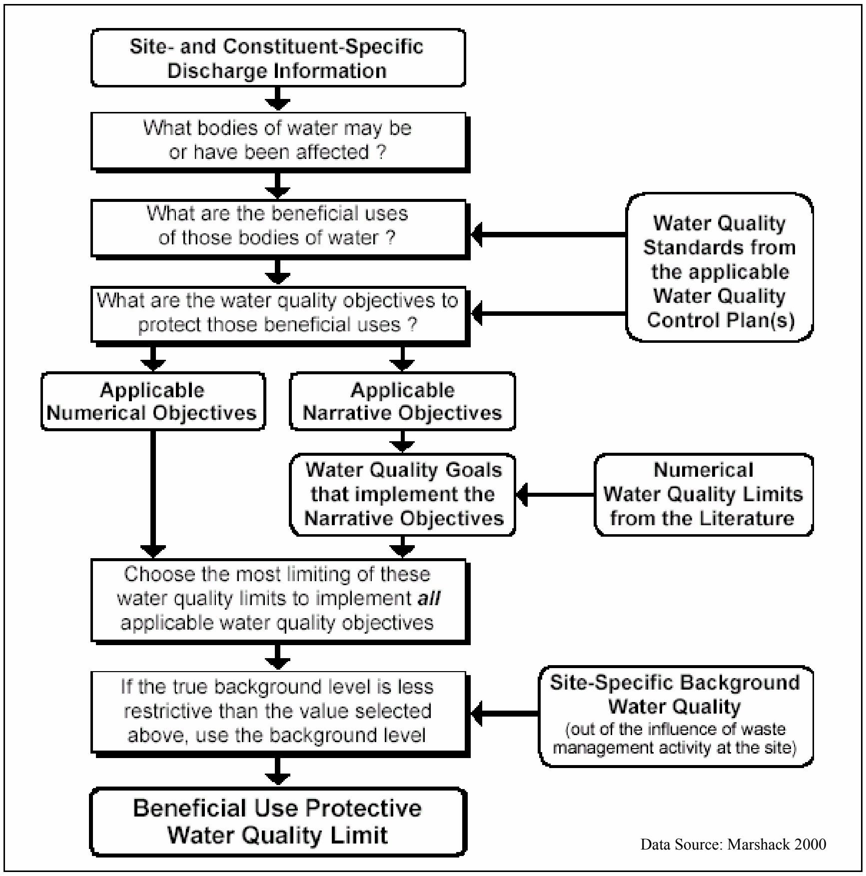

Figure 6. Selecting beneficial use protective numerical limits in water.

Normally, if selecting an enforceable numeric criteria, the lowest applicable value may not apply. For example, if a Maximum Contaminant Level and a Public Health Goal both apply to a selected beneficial use, the Maximum Contaminant Level will usually be the value used to enforce provisions of the Basin plan, even though the Public Health Goal value is typically lower. However, for the purposes of this water quality assessment, the most conservative scientifically based criteria is used so that interested parties are fully informed. To assist resource managers in decision making, all applicable criteria is given in those instances where the most conservative scientifically based criteria is exceeded.

The various categories of criteria used in this assessment have been defined below for ease of reference. More detail on these criteria, which were used to quantify the narrative water quality objectives, is available in Marshack (2000).

Fish Habitat and Populations

Data Compilation and Gap Identification

CDFG collected new data and compiled existing available data and gathered anecdotal information pertaining to salmonids and the instream habitat on the Big River Basin and its tributaries and entered it into a database. Anecdotal and historic information was cross-referenced with other existing data whenever possible and rated for quality. Both were used when the information was of good quality and applicable. Instream habitat gaps were mapped and matched with corresponding land parcels. Where data gaps were identified, access was sought from landowners to conduct habitat inventory and fisheries surveys.

Data Collection

Habitat inventories and biological data were collected following the protocol presented in the *California Salmonid Stream Habitat Restoration Manual* (Flosi et al. 1998). Two-person crews trained in those methods conducted physical habitat inventories June through October 2002. Stream reaches were stratified based upon Rosgen (1996) channel types, and the habitat type and stream length determined for all habitat units within a survey reach.

The parameters measured were stream flow, channel type, temperature, fish habitat type, embeddedness (level of fine sediment surrounding cobble sized substrate particles) , shelter rating (habitat complexity based on elements such as overhanging banks, boulders, large woody debris, submerged vegetation, etc.), substrate composition (percent of different sizes), riparian canopy cover, bank composition, and bank vegetation. The data reflect instream conditions at the time of the survey.

During basin level habitat typing, full sampling of each habitat unit requires recording all characteristics of each habitat unit as per the "Instructions for Completing the Habitat Inventory Data Form" (Part III). It was determined that similar stream descriptive detail could be accomplished with a sampling level of approximately 10% (Flosi et al. 1998).

When sampling 10% of the units all habitat types are measured when encountered for the first time. Thereafter, approximately 10% of the habitat units are randomly selected for measurement of all the physical parameters. The habitat unit type, mean length, mean width, mean depth, and maximum depth are determined for the other 90% of the units. Pool habitat types are also measured for instream cover and embeddedness.

