Chapter 4

Interdisciplinary Synthesis and Findings

An integrative analysis of land use, geologic features, and instream fish habitat information.

A major challenge in watershed assessment is integrating a large amount of information from multiple sources and disciplines in a fashion that allows the exploration and understanding of the interrelationships among watershed processes, land use activities, and conditions. Integrated analysis is a critical part in trying to understand linkages and identify watershed cumulative environmental effects.

While Chapter 2 largely focused on single disciplinary areas, this chapter undertakes additional interdisciplinary analyses to explore interrelationships among different disciplines.

Reid (1996) discussed the requirements for integrated watershed assessment approaches:

> Procedures for watershed analysis…are intended to provide integrated, interdisciplinary evaluations of the biological, physical, and socio-economic interactions that influence the [landscape] and to describe environmental changes and their causes. Interdisciplinary implies that expertise from multiple disciplines is providing an integrated attack on a problem area. *Interdisciplinary* is carefully distinguished from *multi-disciplinary*, which implies only that multiple inquiries are being carried out at the same time or in the same place.

An important part of any watershed assessment work is the identification of cumulative environmental effects. Further, assessing cumulative watershed environmental effects is both a practical challenge and a legal requirement for certain kinds of land use activities under the California Environmental Quality Act (CEQA) and the National Environmental Policy Act (NEPA) (Henly 1993). A practical working definition of watershed cumulative environmental effects is:

> The interaction of the individual environmental impacts of multiple land management activities on a watershed with each other and with natural processes, resulting in a combined impact on some watershed factor of concern. This interaction occurs across both space and time.

Laws requiring project proponents to assess the potential of their actions for causing or contributing to cumulative effects also require them to assess whether those actions will result in a “significant” level of impact. Determination of the “significance” of either individual or cumulative effects, as is done in the CEQA or NEPA arena, is not appropriate for the context of NCWAP’s work.

NCWAP approaches cumulative effects by looking at the multiple land use and natural process factors that can affect aquatic habitat for salmonids (e.g., landslides, erosion, land use, floods) and examining aquatic habitat conditions themselves. Work under NCWAP assumes that the bulk of the adverse impacts to aquatic habitat observed in the NCWAP process in the Gualala River Watershed are the result of the cumulative effects of landslides, land use, floods, and other factors. However, our level of watershed assessment does not allow us to tease out of these cumulative effects the causal relationships at a quantitative or even relative level.

The Gualala North Coast Watershed Assessment Program (NCWAP) team used various methods and models to assess relationships between fish habitat and landscape processes and conditions as follows: (1) the Ecological Management Decision Support (EMDS) model was used to process data and create maps of reach conditions based on CDFG raw data and additional maps showing road density and position on hillslope by Planning Watershed; (2) geographic information system (GIS) data from the California Department of Forestry and Fire Protection (CDF), the California Geological Survey (CGS), the California Department of Fish and Game (CDFG) were composited through a series of database queries intended to reveal relationships; (3) the output of the queries was used to build tables (Integrated Data Tables) and maps that help explain the relationships., including Plate 3, *Potential Restoration Sites and Habitat Limiting Factors for the Gualala River Watershed*; (4) recommendations for restoration priorities were established based on watershed conditions and feasibility of implementation; and (5) potential refugia sites in the watershed were identified.

4.1 Ecological Management Decision Support

4.1.1 INTRODUCTION

NCWAP selected the Ecological Management Decision Support (EMDS) (Reynolds 1999) software to help evaluate and synthesize information on watershed and stream conditions important to salmonids during the freshwater phases of their life history. The general workings of EMDS and the details of the models NCWAP is developing in conjunction with it are described in Appendix 5.

NCWAP staff have constructed "knowledge base" models to identify and evaluate environmental factors (e.g., watershed geology, stream sediment loading, stream temperature, land use activities, etc.) that shape anadromous salmonid habitat. Based upon these models, EMDS evaluates available data to provide insight into the conditions of the streams and watersheds for salmonids. The synthesis EMDS provides can then be compared to more direct measures of salmonid production—i.e., the number of salmonids recently found in streams. EMDS offers a number of benefits for the assessment work that NCWAP is conducting, and also has some known limitations. Both the advantages and drawbacks of EMDS are provided in some detail here and in the appendix.

Our use of the EMDS model outputs in this report is tentative. As discussed below, a scientific peer review process conducted in April of 2002 indicated that substantial changes to NCWAP's EMDS modeling approach are needed. At the time of the production of this report, we have been able to implement some, but not all of these recommendations. Hence, we use the model outputs with caution at this time. NCWAP will continue to work to refine and improve the EMDS model, based on the peer review.

4.1.2 EMDS DEVELOPMENT AND USE BY NCWAP

EMDS 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™. Microsoft Excel is a commonly used spreadsheet program for data storage and analysis. NetWeaver (Saunders and Miller [no date]), developed at Pennsylvania State University, helps scientists build graphics of the models (knowledge base networks) that specify how the various environmental factors will be incorporated into an overall stream or watershed assessment. These networks resemble branching tree-like flow charts, and graphically show the logic and assumptions used in the assessment, and are used in conjunction with environmental data stored in a Geographic Information System (ArcView™) to perform the assessments and facilitate rendering the results into maps. This combination of software is currently being used for watershed and stream reach assessment within the federal lands included in the Northwest Forest Plan (NWFP).

NCWAP 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 NCWAP staff, model developer Dr. Keith Reynolds and several outside scientists also participated. As a starting point, NCWAP used an EMDS knowledge base model developed by the NWFP for use in coastal Oregon. Based upon the workshop, subsequent discussions among NCWAP staff and scientists, examination of the literature, and consideration of California conditions, NCWAP scientists then developed preliminary versions of the EMDS models. The first model was for assessing Stream Reach Condition, and the second was designed to assess conditions over the area of the Watershed Condition.

The two initial NCWAP models were reviewed over two days in April 2002 by an independent nine-member science panel, which provided a number of suggestions for model improvements. According to these suggestions, NCWAP scientists revised their EMDS models, as presented below.

4.1.3 THE KNOWLEDGE BASE NETWORKS

For California's north coast watersheds, the NCWAP team has constructed five knowledge base networks reflecting the best available scientific studies and information on how various environmental factors combine to affect anadromous fish on the north coast. All five models are geared to addressing current conditions (instream and watershed) for salmonids, and to reflect a fish's perspective of overall habitat conditions:

1. The Stream Reach model (Figure 4.1-1 and Table 4.1-1), addresses conditions for salmon on individual stream reaches and is largely based on data collected under the Department of Fish and Game's stream habitat inventory survey protocols,
2. The Sediment Production model (Figure 4.1-2 and Table 4.1-2), evaluates the magnitudes of the various sediment sources in the basin according to whether they are natural or management related,
3. The Water Quality model (Figure 4.1-3 and Table 4.1-3) offers a means of assessing the characteristics of the instream water (flow and temperature) in relation to fish,
4. The Fish Habitat Quality model (Figure 4.1-3) incorporates 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,
5. The Fish Food Availability model (Figure 4.1-3) has not yet been constructed, but will evaluate the watershed based upon conditions for producing food sources for anadromous salmonids.

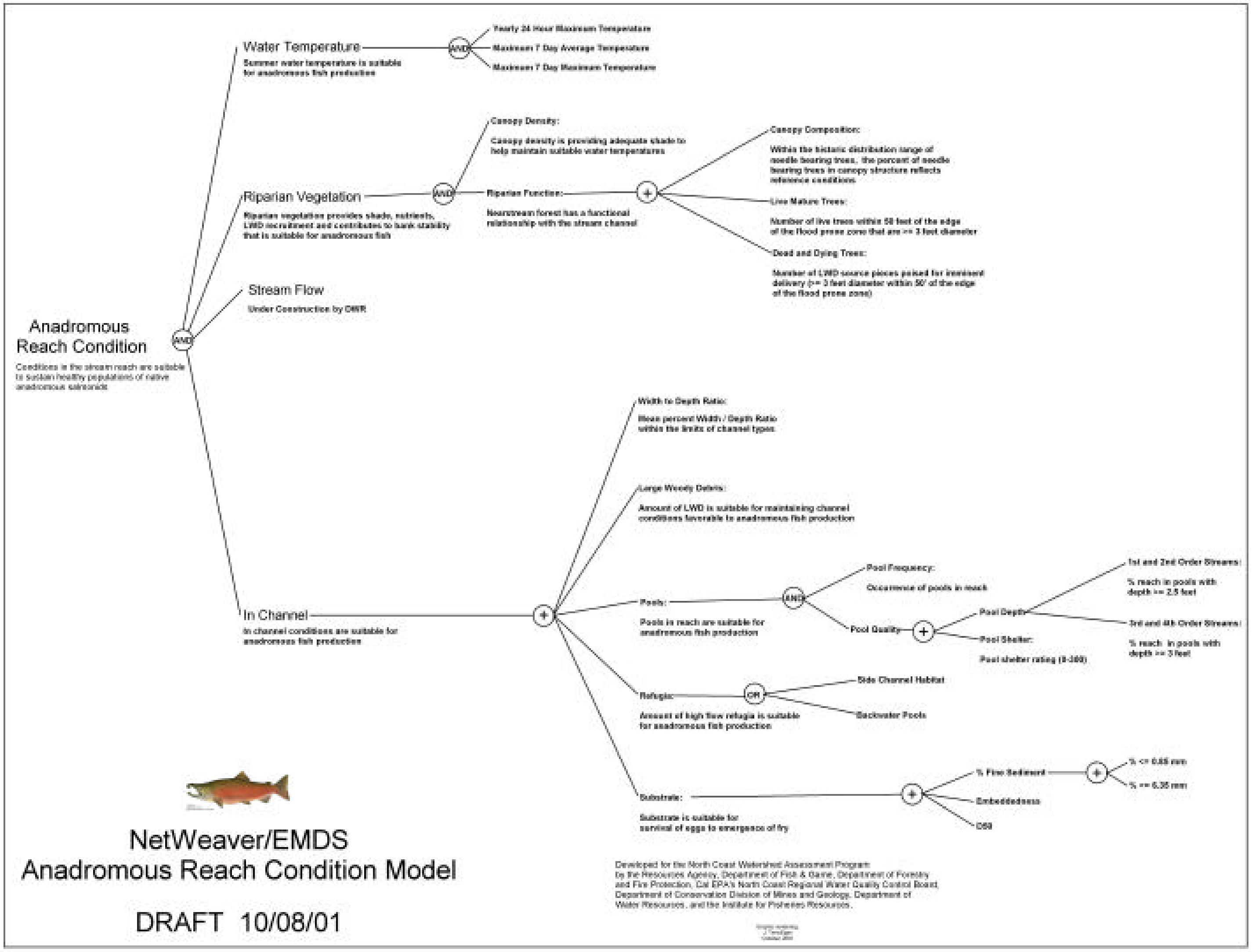

Figure 4.1-1
NCWAP EMDS Anadromous Reach Condition Model

In creating the EMDS models listed above, NCWAP staff have used what is termed a “top-down” approach. This approach is perhaps best explained by way of example. The NCWAP Stream Reach Condition model began with the proposition: The overall condition of the stream reach is suitable for maintaining healthy populations of native coho and chinook salmon, and steelhead trout. A knowledge base (network) model was then designed to evaluate the “truth” of that proposition, based upon data from each stream reach. The model design and contents reflect the specific information NCWAP scientists believe are needed, and the manner in which it should be combined, to test the proposition.