Streams were surveyed until surveyors encountered physical barriers to fish passage, a steep channel gradient of 8-10% for at least 1,000 feet with no anadromous fish above it, or a dry section of the stream 1,000 feet or more in length.

Canopy cover, embeddedness, pool depth, pool frequency, and pool shelter/cover were reported in bar charts for each of the streams surveyed.

Fish Passage Barriers

Free passage is essential for juvenile and adult anadromous fish. 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. Dry or intermittent channels impede free passage for salmonids. Temporary or permanent dams, poorly constructed road crossings, landslides, debris jams, or other natural and/or man-caused channel disturbances can also disrupt stream connectivity. Of these, poorly installed or worn road culverts commonly disrupt fish passage and disconnect fish passage.

Culverts constructed of steel, aluminum or plastic are the most common stream crossing devices found in rural road systems. Culverts often create temporary, partial, or complete barriers for adult and/or juvenile salmonids during their freshwater migration activities (Table 4). Passage barriers that can be created by culverts include an excessive drop at the culvert outlet (too high of an entry jump is required), an excessive velocity within the culvert; a lack of depth within the culvert, an excessive velocity and/or turbulence at the culvert inlet, and a debris accumulation at and/or within the culvert. The cumulative effect of numerous culvert-related passage barriers in a river system can be significant to anadromous salmonid populations. Inventories and fish passage evaluations of culverts within the coastal Mendocino County road system were conducted between August 1998 and December 2000 by Ross Taylor and Associates, under contract with the Department of Fish and Game's Fishery Restoration Grants Program. These inventories included 26 stream crossings in Mendocino County, of which three were in the Big River Basin (Taylor 2001).

Table 4. Definitions of barrier types and their potential impacts to salmonids.

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.

From Taylor 2001

These culvert inventories and fish passage evaluations followed a standardized assessment procedure. First, all culverts in stream crossings that may inhibit fish passage were located and counted. Second, each culvert location was visited during both late-summer/early fall low flow conditions and after early storm events. Third, information was collected regarding culvert specifications. Fourth, fish passage at each culvert was assessed using culvert specifications and passage criteria for juvenile and adult salmonids (from scientific literature and Fish Xing computer software) and on-site observations of fish movement. Last, the quality and quantity of stream habitat above and below each culvert was assessed. Habitat information was obtained from habitat typing surveys conducted by CDFG, the Coastal Land Trust, and the Mendocino Redwood Company.

Following the culvert inventory and fish passage assessment, a prioritized list of culverts that impede fish spawning and rearing activities was compiled for Humboldt and Mendocino counties. Criteria for priority ranking included salmonid species diversity, extent of barrier problem present, culvert risk of failure, current culvert condition, salmonid habitat quantity, salmonid habitat quality, and a total salmonid habitat score. The reports of the culvert inventories and fish passage surveys were provided to the Humboldt and Mendocino counties' Public Works, Natural Resources and Engineering Divisions, the CDFG Native Anadromous Fish and Watershed Branch, and the CDFG North Coast, Northern California, Region Headquarters.

Large Woody Debris

LWD was inventoried by MRC in 2000 using surveys of their design. The surveys covered 44 segments from 28 streams across MRC lands in the basin. The segments measured 20-30 bankfull channel widths in length, and thus ranged from 60-300 meters.

All wood within the bankfull channel was counted and measured if deemed to provide some habitat or morphologic function in the stream channel (i.e. pool formation, scour, debris dam, bank stabilization, or gravel storage). Wood pieces greater than 12 inches in diameter and 20 feet long were recorded as key pieces if bankfull channel width was less than 20 feet. In wider stream segments, a larger minimum size was used to classify key pieces. Debris accumulations (3-10 pieces) and debris jams (>10 pieces) were counted and measured separately. LWD was classified by tree species class, either redwood, fir (Douglas-fir, hemlock, grand fir), hardwood (alder, tan oak, etc.), or unknown (if tree species is indeterminable). Length and diameter were recorded for each piece so that volume could be calculated.

The quantity of LWD observed was normalized by distance, for comparison through time or to other similar areas, and is presented as a number of LWD pieces per 100 meters. This normalized quantity, by distance, is performed for functional and key LWD pieces within the active and bankfull channel. The key piece quantity in the bankfull channel (per 100 meters of channel) is compared to the target for what would be an appropriate key piece loading. The target for appropriate key piece loading is derived from Bilby and Ward (1989) and Gregory and Davis (1992) and presented in Table 5.

Table 5. Target for number of key large woody debris pieces in watercourses of the MRC ownership in the Big River Basin.

Bankfull Width (feet)	Number of Key Pieces		
	Per 100 meters	Per 1000 feet	Per mile
<15	6.6	20	106
15-35	4.9	15	79
35-45	3.9	12	63
>45	3.3	10	53

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. 1998) target values were given for each of the individual habitat elements measured (Table 6). When habitat conditions fall below the target values, restoration projects may be proposed in an attempt to meet critical habitat needs for salmonids.

Table 6. 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 embeddedness values	>40% of stream length 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	>100

From the California Salmonid Stream Habitat Restoration Manual (Flosi et al 1998).

Canopy Density—Eighty Percent or Greater of the Stream is 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 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 Greater of the Pool Tails Sampled are 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 that 51% is not within the range for successful spawning. The target value is for 50% or greater of the pool tails sampled to be 50% or less embedded. Streams with less than 50% of their length greater than 51% embedded do not meet the target value nor provide adequate spawning substrate conditions.

Pool Depth/Frequency- Forty Percent or More of the Stream Provides 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 Better 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 bank, small woody debris, large woody debris, root mass, terrestrial vegetation, aquatic vegetation, bubble curtain (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.

MRC Watershed Analysis

As part of the Watershed Analysis conducted by MRC of their lands in the Big River Basin, MRC evaluated habitat conditions for salmonids in 43 stream segments in 24 tributaries and the mainstem Big River. They used a habitat inventory method during low flow conditions using methods modified from the *California Salmonid Stream Restoration Manual* (Flosi et al., 1998) and described 100% of the wetted width. MRC defined stream segments based mainly on stream gradient and channel confinement. They also took into account the presence of fish, accessibility, stream channel type (response, transport or source reach), and representative segments that were likely to respond similar to other stream channel types within the watershed. Survey efforts focused on low gradient reaches.

Survey lengths were determined to be a distance of 20-30 bankfull widths, representing approximately two meander bends of the stream channel. Data were collected on pool, riffle and flatwater frequency; pool spacing; spawning gravel quantity and quality; over-wintering substrate; shelter complexity and large woody debris (LWD) frequency, condition and future recruitment.

MRC evaluated fish habitat parameters using target values based on scientific literature (Table 7) (Bilby and Ward 1989; Bisson et al. 1987; Bjornn and Reiser, 1991; Flosi et al. 1998; Montgomery et al. 1995; Washington Forest Practices Board 1995) and professional judgment. Spawning habitat conditions were evaluated on the basis of gravel availability and quality (gravel sizes, subsurface fines, embeddedness), and were evaluated for preferred salmonid spawning areas located at the tail-outs of pools. Summer rearing habitat conditions for salmonids were evaluated on the size, depth and availability of pools and the complexity and quantity of cover (particularly large woody debris). Over-wintering habitat was evaluated on the size, depth, and availability of pools, the proportion of habitat units with cobble or boulder-dominated substrate and the quantity of cover.

Table 7. Fish habitat condition indices for measured parameters used by MRC.

Fish Habitat Parameter	Feature	Fish Habitat Quality		
		Poor	Fair	Good
Percent pool/riffle/flatwater (by length)	Anadromous salmonid streams	<25% pools	25-50% pools	>50%pools
Pool spacing (reach length/bankfull/#pools)	Anadromous salmonid streams	> 6.0	3.0 - 5.9	< 2.9
Shelter rating(shelter value x % of habitat covered)	Pools	<60	60-120	>120
% of pools that are >3 feet residual depth	Pools	<25%	25-50%	>50%
Spawning gravel	Pool tail-outs quantity	<1.5%	1.5-3%	>3%
Percent embeddedness	Pool tail-outs	>50%	25-50%	<25%
Subsurface fines (L-P watershed analysis manual)	Pool tail-outs	2.31-3.0	1.61-2.3	1.0-1.6
Gravel quality rating (L-P watershed analysis manual)	Pool tail-outs	2.31-3.0	1.61-2.3	1.0-1.6
Key LWD + root wads / 328 ft of stream	Streams≥40 ft. BFW	<4.0	4.0-6.5	>6.6
	Streams<40 ft. BFW	<3.0	3.0-3.8	>3.9
Substrate for over-wintering	All habitat types	<20% of units cobble or boulder dominated	20-40% of units cobble or boulder dominated	>40% of units cobble or boulder dominated

Analytic Tools and Interdisciplinary Synthesis

Integrated Analysis Tables

The multi-discipline Big River team constructed a series of subject specific data tables, referred to as Integrated Analysis (IA) tables, to track the history and status of watershed processes. Through the use of IA tables the information from CDFG and NCRWQCB were compared to one another, and along with information from CDF and CGS, were used to respond to the six guiding assessment questions. The IA process also helped to identify and explain current watershed conditions. These integrated analyses are presented at both basin and subbasin levels. Land use and vegetation analyses have been further divided at the CalWater 2.2a Planning Watershed level.

The IA approach follows the down-slope movement of the five watershed products commonly delivered to streams by natural or human caused energy: water, sediment, organic woody debris, nutrients, and heat. Fundamental to these watershed processes and products are the underlying geology and geomorphology of the watershed. Geologic conditions determine, in large part, the landslide and sediment production potential of the terrain. Geologic processes are influenced in varying degrees by the vegetative community, which is often linked to human activities across the landscape. Current watershed conditions combine with natural events like fire, flood, and earthquakes to affect the fluvial geomorphology and water quality in the stream reaches of a watershed. Finally, the effects of these combined processes are expressed in stream habitats encountered by the organisms of the aquatic riparian community, including salmon and steelhead.