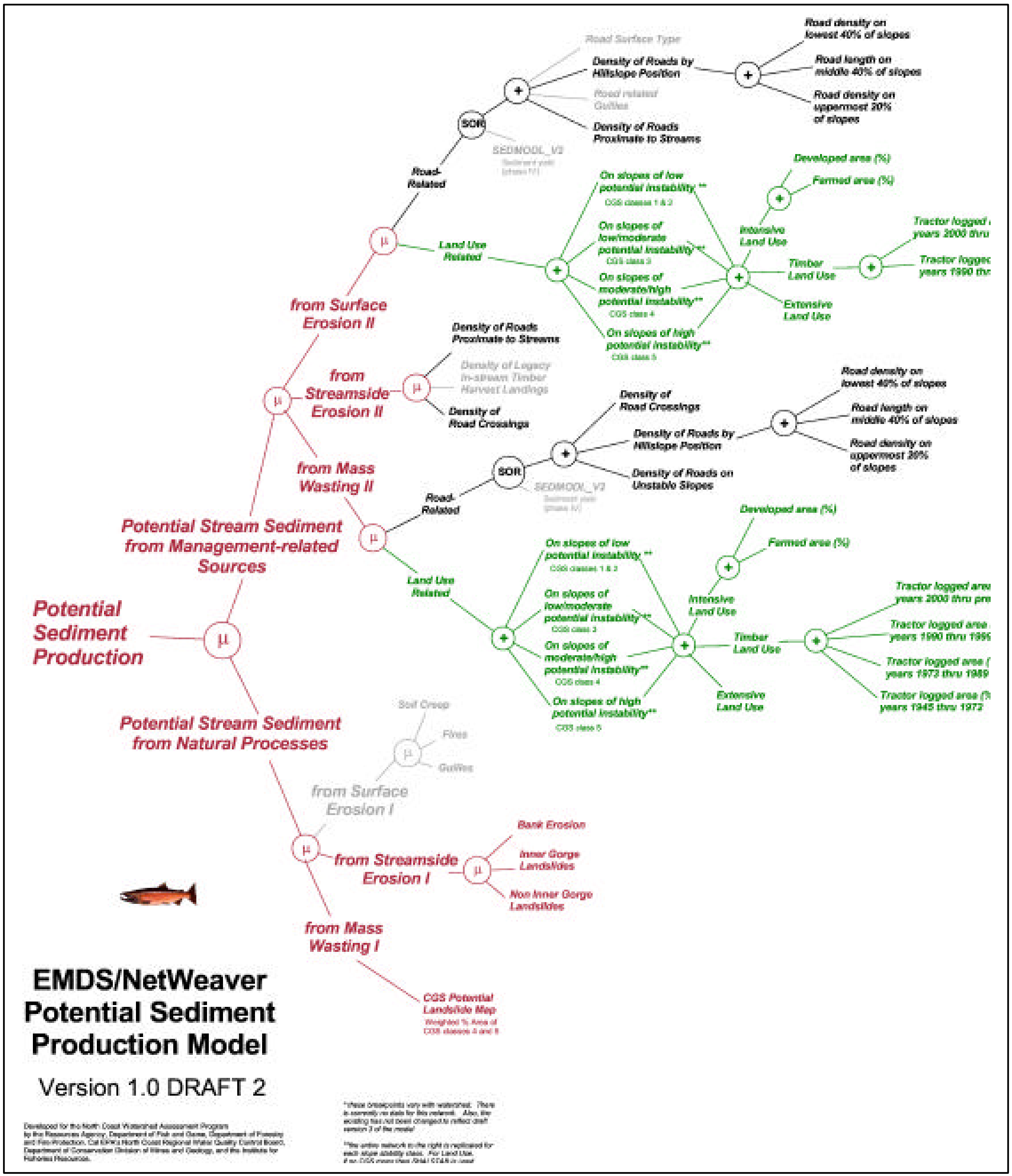

Figure 4.1-2
NCWAP EMDS Potential Sediment Production Model

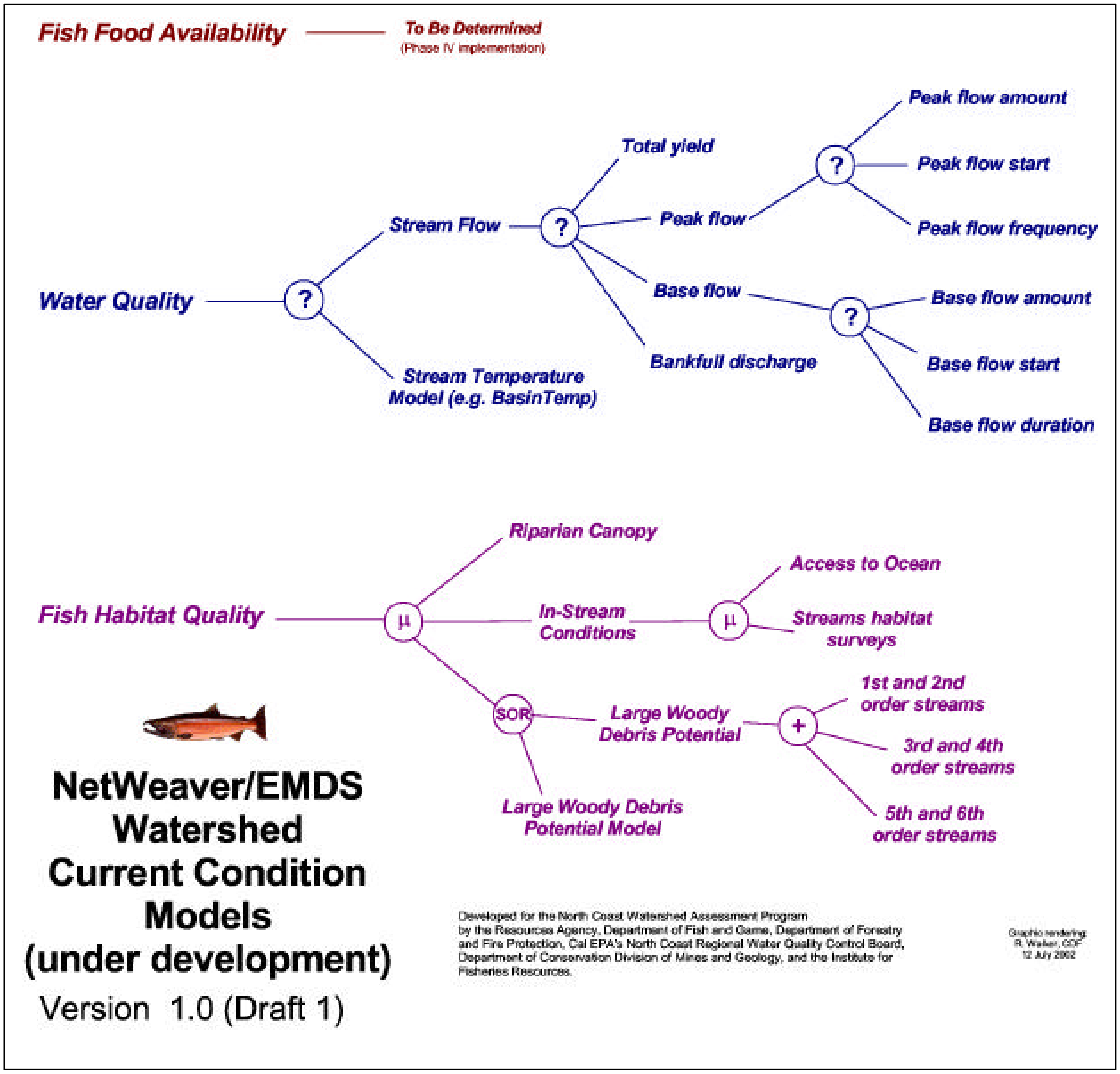

Figure 4.1-3
NCWAP EMDS Fish Food Availability, Water Quality and Fish Habitat Quality Models
Note: None of these models has yet been implemented. This graphic shows their current states of development.

In evaluating stream reach conditions for salmonids, the NCWAP model uses data on several environmental factors. The first branching of the knowledge base network (Figure 4.1-4) shows that information on in-channel condition, stream flow, riparian vegetation and water temperature are all used as inputs in the stream reach condition model. In turn, each of the four branches is progressively broken into more basic data components that contribute to it (not shown). The process is repeated until the knowledge base network incorporates all information believed to be important to the evaluation.

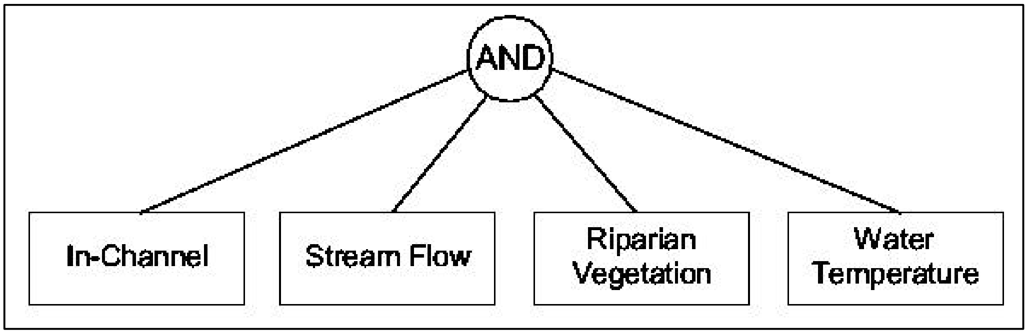

Figure 4.1-4
EMDS Stream Reach Knowledge Base Network
EMDS uses knowledge base networks to assess the condition of watershed factors affecting native salmonids.

Although model construction is typically done top-down, models are run in EMDS from the “bottom up”. That is, data on the stream reach is usually entered at the lowest branches of the network tree (the “leaves”), and then is combined progressively with other information as it 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. For example, the “AND” at the decision node in Figure 4.1-4 means that the lowest value of the four general factors coming in to the model at that point is taken to indicate the potential of the stream reach to sustain salmon populations.

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 4.1-5 is an example reference curve for the proposition: “the stream temperature is suitable for salmon”. The horizontal axis shows temperature in degrees Fahrenheit, while the vertical is labeled “Truth Value” and ranges from –1 to +1. The line shows what are fully unsuitable temperatures (-1), fully suitable temperatures (+1) and those that are in-between (> -1 and <+1). In this way, a similar numeric relation is required for all propositions evaluated in the EMDS models.

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

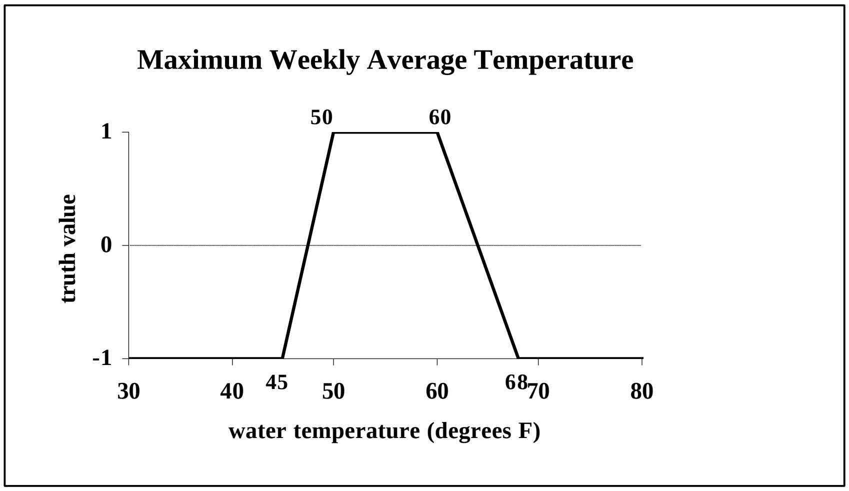

Figure 4.1-5
EMDS Reference Curve

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", with 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 (where the slope of the reference curve changes) in the Figure 4.1-5 example occur at 45, 50, 60 and 68 degrees Fahrenheit. For the Stream Reach model, NCWAP fisheries biologists determined these temperatures by a review of the scientific literature.

For many NCWAP parameters, particularly those relating to upland geology and management activities, effectively no scientific literature is available to assist in determining breakpoints. Because of this, NCWAP has had little alternative but to use a more empirically based approach for breakpoints. Specifically, for each evaluated parameter, the mean and standard deviation are computed for all planning watersheds in a basin. Breakpoints are then selected to rank each planning watershed for that parameter in relation to all others in the basin. We used a simple linear approximation of the standardized cumulative distribution function, with the 10th and 90th percentiles serving as the low and high breakpoints (Figure 4.1-6). Thus the truth values for all Potential Sediment Production model variables are relative measures directly related to the percentile rank of that planning watershed. While these relative rankings are not comparable outside of the context of the basin, they do provide an indication of relative conditions within the basin.

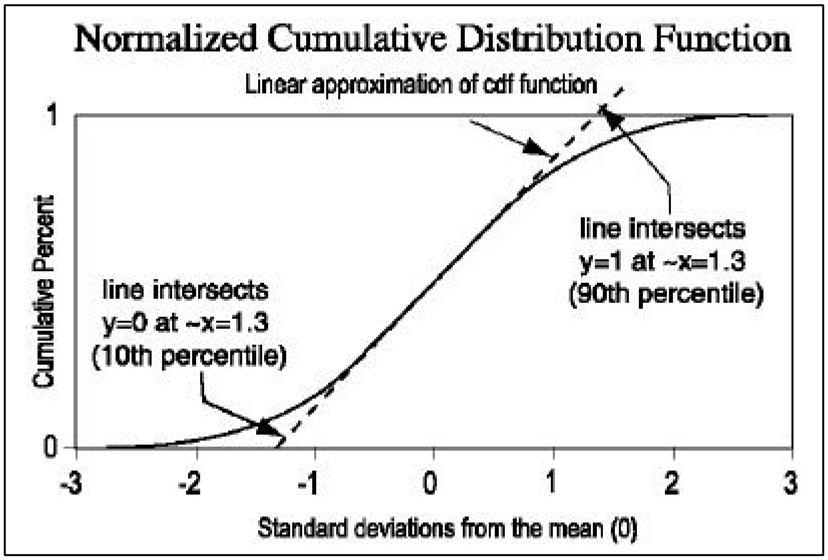

Figure 4.1-6
Using the 10th and 90th percentiles as breakpoints (as with land use) is a linear approximation of the central part of the normalized cumulative distribution function.

The science review panel recommended that this method developed by NCWAP scientists be changed. They advised to use a set of reference watersheds from the region, computing the distributions of land use and other parameters from those watersheds to determine breakpoints. At this point NCWAP staff have not had the resources to select the reference watersheds, nor to process the data for them. This issue will be addressed in future watershed assessment and the breakpoints adjusted as the information from reference watersheds becomes available.

NCWAP map legends use a seven-class system for depicting the EMDS 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).

In EMDS, the data that are fed into the knowledge base models come from GIS layers stored and displayed in ArcView. Thus EMDS is able to readily incorporate many of the GIS data layers developed for the program into the watershed condition syntheses. Figure 4.1-7 portrays an example map of EMDS results. Reference Curves used in NCWAP’s Current EMDS Models

The tables below summarize important EMDS model information. More technical details and justification for each parameter are supplied in the appendix.

1. The Stream Reach Condition model. Parameter definition and breakpoints for this model (shown in Table 4.1-1) are based upon reviews the scientific literature.

2. The Sediment Production Risk model. Parameter definitions and respective weights are shown in Table 4.1-2. Parameters currently not being used in the model for lack of data are noted in the table. All breakpoints for this model are determined empirically (i.e. based upon percentiles of the data distribution, i.e. Figure 4.1-6), due to the use of parameters that have no equivalents nor surrogates in the scientific literature.
3. The Fish Habitat Quality model. This model is still in early stages of development. It will incorporate the results of the Stream Reach model, and breakpoints will be based upon the scientific literature of properly functioning reference watersheds.
4. The Water Quality model. This model is also under development. Water temperature will be modeled with software such as Stillwater Sciences' BasinTemp. Methods for modeling flow parameters have not yet been determined.
5. The Fish Food Availability model. Recommended by the science panel review, this model has yet to be designed and implemented by NCWAP.