Ecological Management Decision Support System

The assessment program selected the Ecological Management Decision Support system software to help synthesize information on stream conditions. The EMDS system 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, the Ecological Management Decision Support (EMDS) ArcView Extension, and ArcView™. 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 show 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. This combination of software is currently being used for watershed and stream reach assessment on federal lands included in the Northwest Forest Plan (NWFP).

NWFP scientists constructed knowledge base models to identify and evaluate environmental factors (e.g. watershed geology, land use impacts, water quality, stream sediment loading, stream temperature, etc.) that shape anadromous salmonid habitat. Using this adaptive model structure, EMDS evaluated available NWFP watershed data to provide insight into stream and watershed conditions in relationship to target conditions known to be favorable to salmonids.

Development of the North Coast California EMDS Model

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 originally constructed two knowledge base networks: 1) The Stream Reach Condition Model, and 2) The Watershed Condition Model. These models were reviewed in April 2002 by an independent nine-member science panel, which provided a number of suggestions for model improvements. According to their suggestions, the team revised the two original models and added three others focused on the analysis of specific components of instream and watershed conditions that affect salmonids:

- **The Stream Reach Condition model** (Figure 8) addresses conditions for salmon on individual stream reaches and is largely based on data collected using CDFG stream survey protocols found in the California Salmonid Stream Habitat Restoration Manual, (Flosi et al. 1998). This model was used in the Big River Basin assessment;
- **The Sediment Production Risk model** evaluates the magnitudes of the various sediment sources in the basin according to whether they are natural or management related. This model was not used in the Big River Basin assessment;
- **The Water Quality model** has not yet been developed, but will offer a means of assessing characteristics of instream water (flow and temperature) in relation to fish;
- **The Fish Habitat Quality model** has not yet been developed, but will incorporate the Stream Reach model results in combination with data on accessibility to spawning fish and a synoptic view of the condition of riparian vegetation for shade and large woody debris;
- **The Fish Food Availability model** has not yet been developed, but will evaluate the watershed based upon conditions for producing food sources for anadromous salmonids.

Only the Stream Reach Condition model was used in the Big River assessment. For more details of the other models see the EMDS Appendix.

In creating these EMDS 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 needed, 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 7). 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's 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 8).

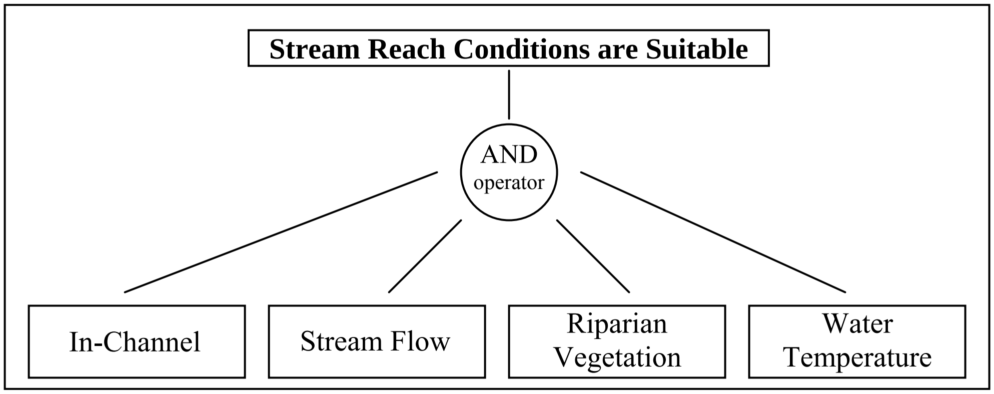

Figure 7. Tier one of the EMDS stream reach knowledge base network.

In Figure 7, 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 EMDS 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 passing the resultant information on up the network (Figure 8).

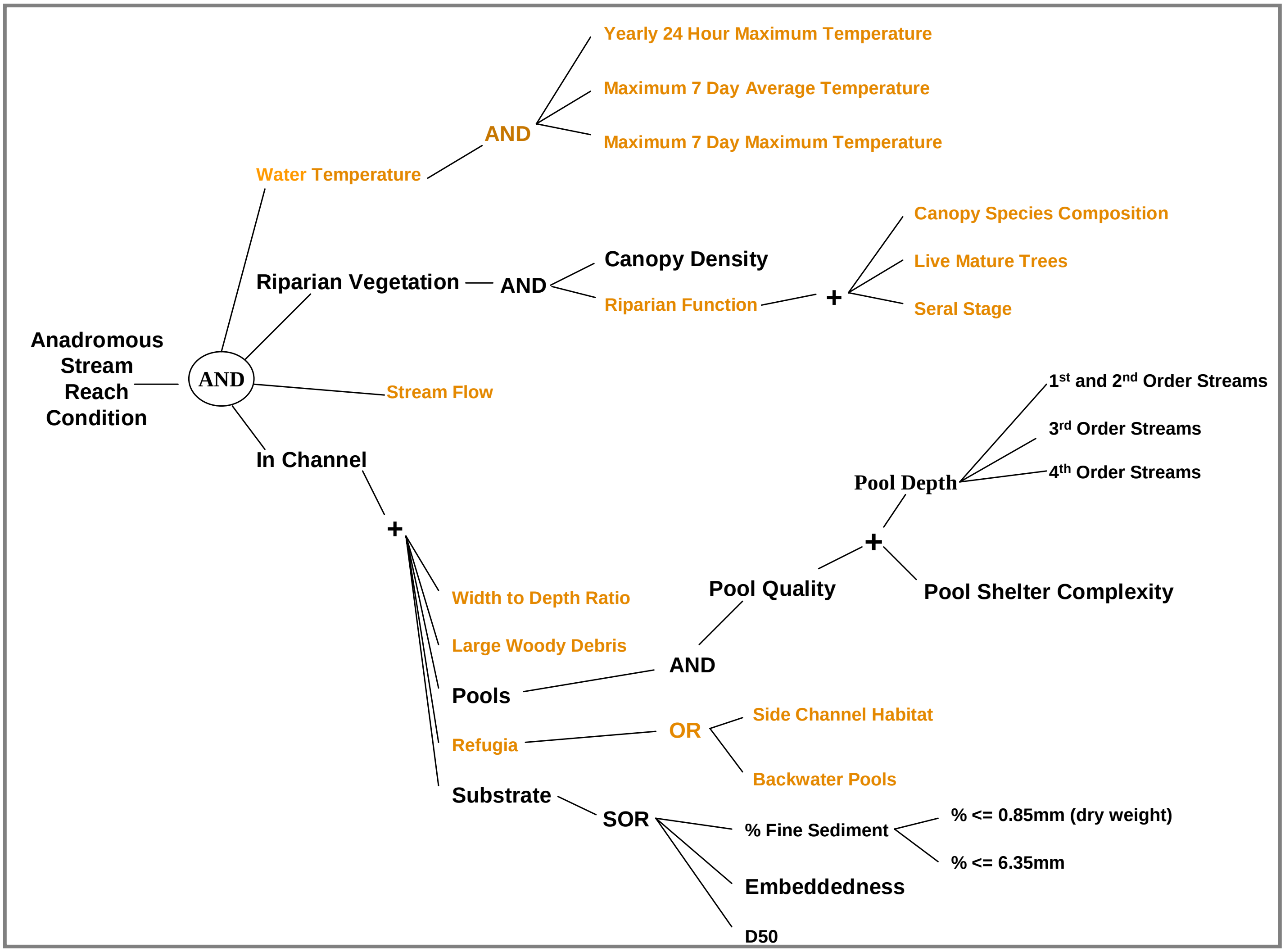

Figure 8. Graphic representation of the Stream Reach Condition model.

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

EMDS models assess the degree of truth (or falsehood) of each model proposition. Each proposition is evaluated in reference to simple graphs called reference curves that determine its degree of truth/falsehood, according to the data's implications for salmon. Figure 9 shows an example reference curve for the proposition *stream temperature is suitable for salmon*. The horizontal axis shows temperature in degrees Fahrenheit 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 are ramped between the fully suitable and fully unsuitable ranges and are rated accordingly. A similar numeric relation is determined for all attributes evaluated with reference curves in the EMDS models.

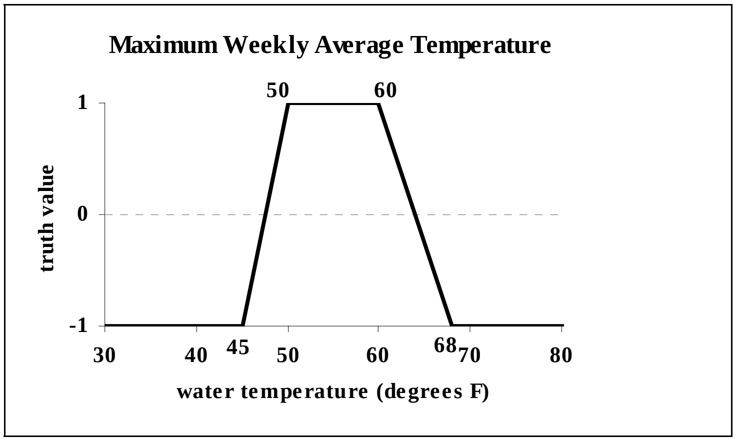

Figure 9. EMDS reference curve for stream temperature.

EMDS uses this type of reference curve in conjunction with data specific to a stream reach. This example reference curve evaluates the proposition that the stream's water temperature is suitable for salmonids. Break points on the curve can be set for specific species, life stage, or season of the year. Curves are dependent upon the availability of data in order to be included in an analysis.

For each evaluated proposition in the EMDS 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 being closer to true and those approaching –1 converging on 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 9 breakpoints occur at 45, 50, 60, and 68°F.

EMDS map legends use a seven-class system for depicting the truth-values. Values of +1 are classed as the highest suitability; values of –1 are classed as the lowest suitability; and values of 0 are undetermined. 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 relationship to the criteria in the reference curves. The following table summarizes important EMDS Stream Reach Condition model information.