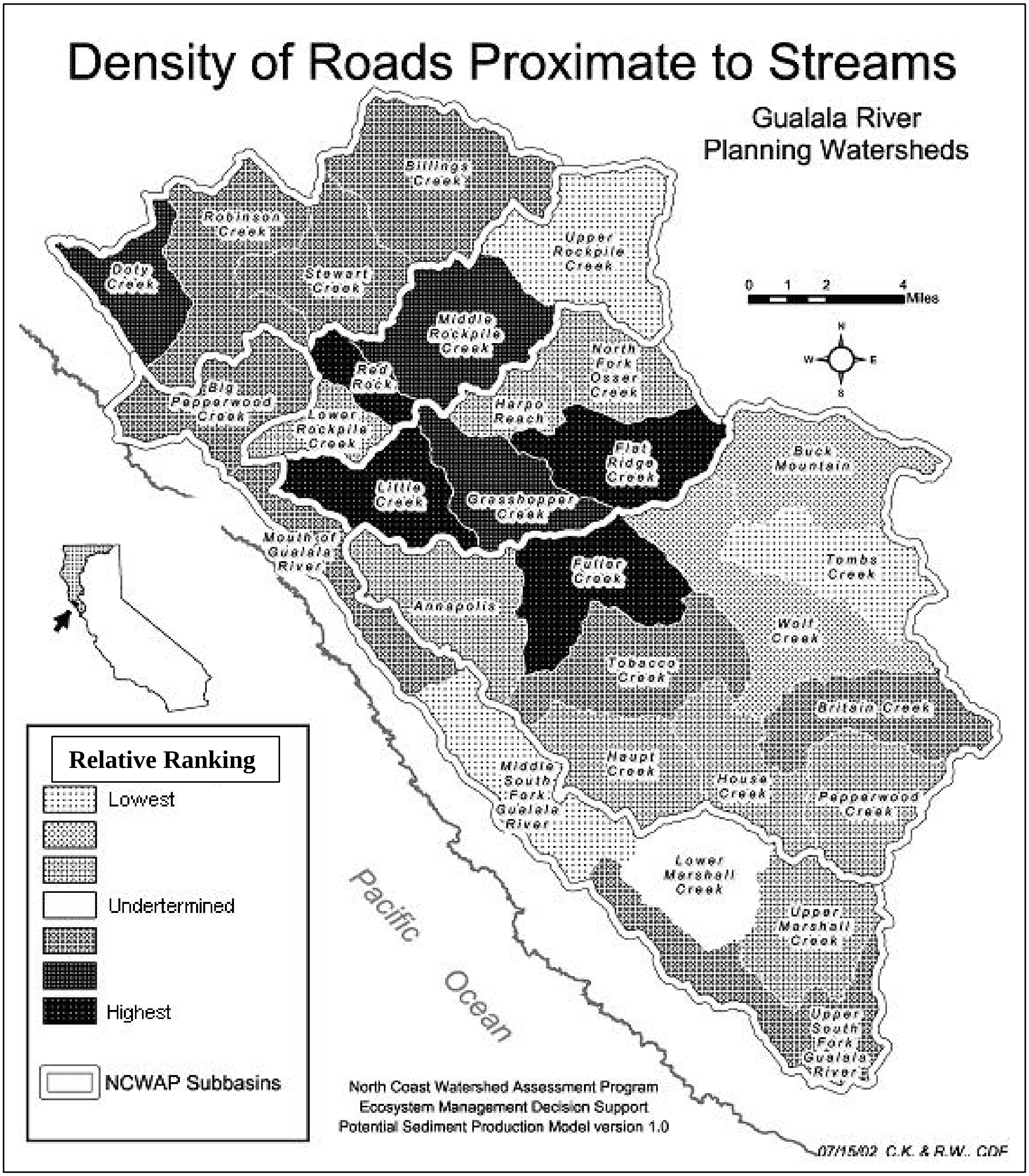

Figure 4.1-7

EMDS Graphical Output, Density of Roads Proximate to Streams

Shows total length of roads near watercourses. Planning watersheds with a high density of roads near streams indicate where additional field scrutiny is advised to determine the necessity of road upgrade and improvement work. Planning watersheds in lighter tones indicate lower priority areas based on this assessment.

Table 4.1-1
Reference Curve Metrics for the EMDS Stream Reach Condition Model.

Stream Reach Condition Factor	Definition and Reference Curve Metrics
Water Temperature	
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	
Canopy Density	Average percent of the thalweg within a stream reach influenced by tree canopy. <50% fully unsuitable, =85% fully suitable.
Seral Stage	Under development
Vegetation Type	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	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 sores are 0.8 or more and -0.8 evaluate to fully false.
Percent fines in substrate <0.85 mm (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
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	The reference values for frequency and volume are derived from Bilby and Ward (1989) and are dependent on channel size. See appendix for details. Most watersheds do not have sufficient LWD surveys for use in EMDS.
Refugia Habitat	Refugia is composed of backwater pools and side channel habitats and deep pools (>4 feet deep). Not implemented at this time.
Pool to Riffle Ratio	Under development
Width to Depth Ratio	Under development

Table 4.1-2
Reference Curve Metrics for the EMDS Sediment Production Risk Model, Version 1.0

Sediment Production Factor	Definition*	Weights**
Total Sediment Production	**The mean truth value from Natural Processes and Management-related Processes**	
Natural Processes	**The mean truth value from Mass Wasting I, Surface Erosion I and Streamside Erosion I knowledge base networks**	**0.5**
Mass Wasting I	The mean truth value from natural mass wasting: Landslide Potential, Deep-seated Landslides and Earth Flows	0.33
Landslide Potential	A selective OR (SOR) node takes the best available data to determine landslide mass wasting potential.	1.0
CGS Landslide Potential Map	(1st choice of SOR node) Percentage area of planning watershed in the landslide potential categories (4 and 5)	1.0
Landslide Potential Class 5	Percentage area of watershed in class 5 (CGS rating)	0.8
Landslide Potential Class 4	Percentage area of watershed in class 4 (CGS rating)	0.2
Probabilistic Landslide Model	(2nd choice of SOR node) Where option 1 is missing, the Probabilistic Landslide Model is used to calculate area of planning watershed with unstable slopes	1.0
SHALSTAB	(3rd choice of SOR node) Where options 1 and 2 are missing, SHALSTAB model is used to calculate area of planning watershed with unstable slopes	1.0
Surface Erosion I	The mean truth value from natural processes of surface erosion: Gullies, Soil Creep, and Fires	0.33
Gullies	Density of natural gullies in planning watershed (currently no data supplied to model here)	0.33
Soil Creep	Percentage area of planning watershed with soil creep (currently no data supplied to model here)	0.33
Fires	Percentage area of planning watershed with high fire potential (currently no data supplied to model here)	0.33
Streamside Erosion I	The mean truth value from natural processes of streamside erosion: Active Landslides Connected to Streams; Active Landslides Not Connected to Streams; Disrupted Ground Near Streams	0.33
Active Landslides Connected to Streams	Percentage of planning watershed with Active Landslides connected to watercourses	0.60
Active Landslides Not Connected to Streams	Percentage of planning watershed with Active Landslides not connected to watercourses	0.30
Disrupted Ground Near Streams	Percentage of planning watershed with Disrupted Ground near to watercourses	0.10
Management-related Processes	**The mean truth value from Mass Wasting II, Surface Erosion II and Streamside Erosion II knowledge base networks**	**0.5**
Mass Wasting II	The mean truth value from management-related mass wasting: Road-related and Land Use-related	0.33
Road-related	Coarse sediment contribution to streams from roads from either SEDMODL_V2 (first choice) or the mean of Density of Road/Stream Crossing, Density of Roads by Hillslope Position, and Density of Roads on Unstable Slopes	0.5

Table 4.1-2
Reference Curve Metrics for the EMDS Sediment Production Risk Model, Version 1.0

Sediment Production Factor	Definition*	Weights**
SEDMODL-V2	(when model is available – 1st choice of SOR node)	1.0
Density of Road/Stream Crossings	(2nd choice of SOR node, averaged with DRHP directly below) Number of road crossings/km of streams	0.33
Density of Roads / Hillslope Position	Weighted sum of road density by slope position (weights determine relative influence, and sum to 1.0)	0.33
Road Length on Lower Slopes	Density of roads of all types on lower 40% of slopes	0.6
Road Length on Lower Slopes	Density of roads of all types on mid-slope (41-80% of slope distance)	0.3
Road Length on Upper Slopes	Density of roads of all types on upper 20% of slopes	0.1
Density of Roads on Unstable Slopes	Density of roads on geologically unstable slopes	0.33
Land Use related	Coarse sediment contribution to streams from intensive, timber harvest, and ranched areas (*see below in table**) <10th percentile highest suitability; >90th percentile lowest suitability	0.5
On slopes of *low* potential instability	Slope stability defined by CGS map classes 1 and 2 (or SHALSTAB if CGS maps unavailable)	0.04
On slopes of *low/moderate* potential instability	Slope stability defined by CGS map class 3 (or SHALSTAB if CGS maps unavailable)	0.09
On slopes of *moderate/high* potential instability	Slope stability defined by CGS map class 4 (or SHALSTAB if CGS maps unavailable)	0.17
On slopes of *high* potential instability	Slope stability defined by CGS map class 5 (or SHALSTAB if CGS maps unavailable)	0.7
Land Use related mass wasting parameter details (evaluated separately for each category of potential slope instability)	(Weights, showing the relative influence of each parameter, sum to 1.0)	
Intensive Land Use		
- developed areas	Percentage of the planning watershed area in high density buildings and pavement	0.2
- farmed areas	Percentage of planning watershed area in intensive crop cultivation	0.2
- area of timber harvests	Percentage of planning watershed area tractor logged weighted by time period (years)	
- Era 0 (2000 – present)	Tractor logged area 2000-present	0.2
- Era 1 (1990 – 1999)	Tractor logged area 1990-1999	0.12
- Era 2 (1973 – 1989)	Tractor logged area 1973-1989	0.06
- Era 3 (1945 – 1972)	Tractor logged area 1945-1972	0.12
- ranched area	Percentage of watershed area used for grazing livestock; estimated based on vegetation type and parcel type	0.1
Surface Erosion II	The mean truth value from management-related surface erosion: Road-related and Land Use-related	0.33
Road-related	Fine sediment contribution to streams from roads from either SEDMODL_V2 (first choice) or the mean of Density of Roads	0.5

Table 4.1-2

Reference Curve Metrics for the EMDS Sediment Production Risk Model, Version 1.0

Sediment Production Factor	Definition*	Weights**
	Proximate to Streams, Density of Road-related Gullies, Density of Roads by Hillslope Position, and Road Surface Type	
SEDMODL-V2	(when model is available – first choice of SOR node)	1.0
Density of Roads Close to Streams	(2nd choice of SOR node, averaged with 3 subsequent road-related measures directly below)	0.25
Density of Roads by Hillslope Position	Weighted sum of road density by slope position	0.25
Road length on lower slopes	Density of roads of all types on lower 40% of slopes	0.6
Road length on lower slopes	Density of roads of all types on mid-slope (41-80% of slope distance)	0.3
Road length on upper slopes	Density of roads of all types on upper 20% of slopes	0.1
Density of Road-related Gullies	Density of gullies related to roads	0.25
Road Surface Type	Percentage of roads with surfaces that are more likely to deliver fine sediments to streams (no data currently supplied to model here)	0.25
Land Use related	Fine sediment contribution to streams from intensive, timber harvest, and ranched areas (*see below in table***)	0.5
On slopes of *high* potential instability	Slope stability defined by CGS map class 5	0.7
On slopes of *moderate/high* potential instability	Slope stability defined by CGS map class 4	0.17
On slopes of *low/moderate* potential instability	Slope stability defined by CGS map class 3 (or SHALSTAB if unavailable)	0.09
On slopes of *low* potential instability	Slope stability defined by CGS map classes 1 and 2 (or SHALSTAB if unavailable)	0.04
Land Use related surface erosion parameter details	(evaluated separately for each of the four categories of potential slope instability)	
Intensive land use	Land where human activity is intensive	
- developed areas	Percentage of the planning watershed area in high density buildings and pavement	0.2
- farmed areas	Percentage of planning watershed area in intensive crop cultivation	0.2
- area of timber harvests	Percentage of planning watershed area tractor logged, by time period	
- Era 0 (2000 – present)	Tractor logged area 2000-present	0.3
- Era 1 (1990 – 1999)	Tractor logged area 1990-1999	0.2
- ranched area	Percentage of planning watershed area used for grazing livestock; estimated based on vegetation type and parcel type	0.1
Streamside Erosion II	The mean truth value from management-related streamside erosion: Road-related and Land Use-related	0.33

* all breakpoints for the sediment production risk model were created from the tails of the cumulative distribution function curves for each parameter, at the 10th and 90th percentiles. Thus all resultant values are relative to the basin as a whole, but are not rated on an absolute basis

** weights for parameters at each node sum to 1.0; indentation of weight shows the tier where it is summed

4.1.4 ADVANTAGES, APPLICATIONS, AND LIMITATIONS OF EMDS

Advantages

EMDS offers a number of advantages for use by NCWAP. 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 the overall watershed condition. This latter feature can help to identify what is most limiting to salmonids, and thus assist to prioritize restoration projects or modify of 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 the 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 (e.g., Figure 4.1-4), 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., subwatersheds) can be aggregated into a large hydrologic unit. With sufficient sampling and data, analyses can be done even upon single or multiple stream reaches.

Management Applications

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 also can 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.

EMDS results can be fed into other decision support software, such as Criterium Decision Plus. CDP employs a widely used approach called Analytic Hierarchy Process (AHP) to assist managers in determining their options based upon what they believe are the most important aspects of the problem.

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 that 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. NCWAP will use these analyses not only to assess conditions for fish in the watersheds and to help prioritize restoration efforts, but also to facilitate an improved understanding of the complex relationships among environmental factors, human activities, and overall habitat quality for native salmon and trout.

Limitations of the EMDS Model and Data Inputs

At the time of the production of this report, we have not been able to implement all of the recommendations made by our peer reviewers. Hence, the current model outputs should be used with caution. NCWAP will continue to work to refine and improve the EMDS model, based on the peer review.

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 currency and completeness of the data available for a stream or watershed will strongly influence the degree of confidence in the results. Where possible, 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. However, we are developing methods of determining levels of confidence in the EMDS results, based upon data quality and overall weight given to each parameter in the model.

NCWAP will use EMDS only as an indicative model, in 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 lifecycle, nor does it consider fishing pressures.

While EMDS provides one part of the watershed picture, integration of physical watershed features and habitat was necessary using GIS and interdisciplinary analysis to gain a better perspective on these relationships.

4.2 Integrated Analysis of Physical Features and Habitat

As introduced in Chapter 2, NCWAP examines relationships among land use, landslides, and relative landslide potential at watershed, subbasin, and planning watershed levels. This section discusses those analyses at the basin (Gualala River Watershed) scale, including comparisons of subbasins. These tables may be used to assess relative impacts of landslides and potential for delivering sediment to streams to guide future management and mitigation activities.

These tables do not imply nor establish causal mechanisms between land use and landslide features. That would require site-specific investigations, which are beyond the scope of the NCWAP assessment. Additionally, there was limited field reconnaissance and verification. This can result in aerial photo interpretation biases against detecting small landslide features, slides under forest canopy compared to grasslands or recently harvested forestland, and slides occurring after the photo was taken.

These tables also contain only current road network data as developed by the University of California's Information Center for the Environment at Davis for the Gualala total maximum daily load (TMDL). Information about the relationship between historical roads and sediment inputs to streams that NCWAP used in the *Potential Restoration Sites and Habitat Limiting Factors Map* (Plate 3) described later in this chapter.

4.2.1 LANDSLIDES AND LAND USE/LAND TYPE

NCWAP developed a series of tables that compared spatial coincidence of historically active landslide features with land use. Tables 1A-1 to 1A-6 in Appendix 6B examine the occurrence of historically active rockslides, earthflows, debris slides and debris flows with four categories of land use or vegetation in each subbasin for every planning watershed. (Percentages in each table refer to the watershed unit of analysis for that particular subbasin.)

Land use or vegetation types are woodland and grassland acreage, timber harvest plan (THP) acreage from 1991 through 2000, timberland acreage with no recent harvest (since 1991), and road mileage. In the Gualala, woodland or grassland is typically used for grazing, though a small portion (estimated between 700 and 1,000 acres) has been converted to vineyards. Timberland without recent harvest may include less substantial forms of timber management, such as pre-commercial thinning.

The purpose of these comparisons is to understand how landscape stability underlies land use. Utilizing this information will help minimize damage to roads and structures as well as reduce reactivation or triggering of landslides or contributing to slope instability from activities such as timber harvest, roads, or construction.

Table 4.2-1 summarizes land use and historically active landslide features data for the whole Gualala watershed that has the tributary data rolled up to the subbasin scale. Percentages are with respect to the entire Gualala River Watershed.

Table 4.2-1 shows historically active landslide features were observed on approximately 18,000 acres (~9 percent) of the entire Gualala River Watershed area. From Table 1A-1 (appendix), almost 16,000 acres of the 18,000 acres of historically active landslides are earthflows. Approximately 8,900 acres, which is over half of the historically active landslide acreage, are in the Wheatfield Fork Subbasin. Areas of historically active landslides in decreasing order for the other subbasins are: Gualala Subbasin ,~4,500 acres, (~2.5 percent); Rockpile Subbasin, ~2,500 acres (~1 percent); North Fork Subbasin, almost 1,200 acres; and Buckeye Creek, ~ 700 acres. Historically active landslides in both the North Fork and Buckeye subbasins occupy less than 1 percent of the entire watershed.

Table 4.2-1

Acres and Percent Area of Historically Active Landslides Associated with Land Use or Type for the Gualala River Watershed

	Historically Active Landslide Features[a]		**Woodland and Grassland[b]**		**THPs 1991 - 2000**		**Timberland, No Recent Harvest[c]**		**Roads[d]**	
	Area (acres)	**% of Area**	**Area (acres)**	**% of Area**	**Area (acres)**	**% of Area**	**Area (acres)**	**% of Area**	**Length (miles)**	**% of Total Length**
Gualala Watershed **(190,992 acres)** **(1,432 road miles)**										
Entire Watershed	**17,785**	**9.3%**	**10,958**	**5.7%**	**1,079**	**0.6%**	**5,520**	**2.9%**	**79**	**5.5%**
Subbasins										
North Fork Subbasin (30,635 acres) - 16% of watershed (291 road miles) - 20% of roads in watershed	1,164	0.6%	361	0.2%	285	0.1%	521	0.3%	8.3	0.6%
Rockpile Subbasin (22,389 acres) - 12% of watershed (167 road miles) - 12% of roads in watershed	2,523	1.3%	1,392	0.7%	435	0.2%	777	0.4%	11.0	0.8%
Buckeye Subbasin (25,767 acres) - 14% of watershed (229 road miles) - 16% of roads in watershed	677	0.4%	452	0.2%	81	0.0%	153	0.1%	1.9	0.1%
Wheatfield Fork Subbasin (71,445 acres) - 37% of watershed (444 road miles) - 31% of roads in watershed	8,899	4.7%	6,281	3.3%	166	0.1%	2,176	1.1%	36.8	2.6%
Gualala Subbasin (40,756 acres) - 21% of watershed (306 road miles) - 21% of roads in watershed	4,522	2.4%	2,472	1.3%	112	0.1%	1,893	1.0%	20.6	1.4%

a Refer to Plate 1 and California Geological Survey appendix. Historically active landslides include earthflows, rock slides, debris slides and debris flows.
b Woodland and grassland includes areas mapped in 1998 as grassland and non-productive hardwood.
c Area of timberlands that were not contained in a THP during the 1991 to 2000 period.
d Roads layer is current roads from University of California at Davis Information Center for the Environment (ICE)
Empty cells denote zero.
Percent of area is based on the area of the entire Gualala River Watershed

Woodland and grassland areas have the largest proportion of historically active landslides in the watershed, approximately 11,000 acres (6 percent) of the entire Gualala watershed, which is consistent with the underlying geology. These areas are in the finer-grained and less competent melange of the Franciscan Complex that typically fail as large earthflows. Conifer forests generally do not grow well on the mélange. Approximately 1,100 acres (less than one percent) of the entire watershed are areas of historically active landslides within THP areas between 1991-2000.

Approximately 5,500 acres (~3 percent) of the watershed area have historically active landslides within timberlands that are not included in THPs since 1991.

With respect to roads, approximately 80 miles or 5 percent of the current roads in the watershed cross areas of mapped historically active landslides. The largest portions of roads that are located in historically active landslides occur in the Wheatfield Subbasin with approximately 37 miles.

4.2.2 RELATIVE LANDSLIDE POTENTIAL AND LAND USE / LAND TYPE

Table 4.2-2 provides information about relative landslide potential in relation to the same land uses or vegetation types used in Table 4.2-1. Relative Landslide Potential categories are based on geology, slope, and presence of historically active and dormant landslides and geomorphic features associated with natural mass wasting processes (Plate 2, *Relative Landslide Potential with Geologic and Geomorphic Features* map shows areas that are prone to different degrees of landsliding potential). These maps can be used to help future land use and management activities avoid or mitigate impacts from landslides. More detailed information on the relative landslide potential map is located in Chapter 2. Appendix 6B contains Tables 2A-1 to 2A-6 which include information down to the planning watershed scale and provide acreage for all five landslide potential categories.

The purpose of these tables is to help landowners, managers, and agencies take measures to protect the naturally unstable slopes. Therefore, Table 4.2-2 focuses on high and very high relative landslide potential areas, based on the assumption that actively sliding material has the lowest relative strength, and thus, the highest relative potential for landsliding of all the geological materials underlying the slopes. The two categories of areas that pose the most concern are the high (Category 4) and very high (Category 5) landslide potential. A brief description of the high and very high relative landslide potential categories and generalized implications and recommendations for each are:

- ***Category 4 – High Landslide Potential:*** Caution should be used before undertaking any land use alteration in these areas. Based on the known occurrence of dormant earth flows, rockslides, disrupted ground and debris slide slopes on moderate to steep slopes (30 – 64 percent), there is the likelihood that land use changes in these areas could activate and or increase existing land sliding activity if appropriate precautions and/or mitigation measures are not considered and implemented. A site-specific evaluation addressing slope stability is recommended prior to changes to existing land use.
- ***Category 5 - Very High Landslide Potential:*** This category includes all historically active landslides. Extreme caution should be used before undertaking any land use alteration in these areas. Based on the known occurrence of historically active earth flows, rockslides, debris flows and debris slides and the presence of debris slide slopes, inner gorges, and slopes over 65 percent, there is a strong likelihood that land use changes in these areas could increase or activate land sliding activity if appropriate precautions and/or mitigation measures are not considered and implemented. A site-specific evaluation with regard to slope stability is highly recommended prior to changes to existing land use.

Table 4.2-2

Acres and Percent of Area by Relative Landslide Potential and Land Use or Type Classes, Gualala River Watershed

Subbasin or Planning Watershed	Relative Landslide Potential[a]	Entire Watershed		Woodland or Grassland[b]		THPs 1991 - 2000[e]		Timberland, No Recent Harvest [c]		Roads [d]	
		Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Length (miles)	% of Total Length
Gualala Watershed (190,992 acres) (1,432 road miles)	Very Low	9,399	5	1,318	1	1,992	1	5,163	3	145.0	10
	Low	17,658	9	3,051	2	4,117	2	9,619	5	246.8	17
	Moderate	54,948	29	9,361	5	14,443	8	30,258	16	450.7	31
	High	75,100	39	23,131	12	16,317	9	34,756	18	432.2	30
	Very High	33,725	18	13,912	7	5,048	3	14,210	7	157.5	11
	High/ Very High Subtotal	108,825	57	37,043	19	21,365	11	48,965	26	589.8	41
	TOTAL	**190,830**	**100**	**50,772**	**27**	**41,918**	**22**	**94,004**	**49**	**1,432.3**	**100**
North Fork Subbasin (30,635 acres) - 16% of watershed (291 road miles) - 20% of roads in watershed	High	12,861	6.7%	2,741	1.4%	4,475	2.3%	5,598	2.9%	101.6	7.1%
	Very High	4,241	2.2%	740	0.4%	1,437	0.8%	2,036	1.1%	29.5	2.1%
	High/ Very High Subtotal	17,101	9.0%	3,481	1.8%	5,911	3.1%	7,633	4.0%	131.1	9.2%
Rockpile Subbasin (22,389 acres) - 12% of watershed (167 road miles) - 12% of roads in watershed	High	9,889	5.2%	1,828	1.0%	3,797	2.0%	4,157	2.2%	63.9	4.5%
	Very High	4,521	2.4%	1,560	0.8%	1,229	0.6%	1,773	0.9%	22.1	1.5%
	High/Very High Subtotal	14,410	7.5%	3,388	1.8%	5,026	2.6%	5,929	3.1%	86.0	6.0%
Buckeye Subbasin (25,767 acres) - 14% of watershed (229 road miles) - 16% of roads in watershed	High	10,607	5.6%	2,906	1.5%	3,019	1.6%	4,847	2.5%	66.1	4.6%
	Very High	2,977	1.6%	700	0.4%	815	0.4%	1,496	0.8%	19.4	1.4%
	High/Very High Subtotal	13,583	7.1%	3,606	1.9%	3,833	2.0%	6,343	3.3%	85.5	6.0%

Table 4.2-2

Acres and Percent of Area by Relative Landslide Potential and Land Use or Type Classes, Gualala River Watershed

Subbasin or Planning Watershed	Relative Landslide Potential[a]	Entire Watershed		Woodland or Grassland[b]		THPs 1991 - 2000[e]		Timberland, No Recent Harvest [c]		Roads [d]	
		Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Length (miles)	% of Total Length
Wheatfield Fork Subbasin (71,445 acres) - 37% of watershed (444 road miles) - 31% of roads in watershed	High	27,577	14.4%	12,338	6.5%	3,737	2.0%	10,933	5.7%	122.6	8.6%
	Very High	15,545	8.1%	8,224	4.3%	1,236	0.6%	5,595	2.9%	59.2	4.1%
	High/Very High Subtotal	43,122	22.6%	20,562	10.8%	4,974	2.6%	16,528	8.7%	181.8	12.7%
Gualala Subbasin (40,756 acres) - 21% of watershed (306 road miles) - 21% of roads in watershed	High	14,167	7.4%	3,317	1.7%	1,289	0.7%	9,221	4.8%	78.0	5.4%
	Very High	6,441	3.4%	2,688	1.4%	332	0.2%	3,310	1.7%	27.3	1.9%
	High/Very High Subtotal	20,608	10.8%	6,006	3.1%	1,621	0.8%	12,531	6.6%	105.3	7.4%

[a] Refer to Plate 1 and California Geological Survey appendix. Historically active landslides include earthflows, rock slides, debris slides and debris flows.
[b] Woodland and grassland includes areas mapped in 1998 as grassland and non-productive hardwood.
[c] Area of timberlands that were not contained in a THP during the 1991 to 2000 period.
[d] Roads layer is from ICE
Empty cells denote zero.
Percent of area is based on the area of the entire Gualala River Watershed

Table 4.2-2 summarizes the occurrence of woodland/grassland, areas in THPs between 1991 and 2000, and timberlands not included in a THP since 1991-2000 and roads with respect to Relative Landslide Potential Categories 4 (high) and 5 (very high). Results are presented for the entire Gualala River Watershed as well as the five subbasins. All percentages on Table 4.2-2 are with respect to area or miles of the entire watershed.

Approximately 109,000 acres, or 57 percent, of the entire Gualala River Watershed's 191,000 acres are in high (Category 4) or very high (Category 5) landslide potential category. Approximately 39 percent (75,000 acres) are categorized as high relative landslide potential and 18 percent (34,000 acres) are very high relative landslide potential. Areas of moderate landslide potential comprise almost 30 percent (55,000 acres) of the watershed. Provisions to protect the naturally unstable slopes are discussed in the subbasin sections.

Of the five subbasins, the Wheatfield Fork contains the largest area of high and very high landslide potential, over 43,000 acres (more than 22 percent of the entire watershed), approximately half of which are located in woodland or grassland. Areas of high and very high landslide potential in each of the other four subbasins range from approximately 21,000 acres (11 percent of the watershed) in the Gualala Mainstem/South Fork Subbasin to 13,000 acres (7 percent) in the Buckeye Subbasin.