Table 8. Reference curve metrics for EMDS 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 EMDS evaluation.
Riparian Function	Under development
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	Under development
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. ≤ 20% fully unsuitable, 30 – 55% fully suitable, ≥ 90% 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. EMDS 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 EMDS evaluations

Stream Reach Condition Factor	Definition and Reference Curve Metrics
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 EMDS 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 EMDS Appendix for details. Most watersheds do not have sufficient LWD survey data for use in EMDS.
Winter Refugia Habitat	Winter refugia is composed of backwater pools and side channel habitats and deep pools (> 4 feet deep). Under development.
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

EMDS offers a number of advantages for use in watershed assessments. Instead of being a hidden black box, each EMDS 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 ESRI Geographic Information System (GIS) software, EMDS maps the factors affecting fish habitat and shows how they vary across a basin. At this time, no other widely available package allows a knowledge base network to be linked directly with a geographic information system such as ESRI's ArcView™. This link is vital to the production of maps and other graphics reporting the watershed assessments. EMDS 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 to identify what is most limiting to salmonids, and thus assist to prioritize restoration projects or modify land use practices.

Another feature of the system is the ease of running alternative scenarios. Scientists and others can test the sensitivity of the assessments to different assumptions about environmental factors and how they interact, through changing the knowledge-based network and breakpoints. What-if scenarios can be run by changing the shapes of reference curves, or by changing the way the data are combined and synthesized in the network.

NetWeaver/EMDS/ArcView tools can be applied to any scale of analysis, from reach specific to entire watersheds. The spatial scale can be set according to the spatial domain of the data selected for use and issue(s) of concern. Alternatively, through additional network development, smaller scale analyses (i.e., sub-watersheds) can be aggregated into a large hydrologic unit. With sufficient sampling and data, analyses can be done even upon single or multiple stream reaches.

Limitations of the EMDS Model and Data Inputs

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. EMDS 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 EMDS 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 EMDS model using fish population data and other information should be done.

One disadvantage of linguistically based models such as EMDS is that they do not provide results with readily quantifiable levels of error. Therefore, EMDS should only be used as an indicative model, one that indicates 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 from a statistically based process model. It does provide a reasonable first approximation of conditions through a robust information synthesis approach; however, its outputs need to be considered and interpreted in the light of other information sources and the inherent limitations of the model and its data inputs. It also should be clearly noted that EMDS does not assess the marine phase of the salmonid life cycle, nor does it consider fishing pressures.

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

- Completion of quality control evaluation procedures;
- Adjust the model to better reflect differences between stream mainstems and tributaries, for example, the modification of canopy density standards for wide streams;
- Develop a suite of Stream Reach Model reference curves to better reflect the differences in expected conditions based upon various geographic watershed locations considering geology, vegetation, precipitation, and runoff patterns.

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

Management Applications of Watershed Synthesis Results

EMDS syntheses can be used at the basin scale to show current watershed status. Maps depicting those factors that may be the largest impediments, as well as those areas where conditions are very good, can help guide protection and restoration strategies. The EMDS model can also help to assess the cost-effectiveness of different restoration strategies. By running sensitivity analyses on the effects of changing different habitat conditions, it can help decision makers determine how much effort is needed to significantly improve a given factor in a watershed and whether the investment is cost-effective.

At the project planning level, EMDS model results can help landowners, watershed groups, and others select the appropriate types of restoration projects and places (i.e., planning watersheds or larger) that can best contribute to recovery. Agencies will also use the information when reviewing projects on a watershed basis.

The main strength of using NetWeaver/EMDS/ArcView knowledge base software in performing limiting factors analysis is its flexibility, and through explicit logic, easily communicated graphics, and repeatable results, it can provide insights as to the relative importance of the constraints limiting salmonids in North Coast watersheds. Thus, the results have utility to assess fish habitat conditions in watersheds and to help prioritize restoration efforts. They also facilitate an improved understanding of the complex relationships among environmental factors, human activities, and overall habitat quality for native salmon and trout.

Adaptive Application for EMDS and CDFG Stream Habitat Evaluations

CDFG has developed habitat evaluation standards, or target values, to help assess the condition of anadromous salmonid habitat in California streams (Flosi et al. 1998). These standards are based upon data analyses of over 1,500 tributary surveys, and considerable review of pertinent literature. The EMDS reference curves have similar standards. These have been adapted from CDFG, but following peer review and professional discussion, they have been modified slightly due to more detailed application in EMDS. As such, slight differences occur between values found in Flosi et al. (1998) and those used by EMDS. The reference curves developed for the EMDS are provided in the EMDS Appendix of this report.

Both habitat evaluation systems have similar but slightly different functions. Stream habitat standards developed by CDFG are used to identify habitat conditions and establish priorities among streams considered for improvement projects based upon standard CDFG tributary reports. The EMDS 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 EMDS 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. (1998), field observations, and results from EMDS 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 EMDS 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 CDFG target values, or to be fully suitable according to EMDS. 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's results is a necessary component of watershed assessment and reporting.