About a third of the high to very high landslide potential areas (37,000 acres) are located in woodlands or grasslands. The Wheatfield has by far the most of these acres (20,562 acres).

Table 4.2-2 shows approximately 21,000 acres (11 percent of the watershed) is categorized as high to very high landslide potential in areas covered by THPs between 1991 and 2000. The North Fork Subbasin had the most acreage of 1991-2000 THPs in the high and very high landslide potential areas in the last decade, approximately 6,000 acres (3 percent of the watershed), commensurate with the steepest slopes in the watershed. Rockpile and Wheatfield Fork subbasins follow closely, each with approximately 5,000 acres or 2.5 percent of the watershed. Buckeye Subbasin contains almost 4,000 acres (2 percent of the watershed).

About 49,000 acres (25 percent of the watershed) is classified as high and very high landslide potential and occurs within timberland that is not included in THPs since 1991. The largest portion of this area is located in the Wheatfield Fork Subbasin (16,500 acres, almost 9 percent of the entire watershed). The Gualala Mainstem/South Fork Subbasin contains 12,500 acres (almost 7 percent of the entire watershed) of high to very high landslide potential in timberlands not harvested between 1991 and 2000. The remaining 20,000 acres of timberland not harvested between 1991 and 2000 that is included in areas of high to very landslide potential are almost equally divided among the North Fork, Rockpile and Buckeye subbasins.

4.2.3 ROADS AND THE LANDSCAPE

CDF's studies of the implementation and effectiveness of the Forest Practice Rules indicate that mass wasting failures associated with current timber operations have been mostly related to roads. Roads produced the highest sediment delivery to watercourse channels when compared to other erosion processes (Monitoring Study Group 1999). The majority of the road related mass failures were associated with fill slope problems, indicating that proper road construction techniques are critical for protecting instream resources.

Timber and ranchland roads crossing steep slopes, historically active landslides, debris slide slopes or inner gorges can be sources of excess sediment to stream channels through erosion, fill failures and landsliding. Roads with undersized culverts and improper drainage design are vulnerable to stream crossing blowouts and debris slide failures during large storm events. Such roads can impact streams and delay or reverse recovery process downstream. In addition, abandoned streamside roads and landings can continue to discharge sediment during these storms. The Gualala River Watershed Council targets much of their restoration funds to abandonment and proper stabilization of the mid-20th-century instream road network (Figure 4.2-1).

Roads as Features

NCWAP examined both historical and modern road networks to characterize impacts by the road debris slides and road crossing failures on stream channel morphology. Maps of road networks were interfaced with (1) CGS Relative Landslide Potential maps, and (2) historically active landslides to show slide prone areas with roads. CGS mapping of landslides and selected fluvial geomorphic features allowed comparison of landslide activity to instream sediment accumulations and comparison of instream sediment levels between 1984 and 1999/2000. The integrated analysis then compared the naturally occurring historically active landslides with the road network. In addition, CDF used 1965 air photos at close scale (1:1200) to compare evolving stream channel morphology with the CGS 1984 and 1999/ 2000 fluvial geomorphology mapping.

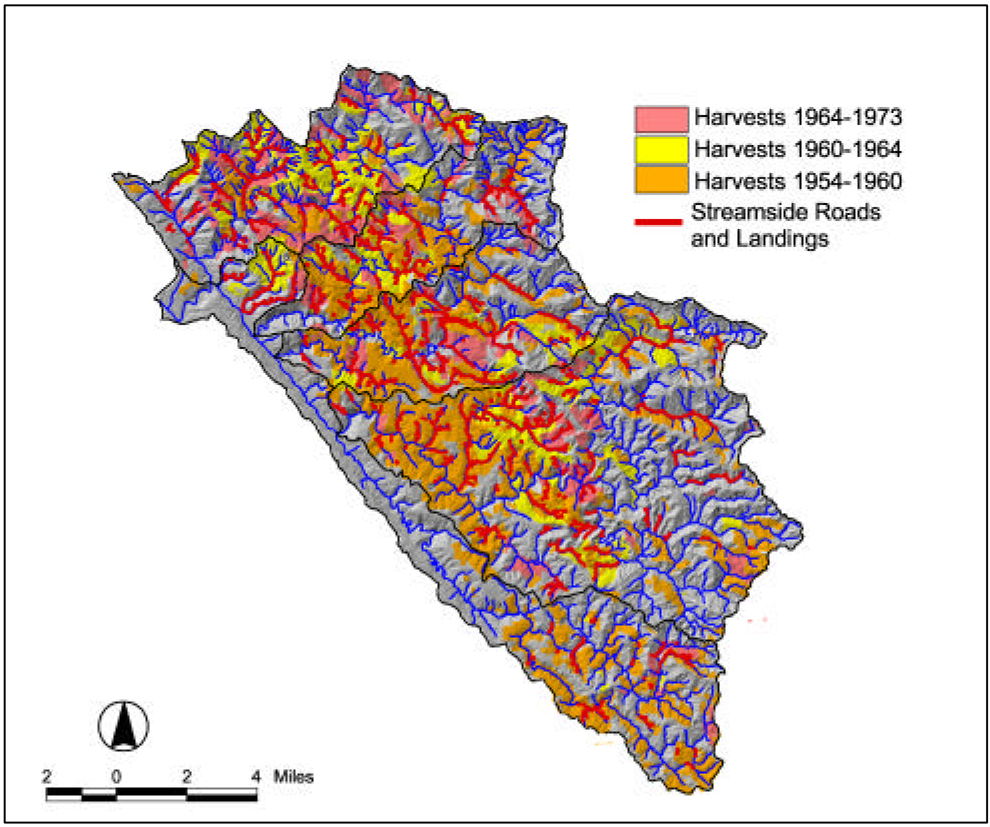

Figure 4.2-1
Mid-20th-Century tractor logging areas shown in three separate time strata, and instream/ streamside roads (lines) and landings (circles)

The following table provides estimates of mileage of historical and modern roads near or within watercourses by subbasin. CDF mapped the historical timber and ranchland roads using 1961, 1963, 1965, and 1981 aerial photographs. CDF mapped only those road segments that were (1) in the streambed or (2) following the stream channel at an equal elevation to the outer streambank. The modern roads were clipped to show those sections within 50 feet of blue line streams (Figure 4.2-2 and Table 4.2-3).

Table 4.2-3

Comparison of Historical Instream Roads with Modern Roads within 50 Feet of Blue Line Streams

Subbasin	In Stream/ Streamside Roads (miles) 1952 – 1968	Modern Roads (miles) Within 50 Feet of Streams/ Total Road Length in Subbasin
North Fork	18	2.5 / 291
Rockpile	16	1.5 / 168
Buckeye	27	1.5 / 229
Wheatfield	19	3.0 / 444
South Fork	15	1.5 / 116

Mid-20th-Century Stream Channel Impacts

1965 photos confined to the east portion of the watershed show stream channel aggradation along (1) Grasshopper Creek in the Buckeye subbasin, and (2) major tributary streams of the Lower Wheatfield Super Planning Watershed. Throughout Grasshopper, Fuller, Sullivan, Tobacco, and Haupt creeks, the sinuous stream channel patterns through the logged areas showed either (1) channel meandering through wide, flat areas of sediment fans in low gradient steps, or (2) stream deflections around fresh debris slides. Multiple road debris slide failures triggered by large storm events represented substantial mid-20th-century sediment sources (Figure 11, Appendix 6a). Meandering channel patterns returned to a more lineal pattern through 1984 and more so by 1999, indicating decreasing bedload sediment (Figure 14, Appendix 6a).

Movement Towards Stream Channel Recovery

Approximately 95 total miles of mid-20th-century in stream/streamside roads followed watercourses in or along the stream banks throughout the watershed. Many more of these roads were located slightly upslope but still within 50 feet of blue line streams. These older road sections were not mapped with this study. However, historical roads were predominately located low on the sideslope, frequently crossing “very high” Relative Landslide Potential Category areas. There were a total of 145 instream landings associated with stream aggradation or braiding.

Thirteen hundred miles of modern timber and ranchland roads (mapped using current photos) mostly follow mid-slope benches and ridgelines. Only approximately 10 miles are located within 50 feet of blue line streams as compared to approximately 95 miles in mid-20th-century.

The database shows that road debris slides can be triggered by proximity to streams and steep sideslopes. A review of fluvial impacts of the mid-20th-century aerial photographs showed a high frequency of road and landing failures along streamside roads throughout steep and deeply incised terrain. This is especially evident and seen as channel aggradation from pre-1973 unregulated mid-20th-century roads located low on the sideslope following stream channels. These roads frequently crossed inner gorges and slide prone areas. Large storm events activated numerous debris slides that buried stream pools throughout long portions of anadromous fish-bearing streams.

Active timber management during the last decade has required road upgrade specifications with any timber harvesting. New road construction associated with Timber Harvest Plans preferentially follow ridgelines and mid-slope benches to distance excavation disturbances from streams. Timber located near streams on steep slopes can be accessed only by cable yarding systems.

With the shift in road construction practices to mid-slope benches and ridgeline locations most contemporary sediment source sites are associated with road watercourse crossing locations. Modern roads cross streams at a perpendicular angle rather than following the stream on one side. Modern road sediment inputs are more related to the immediate road watercourse crossing sites and road approaches to streams. Historical roads following the creek are prone to failure where stream banks undercut the road causing collapse during storms as a function of stream velocity, slope steepness, and road and geologic instabilities.

The shift in the road network to upslope positions away from blue line streams has allowed improvement towards recovery of channel conditions. Stream channel morphology experienced the following general evolution over the last half century: (1) a high density of debris flow mounds in the active channel triggered by mid-20th-century storm events; (2) progressive abatement of the frequency of these point sources over successive decades; and (3) apparent movement towards recovery of instream channel substrate between 1984 and 1999/ 2000 as evidenced by a reduction in the percentage of channel length affected by excess sediment storage or sediment sources. CGS fluvial geomorphic mapping of stream conditions documents that the channel has improved from 1984 to 1999/2000 throughout the watershed. This period includes recent active timber harvesting in the northern portion of the watershed that included road building.

The current road network shows less overall coincidence of debris slides and stream crossing failures compared to historical times. Proximity to streams and steep slopes, however, continues to be associated with most of the contemporary road failures. Recent Timber Harvest Plans report numerous road failures triggered by the 1986 and 1996 storms. Undersized culverts and substandard road crossings were particularly vulnerable to failure during these storms.

The extent to which additional input of sediment may have slowed channel substrate recovery from mid-20th-century discharges is not known. Sediment generated by mid-20th-century tractor era disturbances would be routed through the river network over a period of decades to centuries. Some of the sediment likely is still stored in the lower stream reaches and flood plains. In addition, as recently as 1996, Timber Harvest Plan records reference mid-20th-century generated debris still present in streams in the middle watershed reaches. This includes Stewart Creek in the North Fork, the central Rockpile Subbasin and the upper reaches of Grasshopper and Osser creeks in the Buckeye Subbasin.

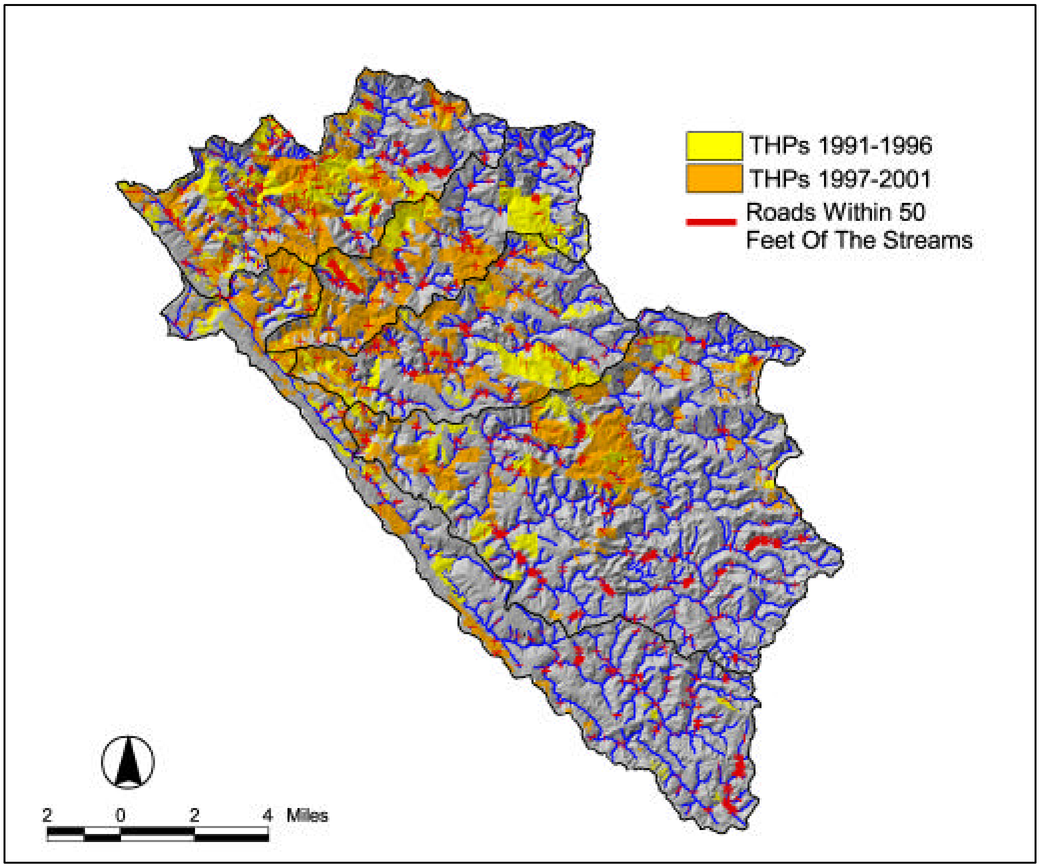

Figure 4.2-2
Segments of Modern Roads Located within 50 Feet of Blue Line Streams (Red),
with 1991 to 2001 Timber Harvest Plans indicated.

Relative Landslide Potential and Roads

Prior to 1973, the road network was nearly all located in Relative Landslide Potential Category 5 areas. Road construction following the stream channel was the most efficient and economical log transportation route. Built during the mid-1950s through 1968, streamside and instream road and landing networks spanned most of the natural fluvial drainage system of the north and central watershed areas. These roads dominated stream channel structure throughout the North Fork, Rockpile, Buckeye, and Lower Wheatfield Subbasins.

The steep channels in several Relative Landslide Potential Category 5 areas concentrated flows during storm events. The steep topography and high stream density probably caused intense, flashy runoff that often removed the primitive log and dirt road stream crossings and instream landings. Storm events also undermined the streamside roads collapsing road segments into the streams.

The shift in the road network to upslope positions away from blue line streams resulted in fewer miles of roads located in Relative Landslide Potential Category 5 areas. Approximately 40 percent of the modern roads in the watershed (approximately 600 miles) are located in areas of high to very high relative landslide potential in all of the subbasins. The largest number of miles of modern roads in high to very high relative landslide potential are in the Wheatfield and North Fork subbasins with approximately 180 and 140 miles, respectively. The Gualala Subbasin contains approximately

105 miles and the Rockpile and Buckeye Subbasins each include approximately 85 miles of roads in high to very high relative landslide potential areas.

4.2.4 RELATIVE LANDSLIDE POTENTIAL AND SILVICULTURE AND YARDING METHODS

Tables 2B-1 through 2B-6 (Appendix 6B) compare timber harvesting by silvicultural system and yarding methods. This presentation overlays the amount and types of harvesting activities occurring on various relative landslide potential categories. These are broad comparisons to show general trends throughout variable terrain.

However, this approach has limitations to its usefulness for predicting potential sediment sources. In 1998, the California Board of Forestry's Hillslope Monitoring Study Group found the contribution of rill erosion over clear-cut areas that eventually accessed streams was proportionately small compared to roads, especially road watercourse crossing points (California State Board of Forestry, Monitoring Study Group 1998.

Additionally, while the GIS database includes total acreage within the THP boundary, certain management activities are prohibited as part of a watercourse and lake protection zone (WLPZ) protective buffer corridor ranging from 100 to 150 feet or more from the base of the stream bank, in buffer zones, corridors over streams, and areas of active sediment sources such as inner gorges. Cable yarding is also typically specified for such areas. However, the GIS database includes WLPZ buffer zones as part of overall clearcutting acreage tabulations. Similarly, active landslides and debris slide slopes in the field are excluded from clearcutting. Such field mitigations are verified on the ground during pre-harvest inspections. The NCWAP GIS database does not assimilate these considerations and therefore overestimates the total acreage of harvest in THPs for clearcuts and even more so for selection cuts.

Tables 2B-1 through 2B-6 (Appendix 6B) compare timber harvesting and relative landslide potential. These tables break out timber harvesting by silvicultural system and yarding methods. This presentation compares the amount and types of harvesting activities occurring on areas of various relative landslide potential. In general, cable and helicopter methods are combined to show similar means of mitigation in Relative Landslide Potential category 4 and 5 areas.

The ratio between tractor to cable generally ranges from an even split to a 2 to 1 ratio of tractor to cable for THPs between 1991 and 2001 throughout the subbasins. Table 4.2-4 lists the break down of cable yarding and tractor logging for each subbasin over the period of 1991 to 2001.

Table 4.2-4
THP Yarding Methods By Subbasin, 1991-2001, Gualala River Watershed

Subbasin	Percent Cable Yarding	Percent Tractor Logged
North Fork	43	57
Rockpile	44	56
Buckeye	42	58
Wheatfield	30	70
South Fork	32	68

In the early to mid 1990s, THPs in the central watershed reaches had a higher proportion of tractor yarding and used existing skid trails left from the mid-20th-century logging. The forest practice rules allow tractors to use existing skid trails on sideslopes up to 50 percent. Existing skid trails between 50 percent and 65 percent can be used providing these are explained and justified in the THP and flagged on the ground for review during the pre-harvest inspection. These skid trails must be properly stabilized by completion of operations. Most of the Coastal Forestland THPs in the mid-1990s frequently used older vegetated skid trails as “designated skid trails” to access scattered remnant conifers left on steep terrain that were inaccessible or avoided during the mid-20th-century logging. Other private logging also reused previously excavated skid trails crossing moderate to steep sideslopes. These THPs specified “tractor operations” using “designated skid trails”. The operations covered large areas to access scattered leave timber. However, the ground was not fully traversed by tractors to the extent of actual clear cut harvesting when removing an entire mature stand. Such areas were left predominantly vegetated after operations as verified with 1999/2000 photos. However, the GIS database makes no distinction between these degrees of tractor harvesting.

The per cent area of allowable tractor harvesting on Category 4 and 5 clearcut (even-aged silvicultural treatment areas) is under 10 percent and shows proper mitigation applied during multi-agency review on site: North Fork: 109 acres (1.5 percent of watershed), Rockpile: 200 acres (3.4 percent), Buckeye: 261 acres (6.2 percent), Wheatfield: 461 acres (5.8 percent), and South Fork: 364 acres (3.4 percent). These tables show cable/helicopter as predominant methods for steep terrain.

These GIS reference comparisons also show the following trends: (1) the early 1990s had a higher proportion of tractor harvesting than recent years, and (2) the use of cable yarding is expanding. In addition, the shift in the road network to upslope locations is more suited to cable yarding.

In contrast, during the 1950s and 1960s, tractors operated indiscriminately throughout Category 5 (very high landslide potential) areas across steep sideslopes following straight parcel lines regardless of terrain. Across extreme sideslopes in excess of 65 percent, tractors cut into the sidebank to keep from falling over. This created a terraced landscape of step skid trails cut into the sideslope. No erosion control or ditching was installed prior to winter rains. Analysis of 1965 photos found gully erosion and collapsed skid ramp terraces onto one another after the 1964 rains.

Timber Harvest Plan areas (from 1991 to 2001) on high or very high Relative Landslide Potential areas compare similarly with the mid-20th-century areas. For the watershed, overall acreage on Category 4 and 5 areas are about the same (51 and 52 percent, respectively). In the Rockpile Subbasin, a higher percent of 1991 to 2001 THPs occurred in high and very high relative landslide potential classes compared to the percent of previously harvested timberland. In the Buckeye and North Fork Subbasins, the percent of 1991 to 2001 THPs in Category 4 and 5 areas were also slightly higher than that of timberland harvested earlier, while the Wheatfield and South Fork Subbasins’ percentages were lower.

Although the overall areas in Relative Landslide Potential categories 4 and 5 areas were similar and operated between the two time periods, the sharp differences in methods of operation showed marked contrasts in stream channel morphology. The 1991 to 2001 THPs combined cable and tractor harvesting, using upslope road locations. The mid-20th-century operations used tractors over all types of terrain and roads following blue line streams. The erosional downcutting, gullying, and multiple debris slide failures caused channel aggradation during storm events. This was not similarly evident in the 1991 to

2001 THP areas. These plans required proper drainage dispersal by completion of operations and restricted tractor access on steep sideslopes.

When comparing acreage harvested from 1932 to 1990 with acreage harvested after 1990, there are approximately twice as many acres harvested in 1932 (100,000 acres to 53,000), but about five times the amount of landslide acreage (2.9 percent of the watershed versus 0.6 percent). This broad comparison suggests that recent regulation under the Forest Practices rules has resulted in more avoidance of landslide features and prevented or mitigated erosion. Historically active landslides on timberland harvested since 1991 occupied approximately 1,000 acres (less than 1 percent) of the entire watershed. Historically active landslides on timberland outside of THP areas since 1991 occupied approximately 5,500 acres (3 percent) of the entire watershed.

4.2.5 FEATURES IN AND NEAR STREAMS WITH POTENTIAL FOR SEDIMENT DELIVERY

The association of landslides, gullying, and certain fluvial geomorphic features were analyzed with respect to proximity to the stream channel. Landslides and gullying in close association with stream channels have a higher likelihood of sediment delivery to a stream. Actual fluvial geomorphic features within the stream were analyzed as indicators of stream channel condition, including sediment deposits. This section narrows the perspective from the hillslope associations presented above to the stream channel, a transition in thought to the relevance of hillslope conditions to fish habitat in the streams.

Landslides and Geomorphic Features With High Sediment Delivery Potential

The presence of landslides and geomorphic features proximate to streams is important. Landslides and certain geomorphic features have a high potential to deliver sediment to near-stream or directly into the stream channel, where adverse-impacts to salmonids and their habitat are more likely. The landslide and geomorphic features (as determined from review of aerial photos) are divided into a number of classes (Tables 3A-1 through 3A-6, Appendix 6B):

- Historically active landslide features (movement within the past 150 years) - earthflows, rock slides, debris slides and debris flows
- All dormant landslides as a combined category
- Geomorphic features -- disrupted ground, debris slide slopes and inner gorges.

Most features are reported in terms of area unless they are less than 100 feet wide, in which case the feature was mapped as a linear feature and reported as a length rather than in terms of area. Linear landslide features found on both sides of the stream were counted twice for calculating the percentage of total blue line streams with adjacent linear landslide features. The analysis was based on intersections of listed features with the blue line streams from the United States Geological Survey topographic maps at a scale of 1:24,000.

Areas (acres) or length (miles) of landslide and geomorphic features with respect to three distance ranges from each side of the blue line streams (0 to 180 feet, 180 to 660 feet, and more than 660 feet) were analyzed. Features within 180 feet of the blue line streams were also calculated as: (1) percentage of area of landslides and geomorphic features within 180 feet of blue line streams within the entire Gualala River watershed and (2) percentage of the length of eroding banks, inner gorge and other linear geomorphic features over the total blue line stream length in the entire watershed.

This analysis assumed that landslides (historically active and dormant) and selected geomorphic features including disrupted ground, inner gorges, debris slide slopes, and eroding banks are sources of direct delivery of sediment to streams and that the closer the feature is to a stream, the higher the likelihood of delivering sediment. The rates of delivery of different features vary and are discussed in more detail in Appendix 2. The distance categories used are exclusive, i.e., slide areas or lengths reported in the 0-180 feet column are not repeated in the 180-660 feet or >660 feet columns. Additionally, the >660 feet column includes landslide and geomorphic features that extend to the ridgetop of the unit of analysis (i.e., entire watershed, subbasin, or planning watershed).

Approximately 15,000 acres of landslides (historically active and dormant) and the above listed geomorphic features (covering 7 percent of the watershed area) are located within 180 feet of the blue line streams in the watershed (Table 3A-1, Appendix 6B). This constitutes only 15 percent of all landslides. Approximately 43 miles of the blue line stream in the Gualala River watershed are adjacent to landslides and geomorphic features mapped as linear features as well as inner gorges and eroding banks. These are areas of likely high sediment delivery.

However, using the blue line streams underestimates the total drainage length and in turn underestimates the potential sediment input from historically active and dormant landslides and selected geomorphic features that are sediment sources, many of which are naturally occurring. The drainage network of the Gualala River watershed is much denser than the blue line stream network depicted at a scale of 1:24,000.

Although the actual density of the stream network is much higher than the blue line stream, the relative percentage of landslide area in a subbasin can be used to estimate the relative length of impacted stream after the watershed-wide impact is calculated. (Please refer to the CGS Appendix 2 for further discussion on this issue.) Rather than 15 percent of landslides delivering to blue line streams, analysis using the 10-meter Digital Elevation Models (DEMs) results in 30 percent of landslides contributing to sediment delivery. This is discussed further in Appendix 2 and later in this section.

Gullies and Sediment Delivery

Gullies are another important geomorphic feature for the generation and delivery of sediment to the stream network. Gullies are distinct, narrow channels formed by erosion of soil or soft rock material by running water. As such, they are likely to deliver sediment to streams regardless of their location on the hill slope. Channels are larger and deeper than rills and usually carry water only during and immediately after heavy rain. Gullies often form in response to concentrated surface water flow that can result from high intensity storms, loss of vegetation, and diversion of surface flow at scarps, culverts and road drainage systems. Gullies can deliver sediment from landslides, hillslopes and/or roads directly to drainages and streams as well as widen and downcut hillslopes. Gullies can serve as sediment sources as well as sediment delivery mechanisms.

In the Gualala River Watershed, gullies appear to be stable over the past few decades because gullies visible in aerial photographs are depicted on topographic base maps created at least two decades ago. Although aerial photo analysis identified numerous gullies in the Gualala River Watershed (Table 4.2-5), it is important to note that gullies are often smaller scale geomorphic features, and are difficult to detect under forest canopy or may not be large enough to be visible in aerial photographs. Hence, identifying gullies from aerial photos tends to underestimate the length and number of gullies found in forested areas.

The high occurrence of gullies in the Wheatfield Subbasin is expected because a large portion of the subbasin is underlain with mélange from the Franciscan Complex, and 30 percent of the subbasin is in high or very high landslide potential category. Just as the geologic conditions are responsible for large earthflows in the subbasin, the geology provides the right conditions for gullies. In addition, gullies are more visible in aerial photographs in woodland and grassland areas. Fewer gullies in the other subbasins are likely influenced by several factors and are likely underestimated. These factors can include less visibility in aerial photographs in the forested areas and more competent bedrock (Coastal Belt terrane of the Franciscan Complex) that is less prone to gullying and earthflows. Gullies are shown on Plate 1, *Geologic and Geomorphic Features Related to Landsliding, Gualala River Watershed.*

Table 4.2-5

Length, Number and Percent of Gullies in 1999/2000 Aerial Photographs by Watershed and Subbasin, Gualala River Watershed.