Limiting Factors Analysis

A main objective of CDFG 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 over abundance, 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, habitat loss and modification are major determinants of their current status (FEMAT 1993). 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 stream's ability to support viable populations.

The first method uses priority ranking of habitat categories based on a CDFG team assessment of data collected during stream habitat inventories. The second method uses the EMDS 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 a watershed's ability to produce viable salmonid populations.

The LFA assumes that poor habitat quality and reduced quantities of favorable habitat impairs fish production. Limiting factors analysis is focused mainly on those physical habitat factors within 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 and
- Density dependent mechanisms.

Density independent mechanisms 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 water temperatures or chemistry reach lethal levels. Density dependant mechanisms generally operate according to population density and habitat carrying capacity. Competition for food, space, and shelter are examples of density dependant factors that affect growth and survival when populations reach or exceed the habitat carrying capacity.

The program's approach considers these two types of habitat factors before prioritizing recommendations for habitat management strategies. Priority steps are given to preserving and increasing the amount of high quality (density independent) habitat in a cost effective manner. More details of the LFA are presented in the CDFG Appendix.

Restoration Needs/Tributary Recommendations Analysis

CDFG inventoried 57 tributaries to the Big River and three sections of mainstem Big River using protocols in the *California Salmonid Stream Habitat Restoration Manual*. The tributaries of the Big River surveyed were composed of 106 stream reaches, defined as Rosgen channel types. 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.

CDFG biologists selected and ranked recommendations for each of the inventoried streams, based upon the results of these standard CDFG habitat inventories, and updated the recommendations with the results of the stream reach condition EMDS and the refugia analysis (Table 9). It is important to understand that 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 provide focus for on-the-ground project design and implementation. Bear in mind that stream and watershed conditions change over time and periodic survey updates and field verification are necessary if watershed improvement projects are being considered.

Table 9. List of tributary recommendations in stream tributary reports.

Recommendation	Explanation
Temp	Summer water temperatures were measured to be above optimum for salmon and steelhead
Pool	Pools are below CDFG target values in quantity and/or quality
Cover	Escape cover is below CDFG 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 CDFG target values
Spawning Gravel	Spawning gravel is deficient in quality and/or quantity
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

In general, the recommendations that involve erosion and sediment reduction by treating roads and failing stream banks, and riparian and near stream vegetation improvements precede the instream recommendations in reaches that demonstrate disturbance levels associated with watersheds in current stress. Instream improvement recommendations are usually a high priority in streams that reflect watersheds in recovery or good health. Various project treatment recommendations can be made concurrently if watershed and stream conditions warrant.

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/CDFG 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 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 that enter into a recommendation's subsequent ranking 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 the candidate work sites. Biological considerations are made based upon the propensity for benefit to multiple or single fishery stocks or species. Cost benefit and project feasibility are also factors in project selection for design and development.

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 (Moyle and Yoshiyama 1992; Li et al. 1995; Reeves et al. 1995). Protecting these areas will prevent the loss of the 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 populations;
- Refugia areas provide a hedge against the difficulty in restoring extensive, degraded habitat and recovering imperiled populations in a timely manner (Kaufmann et al. 1997).

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 salmonids in such vital activities as 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 relative 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 several suitable habitat patches and maintaining 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. 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. 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 1990; Moyle and Yoshiyama 1992; Frissell 1993, 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 sub-watershed 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. Although fragmented areas of suitable habitat are important, their connectivity is necessary to sustain the fisheries. 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 CDFG data collection at the regional scale. The program uses these values in its EMDS models and stream inventory, improvement recommendation process. Li et al. (1995) suggested three prioritized steps to use the refugia concept to conserve salmonid resources.

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

Refugia and Meta-population Concept

The concept of anadromous salmonid meta-populations is important when discussing refugia. The classic metapopulation model proposed by Levins (1969) assumes 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 sub-populations (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 nicely into the sub-population and metapopulation concept because they exhibit a strong homing behavior to natal streams forming sub-populations, and have a tendency to stray into new areas. The straying or movement into nearby areas results in genetic exchange between sub-populations 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 as refugia.

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 dependant on migrants from the source population to survive (McElhany et al. 2000). 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, 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, meta-populations and habitat conditions and productivity across large areas. This lack of information holds true for all study basins especially in terms of meta-population 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; Kitsap County 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. With implementation of ecosystem management strategies aimed at maintaining or restoring natural processes, some of these areas may improve in habitat quality, show an increase in fish numbers, and add to the metapopulation strength.

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

Approach to Identifying Refugia

The program's interdisciplinary refugia identification team identified and characterized refugia habitat by using expert professional judgment and criteria developed for North Coast watersheds. The criteria used 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 programs 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 collected 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, analyzing field notes, 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 to the survey results from that particular stream and to field notes taken during 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 took into account that anadromous salmon have several non-substitutable habitat needs for their life cycle. A minimal list (NMFS 2001) includes:

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

The best 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 for only some of the requirements have become very important areas, but 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. Therefore, the refugia team considered relatively small, tributary areas in terms of their ability to provide at least partial refuge values, yet contribute to the aggregated refugia of larger scale areas. Therefore, the team's analyses used the tributary scale as the fundamental refugia unit.

CDFG created a tributary scale refugia-rating worksheet, (Table 10, page 47). The worksheet has 21 condition factors that were rated on a sliding scale from high quality to low quality. Twenty-one 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 biologic community).

Additionally, NCRWQCB created a worksheet specifically for rating water quality refugia, Table 11. The worksheet has 13 condition factors that were rated on a sliding scale from high quality to low quality. Thirteen factors were grouped into three categories:

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

Tributary ratings were determined by combining the results of NCRQCB water quality results, EMDS results, and data in CDFG tributary reports by a multi-disciplinary, 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 analysis.

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 biotic 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).

The Report of the Panel on the Ecological Integrity of Canada's National Parks submitted this definition:

A Definition of Ecological Integrity

The Panel proposes the following definition of ecological integrity: "An ecosystem has integrity when it is deemed characteristic for its natural region, including the composition and abundance of native species and biological communities, rates of change and supporting processes." "In plain language, ecosystems have integrity when they have their native components (plants, animals and other organisms) and processes (such as growth and reproduction) intact."

Salmonid Refugia Categories and Criteria:

High Quality Habitat, High Quality Refugia

- Maintains a high level of watershed ecological integrity (Frissell 2000);
- Contains the range and variability of environmental conditions necessary to maintain community and species diversity and supports natural salmonid production (Moyle and Yoshiyama 1992; Frissell 2000);
- 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 (Li et al. 1995);
- 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 (Frissell 2000);
- 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 has resilience to degradation, which demonstrates a strong potential to become high quality refugia (Moyle and Yoshiyama 1992; Frissell 2000).

Medium Potential Refugia

- Watershed ecological integrity is degraded or fragmented (Frissell 2000);
- 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;
- Relative 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 (Frissell 2000);
- Most components of instream habitat are highly impaired;
- Riparian corridor components are degraded;
- Salmonids are poorly represented at all life stages and year classes, but especially in 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.

Other Related Refugia Component Categories:

Potential Future Refugia (Non-Anadromous)

- Areas where habitat quality remains high but does not currently support anadromous salmonid populations;
- An area of high habitat quality, but anadromous fish passage is blocked by man made obstructions such as dams or poorly designed culverts at stream crossings etc.

Critical Contributing Areas

- Area contributes a critical ecological function needed by salmonids such as providing a migration corridor, conveying spawning gravels, or supplying high quality water (Li et al. 1995);
- Riparian areas, floodplains, and wetlands that are directly linked to streams (Huntington and Frissell 1997).

Data Limited

Areas with insufficient data describing fish populations, habitat conditions, watershed conditions, or management practices.

Table 10. Refugia rating worksheet.

Stream Name:			**Date:**
Raters:			
Ecological Integrity - Overall Refugia Summary Ratings:	**High Quality; High Potential; Medium Potential; Low Quality (Other: Non-Anadromous; Contributing Functions; Data Limited)**		
Stream Condition:	**High Quality**	**Medium Quality**	**Low Quality**
Stream Flow			
Water Temperature			
Free Passage			
Gravel			
Pools			
Shelter			
In-Channel Large Wood			
Canopy			
Nutrients			
Stream Summary Rating:			
Riparian Condition:	**High Quality**	**Medium Quality**	**Low Quality**
Forest Corridor Seral Stage			
Fluvial Dis-equilibrium			
Aquatic/Riparian Community			
Riparian Summary Rating:			
Native Salmonids Status: (Native Species and Age Classes)	**Present**	**Diminished**	**Absent**
Chinook			
Coho			
Steelhead			
Species Summary Rating:			
Salmonid Abundance:	**High**	**Medium**	**Low**
Chinook			
Coho			
Steelhead			
Abundance Summary Rating:			
Management Impacts:	**Low Impacts**	**Medium Impacts**	**High Impacts**
Disturbed Terrain			
Displaced Vegetation			
Native Biologic Integrity			
Impacts Summary Rating:			
Comments:			

Table 11. Water quality refugia rating sheet.

Stream Name:			**Date:**
Rater(s):			
In-stream Sediment Related:	**Suitable**	**Somewhat Suitable**	**Unsuitable**
Pebble Counts (D50)			
Mc Neil			
Spawning Substrate			
% Fines <0.85 mm			
% Fines <6.4 mm			
V*			
Permeability			
Turbidity/Suspended Sediment			
Thalweg			
Stream Summary Rating:			
Stream Temperature:	**Suitable**	**Undetermined**	**Unsuitable**
MWAT			
Seasonal Maximum			
Riparian Summary Rating:			
Water Chemistry:	**Suitable**	**Somewhat Suitable**	**Unsuitable**
Dissolved Oxygen			
pH			
Specific Conductance			
Species Summary Rating:			
Ecologic Integrity - Overall Refugia Summary Rating:	**Category: High Quality; High Potential; Potential; Low Quality; (Non-Anadromous; Contributing Functions; Data Limited)**		
Comments:			

NI= No Information NR= Not Rated