Watershed or Subbasin	Subbasin Area as Percent of Watershed	Length of Gullies (feet)	Percent of Total Gully length	Number of Gullies	Percent of Number Gullies
Entire Gualala		511,413		1,367	
North Fork Subbasin	16	72,561	14%	219	16%
Rockpile Subbasin	12	34,851	7%	86	6%
Buckeye Subbasin	19	58,064	11%	177	13%
Wheatfield Fork Subbasin	37	230,712	45%	601	44%
Gualala Subbasin	21	115,225	23%	284	21%

Fluvial Geomorphic Features and Sediment Delivery

CGS mapped landslides and selected fluvial geomorphic features from aerial photos taken in 1984 and 1999/2000. That mapping allowed comparison of landslide activity to instream sediment accumulations and comparison of instream sediment levels between 1984 and 1999/2000. The methods are described in more detail in Chapter 2 and Appendix 2. More detailed descriptions of the findings are presented in the subbasin sections and Appendix 2.

CGS looked at fluvial geomorphic features indicative of stored channel sediment or sources of sediment that could be identified on the available aerial photographs. Twenty fluvial geomorphic attributes were selected and mapped as indicators of excess sediment in storage or sediment sources that could be considered detrimental to optimum habitats for anadromous salmonids (Table 4.2-6). While most of these features are always associated with increased sediment or impaired conditions, others, such as lateral bars, may or may not represent impairment.

As an example, the lateral bars were considered a detrimental feature whereas the point bars were not. Lateral bars were considered detrimental because they appeared more dynamic than the point bars, changing their size and position more readily than point bars. Lateral bars were often observed directly adjacent to a source of channel sediment, such as a landslide, and often remain for some time after the landslide has healed.

To be conservative, if one of the features on Table 4.2-6 was assigned an attribute that indicates excess sediment storage or sediment sources some of the time, it was included with those characteristics selected as “negative” attributes. (Refer to CGS Appendix 2 and Chapter 2 for additional information on fluvial geomorphology mapping methods, definitions of mapped features and results.)

Table 4.2-6

GIS Mapped Fluvial Geomorphic Attributes Considered Detrimental to Optimum Habitat for Anadromous Salmonids

Wide channel	Braided channel
Incised	Turbulent flow
Aggrading	Degrading
Cutoff Chute	Backwater
Tributary fan	Eroding left bank (facing downstream)
Transverse bar	Eroding right bank (facing downstream)
Lateral bar	Inner Gorge
Mid-channel bar	Bar at junction of channels
Blocked channel	Displaced riparian vegetation
Active landslide deposit	Older landslide deposit

Time-series mapping helps track changes and trends in channel conditions. The time-series fluvial geomorphic mapping of all watercourses in the Gualala River Watershed provided data to allow for evaluation of changes in channel geomorphology over the 15-year period from 1984 to 1999/2000 (Figure 4.2-3).

The map shows the stream reaches with fluvial geomorphic features detrimental to optimum habitat conditions for anadromous salmonids. The features mapped from 1984 photos are green and 1999/2000 features are blue. The map shows less channel length of fluvial geomorphic features detrimental to optimum habitats for anadromous salmonids mapped in 1999/2000 compared to 1984. Table 4.2-7 shows the length of channel disturbances mapped for the entire watershed and each subbasin and the percent decrease of channel disturbances between 1984 and 2000 based on the aerial photos. Although the NCWAP data do not provide specific information that may be used to clearly identify contributions of individual THPs or other anthropogenic sources of sediment, the fluvial geomorphic mapping documents that throughout the entire watershed approximately 47 percent of the channels with disturbances improved from 1984 to 2000. The largest improvement (57 percent) occurred in the Buckeye Subbasin. Improvements ranged from 38 percent to 47 percent for the other four subbasins. More inclusive tables listing changes in channel disturbances for the Gualala River Watershed and each subbasin are located in the respective subbasin sections of Chapter 5 later in this report and in Appendix 2.

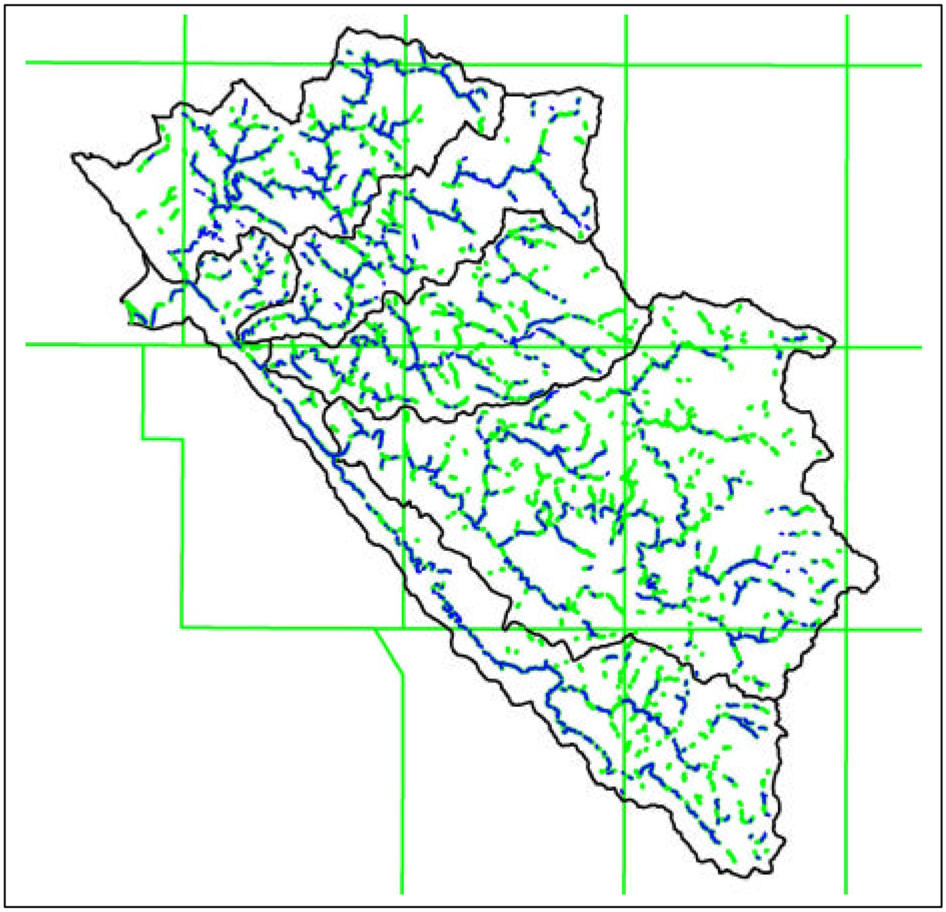

Figure 4.2-3

Fluvial Geomorphic Channel Disturbances Detrimental to Optimum Habitats for Anadromous Salmonids Mapped from Aerial Photographs for the Gualala River Watershed

1984 features are shown in green, 2000 features are shown in blue and the subbasin boundaries are shown in black

Table 4.2-7

Mapped Changes Between 1984 and 1999/ 2000 in Fluvial Geomorphic Channel Disturbances Detrimental to Habitat for Anadromous Salmonids in the Five Subbasins

	Gualala River Watershed	**North Fork**	**Rockpile**	**Buckeye**	**Wheatfield Fork**	**Gualala/ South Fork**
Total Stream Length (miles)	746	127	88	90	301	140
Mapped Channel Disturbances from 1984 Photos (miles)	298	48	32	42	119	57
Percent of Total Stream Length with Channel Disturbances in 1984 Photos	40%	38.1%	36.3%	46.0%	39.6%	40.8%
Mapped Channel Disturbances from 1999/2000 Photos (miles)	157	29	20	18	57	33
Percent of Total Stream Length with Channel Disturbances in 1999/2000 Photos	21%	23.0%	22.4%	19.8%	18.9%	23.7%
Percent Change from 1984 to 2000	-47%	-40%	-38%	-57%	-52%	-42%

Historically active landslides are presumed to represent the major source areas of sediment that entered the stream system over the past 150 years (refer to Appendix 2 for more details). Much of the coarser fraction of that sediment, mixed with older sediment, likely remains in the channels as indicated by the widespread correlation of instream sediment with the toes of landslides. Specifically, in the Gualala River Watershed, 70 percent of the “excess” instream sediment occurred within 50 meters of landslides that constitute about 35 percent of the landscape. Dormant landslides are interpreted to be substantial sources for instream sediment loads observed in the aerial photos.

In order to explore the other potential mechanism for major sediment inputs into the streams in the Gualala River Watershed, NCWAP compared instream or near-stream roads, including those constructed during the 1950s and 1960s, with the landslide and fluvial geomorphic mapping.

In addition to landsliding, creep and surface erosion, instream or near stream roads are important sediment source areas. Most of those roads in the Gualala River Watershed were constructed during the 1950s and 1960s. The CDF mapped the instream and near-stream roads across the watershed, and found a strong spatial correlation between those roads and braided and or aggraded stream reaches in 1984. Other relationships including lateral bars and wide channels in 1999/2000 were weak. Despite the strength of the relationship, the total length of channel mapped as aggraded and/or braided is a small fraction of the total length of channel mapped with other “excess” sediment. This suggests that historically active and older landslides are a major source of the sediment load in the Gualala River system.

4.2.6 MANAGEMENT IMPLICATIONS – LAND USE AND ROADS

Indicators of slope instability exist in over half of the watershed and merit caution with respect to land use activities. Given the current extent of land use in the Gualala River watershed and the relatively high potential of landsliding (57 percent of entire watershed is categorized as high or very high landslide potential), land management activities should seek to minimize additional sediment inputs into the streams. New projects should be designed with special care to address unstable slopes and landslide terrain as indicated on the CGS maps, *Geologic and Geomorphic Features Related to Landsliding, Gualala River Watershed* (Plate 1) and *Relative Landslide Potential with Geologic Features, Gualala River Watershed* (Plate 2). Provisions to prevent or minimize activities that could worsen or cause slope failures is highly recommended, especially on areas of high and very relative landslide potential (categories 4 and 5, respectively). Land use management practices should address areas affected by natural mass wasting processes. Preventing slope failures and/or avoiding naturally unstable areas prior to land use changes or operations are generally more cost effective and achieve better results than mitigating a problem.

On the project level, road building across unstable areas can: (1) remove support from the sides or toes of landslides, (2) put weight (such as a landing) on the head of a landslide, or (3) add water to the landslide mass by improper drainage or diverting water onto the landslide. These activities can worsen slope instabilities by initiating slope failures, and/or reactivating landslides. Areas in landslide potential categories 4 and 5 deserve particular attention and caution based on the known presence of factors affecting unstable slopes. Such indicators include, active and dormant landslides, steep slopes, inner gorges and debris slide slopes. These factors are often inter-related and affect the natural slope stability. Anthropogenic activities can worsen the conditions.

Reduction of the fine sediment load across entire planning watersheds is needed to reduce the embeddedness of spawning gravels in those planning watersheds where embeddedness is a limiting factor as shown on Plate 3. Most of the roads in the Gualala River Watershed are unpaved ranch and forest roads. To the degree that roads are a substantial contributor of fine-grained sediment, road improvements can reduce the amount of fine sediment generation. The effectiveness of the improvements in reducing sedimentation should be monitored.

It is important to note that timber harvesting operations that go through the THP preparation and review process are reviewed on a site-specific project level. This review process involves geologic review of unstable areas identified in a THP and on-site inspection of unstable areas by CGS geologists as part of the interdisciplinary THP review process. Representatives from both the Water Quality Control Board and the CDFG also review proposed timber operations proximate to unstable areas. They often develop mitigations to slope instabilities to protect water quality and fisheries resources. As a result, the operating methods and mitigations included in THPs provide a high level of assurance that the operations will adequately address unstable slopes.

Slope is an important consideration for road construction and timber harvesting. Equipment capabilities require that road grades be kept relatively low, predominantly under 10 percent and not exceeding 15 percent. The steeper the slope a road crosses, the higher the road engineering and construction costs. Full bench road construction excavation procedures and end hauling are generally required when building roads across 50 percent sideslopes, and mandatory when crossing sideslopes of 65 percent. Culverts are sized for at least 100-year storm events under current regulations.

For timber harvesting, the Forest Practice Rules require cable yarding on steep sideslopes. Tractors are limited to moderate terrain. Skid roads are more susceptible to erosion and delivery of sediment on steeper slopes.

On woodland and grassland areas, where the predominant land use is presumed to be grazing, the main consideration on sediment control continues to be roads. Gullies are also common in the woodlands and grasslands in the mélange of the Franciscan Complex (east of the Tombs Creek fault zone on Plate 1). Increased sediment delivery to streams and drainages can result from land use activities that do not take into consideration the natural instability present in areas of high and very high relative landslide potential in the Gualala River Watershed.

The CDFG habitat inventory surveys indicate that pool depth and pool shelter in most of the streams are primary limiting factors. Watershed-wide sediment reduction and appropriate flows will improve the streams' ability to flush excess sediment. Where shallow pool depths resulted from increased sediment, reduction of high sediment may improve pool depths. Instream structures should be built to create scour pools, riffles, and shelter that will enhance channel habitat complexity. Natural recruitment of LWD should be encouraged as well.

Canopy cover is a limiting factor in some reaches. Damage to seedlings and saplings by livestock and feral pigs may be inhibiting riparian regeneration. Exclusion of livestock and feral pigs coupled with planting and protecting seedlings should be implemented within the riparian zones of those reaches indicated on the *Map of Potential Restoration Sites and Habitat Limiting Factors for the Gualala River Watershed* (Plate 3) as having inadequate canopy cover.

Some local ordinances are aimed at reducing erosion and mass wasting. Grading ordinances address rural roads, among other disturbances. However, Mendocino County has not adopted a grading ordinance. The Mendocino County Board of Supervisors appointed a committee in 2002, representing both stakeholders and agencies, that drafted a grading ordinance regulating all grading, including agricultural. The draft ordinance is still under consideration by the Planning Commission, who will pass it on to the Board for their decision.

Sonoma County has an active hillside vineyard ordinance and compliance program, aimed at reducing erosion and sediment delivery to streams. The County also has chosen a technical working group to assist in the development of a comprehensive grading ordinance, to be drawn up by County staff.

4.3 Limiting Factors Analysis

A main objective of the NCWAP and a task assigned to CDFG was to identify factors that limit production of anadromous salmonid populations in north coast watersheds. A loosely termed approach to identify these factors is often called 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 resources (Hilborn and Walters 1992) or that a population’s potential may be constrained by an over-abundance, deficiency, or absence of a watershed habitat component. Identifying stream habitat factors that limit or constrain anadromous salmonid populations 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. The NCWAP LFA was centered on evaluating summer aquatic habitat conditions. Only the freshwater habitat requirements of anadromous salmonids were addressed.

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. In general, if water temperatures exceed lethal levels, fish will die regardless of the population density. *Density dependent mechanisms* generally operate according to population density and habitat carrying capacity. Competition for food, space, and shelter are examples of density dependent factors which affect growth and survival when populations reach or exceed the habitat carrying capacity. The NCWAP’s approach considers these two types of habitat factors before prioritizing recommendations for habitat management strategies. The LFA was a simplified approach to identify ecosystem components that constrain habitat capacity, fish production, and species life history diversity (Mobrand et al 1997). The Gualala River Watershed LFA was developed for assessing coarse scale stream habitat components and may not satisfy the need for site-specific analysis at an individual landowner scale.

Components essential to the health of anadromous fish populations in freshwater habitat include canopy cover, embeddedness, pool depth, pool frequency, pool quality, and shelter/cover. Unsuitable components were associated with their effects on salmonid health and productivity. Unsuitable canopy cover was associated with increases in water temperature; unsuitable embeddedness was related to poor spawning substrate; unsuitable pool depth and frequency was associated with poor summer conditions; unsuitable shelter was related to decreased escape cover, which relates to increased predation and decreased high flow refuge.

Both the analysis of data collected during habitat inventory surveys taken in 1999 and 2001 and the EMDS outputs identified unsuitable key components for each stream surveyed. After identifying the potential limiting factors, the factors were ranked according to the most detrimental habitat deficiencies. Higher rankings indicated higher unsuitability. The biologist's professional judgment took precedence when partial surveys were conducted that did not represent the limiting factor, or data and observation inconsistencies existed. Following that, recommendations were selected and prioritized for potential habitat improvement activities.

The overall limiting factors for the Gualala River Watershed are based upon limited data. Only 81 percent of the North Fork Subbasin, 39 percent of the Rockpile Subbasin, 37 percent of the Buckeye Subbasin, 62 percent of the Wheatfield Subbasin, and 31 percent of the South Fork/Mainstem Subbasin were surveyed in 2001. Watershed-wide, pool shelter related to escape cover was the first or most limiting factor, pool depth the second, canopy cover third, and embeddedness was the fourth limiting factor based on the surveys conducted in 2001. Pool depth related to summer conditions and pool shelter related to escape/cover were the most limiting factors on all five subbasins. Canopy cover related to water temperature was the third limiting factor in Rockpile, Buckeye and the North Fork Subbasins. Embeddedness related to spawning substrate conditions was the third limiting factor in the Wheatfield Fork and Mainstem/South Fork Subbasins, and the fourth in both the North Fork, Rockpile and Buckeye Subbasins (Table 4.3-1). Embeddedness related to spawning substrate conditions was the third limiting factor in the Wheatfield Fork and Mainstem/South Fork Subbasins, and the fourth in the North Fork, Rockpile and Buckeye Subbasins (Table 4.3-1).

In 1995, embeddedness related to spawning substrate conditions was the greatest limiting factor in the Fuller Creek areas located in the Wheatfield Fork Subbasin. Pool depth related to summer conditions and pool shelter related to escape/cover were the second and third limiting factor respectively. These data were not included in Table 4.3-1.

Table 4.3-1

Limiting Factors Affecting Salmonid Health and Production Based Upon Habitat Inventory Surveys Conducted in 1999 and 2001, and EMDS Scores for the Gualala River Watershed, California

Rank 1 is the most limiting factor

Gualala River Watershed	Canopy Cover Related to Water Temperature	Embeddedness Related to Spawning Suitability	Pool Depth Related to Summer Conditions	Pool Shelter Related to Escape and Cover
Gualala Watershed	3	4	2	1
North Fork Subbasin	3	4	2	1
Rockpile Subbasin	3	4	1	2
Buckeye Subbasin	3	4	1	2
Wheatfield Fork Subbasin	4	3	2	1
Main stem/ South Fork (1999 and 2001)	4	3	2	1

4.4 Potential Restoration Opportunities

Restoration opportunities were explored using GIS queries to create a map based on CDFG, CGS and CDF data for fish habitat, geomorphic and geologic features and historical roads and landings. The following sequence presents the map (Plate 3, *Potential Restoration Sites and Habitat Limiting Factors for the Gualala River Watershed*), followed by the finer details of restoration priorities arising from the CDFG analyses and a summary of hydrologic characteristics to note when developing restoration projects.

4.4.1 MAP OF POTENTIAL RESTORATION SITES AND HABITAT LIMITING FACTORS

Purpose

Habitat inventory surveys were conducted in 2001 to determine what factors were limiting salmonid populations in the Gualala River Watershed. Generally, the major tributaries showed habitat deficiencies in pool depths, pool shelter, canopy cover, and spawning substrate. The major limitation in regard to spawning substrate was embeddedness. Both embeddedness and pool depths are related to sediment deposition.

Because of this, an effort was made to identify sediment sites (i.e., sources and deposits) that may contribute to the shallow pools and embeddedness. The potential sediment sites, both upslope and instream, are shown on the map along with the limiting factors in order to illustrate spatial relationships and possible linkages between sediment sites and limiting instream sediment conditions (Plate 3, *Map of Potential Restoration Sites and Habitat Limiting Factors for the Gualala River Watershed*). Sediment sites were categorized as follows: (1) historically active landslides, (2) historical instream roads possibly related to fluvial sediment, (3) roads possibly related to landslides and/or eroding banks, (4) fluvial sediment conditions possibly related to landslides, and (5) potentially unrelated fluvial sediment conditions.

In order to provide guidance for future analysis, mitigations, and restoration, the sediment sites are considered as potential restoration sites, especially where there are upslope of reaches affected by limiting sediment conditions. General recommendations are made for each category of sediment site and limiting factor.

Intended Use

Use this map to quickly locate:

a. Limiting factors for salmonid habitat in surveyed streams

b. Streams that were surveyed in 2001

c. Areas upslope of stream reaches in which embeddedness is a limiting factor

d. Potential sediment sites in upslope areas that may be contributing to embeddedness or shallow pool depths

Construction

This map was produced using multiple database queries of Geographic Information System (GIS) data developed under the North Coast Watershed Assessment Program (NCWAP). The data are available to the public.

The following data were used:

a. California Geological Survey (CGS) landslide data
b. CGS fluvial sediment mapping
c. California Department of Fish and Game (CDFG) instream habitat inventory surveys
d. California Department of Forestry and Fire Protection (CDF) mapping of historical roads that were either in streams or near streams
e. University of California Information Center for the Environment (ICE) roads map of the current roads in the watershed

The map shows:

a. Segments of the modern roads that cross or are within 60 meters of a historically active landslide
b. Segments of the modern roads that are both within 60 meters of historically active landslides and within 60 meters of eroding stream banks
c. The segments of the modern roads that are within 60 meters of dormant landslides
d. The segments of the historical instream or near stream roads that may be active sediment sources
e. Areas upslope of stream reaches in which embeddedness is a limiting factor
f. The primary limiting factor for salmonids for each stream reach that was surveyed
g. The extent of the CDFG stream habitat inventory surveys in 2001

Recommendations

CDFG stream habitat inventory surveys indicate that pool depth and pool shelter in many of the streams are primary limiting factors. Instream structures can be built to create scour pools, riffles, and shelter that will enhance channel habitat complexity. Instream structures can also meter sediment transport. NCWAP recommends that the construction of instream structures and enhancing the natural recruitment of LWD be considered in the development of a restoration plan.

Embeddedness can result from erosion of fine-grained sediment from instream, stream bank, and upslope sources. Reduction of the fine sediment load across entire upslope areas may be needed to reduce the embeddedness of spawning gravels in those stream reaches where embeddedness is a limiting factor. Most of the roads in the Gualala River Watershed are unpaved ranch and forest roads. To the degree that roads are a substantial contributor of fine-grained sediment, road improvements can reduce generation of fine sediment. The map shows the upslope areas drained by the streams that were surveyed in 2001 by CDFG in which embeddedness was a limiting factor. The survey was limited to the stream reaches indicated on the map. Additional habitat surveys are needed to determine whether the unsurveyed areas possess any limiting factor.

The map also identifies potential road related sediment sources in each subbasin that may be good remediation targets for the reduction of fine sediment generation. Historically active landslides are shown as additional sediment source areas. Potential road related sediment sites are shown based on the premise that elevated loads of fine sediment from roads can be mitigated. NCWAP recommends field investigation of the potentially road related sediment sites within areas upslope of reaches with embeddedness as a limiting factor. The investigation should verify the actual site conditions and propose road improvements and erosion control as needed.

4.4.2 PRIORITIES FOR RESTORATION IN THE GUALALA RIVER TRIBUTARIES

The streams listed in Table 4.4-1 and presented in Figure 4.4-1 (Figure 3 of Appendix 5) were habitat inventory surveyed using protocols in the *California Salmonid Stream Habitat Restoration Manual, Third Edition* (Flosi et al, 1998).

Table 4.4-2 (and in Appendix 5) was developed from those in-the-stream habitat inventory surveys conducted by biologists. Within those reaches inventoried, priorities for restoration were assigned based on the biologist's recorded observations from within the stream. This table includes priority ranking of habitat categories that provide improvement opportunities for each stream based upon the habitat survey and observations. The most urgent concern is assigned a '1', the next highest a '2', etc. Conditions not visible from within the stream were neither systematically observed nor considered. Areas identified as potential restoration targets on the map that have not been habitat inventoried should be surveyed to understand their significance to habitat.

Where instream pool shelter/cover was recorded as unsuitable, the placement of instream structures of large wood is recommended to help form scour pools and increase habitat complexity. The design of those structures should consider the hydrologic data table (Table 4.4-2) as well as general temporal trends of aggradation and incision as discussed in Appendix 2.

Table 4.4-1 recommendations are created from the results of standard CDFG habitat inventories. These inventories are a combination of several stream reach surveys: habitat inventories, channel typing, and biological assessments. An experienced biologist and/or habitat specialist conducts quality assurance/quality control (QA/QC) on the field crews and collected data, performs data analysis, and determines general areas of habitat deficiency based upon the analysis and synthesis of information. Finally, recommendation categories for potential habitat improvement activities are selected and ranked.

It is important to understand that these selections are made from stream reach conditions that are observed at the times of the surveys and do not include upslope watershed observations other than those that can be seen from the streambed. They also 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. Stream and watershed conditions change over time and periodic survey updates and field verification are necessary if projects are being considered.

Figure 4.4-1

Areas Habitat Inventoried in the Gualala River Watershed, California (Figure 3 of Appendix 5)

Table 4.4-1

Summary of Habitat Inventory Survey Data From 1995, 1999, and 2001 for the Gualala River Tributaries, Gualala River Watershed, California

Stream	Surveyed Length Feet	Bank	Roads	Canopy	Temp	Pool	Shelter Cover	Spawning Gravel	LDA	Livestock And/or Feral Pigs	Fish Passage
North Fork Subbasin											
Doty Creek	6,237		X			X	X	X	X		X
Dry Creek	11,161			X	X	X	X				
Dry Creek Tributary #1	2,695			X		X	X				
Little North Fork	20,806		X				X				
Little North Fork Tributary #1	5,460						X	X			
Log Cabin Creek	1,698	X	X			X	X		X		
McGann Creek	1,980		X				X				
North Fork	59,362		X		X		X				
Robinson Creek	7,819	X	X	X	X	X	X		X		
Rockpile Subbasin											
Rockpile Creek	44,500	X	X	X	X	X	X				
Buckeye Subbasin											
Buckeye Creek	51,085		X	X	X	X	X				
Wheatfield Fork Subbasin											
Danfield Creek	12,103	X			X	X		X		X	
Fuller Creek	17,952	X	X	X			X	X			
Fuller Creek North Fork	14,275			X	X	X	X	X			
Fuller Creek South Fork	23,198			X	X	X	X	X			
Haupt Creek (*partial survey*)	2,129					X					
House Creek	54,916	X	X	X	X	X				X	?

Table 4.4-1

Summary of Habitat Inventory Survey Data From 1995, 1999, and 2001 for the Gualala River Tributaries, Gualala River Watershed, California

Stream	Surveyed Length Feet	Bank	Roads	Canopy	Temp	Pool	Shelter Cover	Spawning Gravel	LDA	Livestock And/or Feral Pigs	Fish Passage
Pepperwood Creek	17,931	X		X		X	X			X	
Sullivan Creek	5,015					X	X	X			
Tombs Creek	37,359	X		X		X	X			X	
Wheatfield Fork (*partial survey*)	116,878	X	X	X			X			X	
Mainstem /South Fork Subbasin											
Camper Creek	3,546		X				X				
Carson Creek	6,834		X			X	X	X			
Marshall Creek (*partial survey*)	21,698	X	X	X	X	X	X				
McKenzie Creek	13,801		X			X	X				
Palmer Canyon Creek (*partial survey*)	395		X		X						X
South Fork (*partial survey*)	8,451					X	X				
Wild Hog Creek	2,493		X			X	X				

An “X” indicates that the category did not meet the target values in the Salmonid Restoration Manual or were recorded by field crews during the survey period

Key to fields:
Temp = summer water temperatures seem to be above optimum for salmon and steelhead trout
Pool = pools are below target values in quantity and/or quality
Cover = escape cover is below 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 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/Feral Pig= there is evidence that stock or feral pigs are impacting the stream or riparian area and exclusion should be considered
Fish Passage = there are barriers to fish migration in the stream

Table 4.4-2

Priorities for Restoration for the Gualala River Tributaries, Gualala River Watershed, California

(numbers indicate priority rating with one being the highest priority)

Stream	Bank Stabilization	Roads Repair or Removal	Riparian Canopy Development	Instream Structure Enhancement	Livestock or Feral Pig Exclusion	Barrier Removal
North Fork Subbasin						
Doty Creek		2		1		3
Dry Creek			2	1		
Dry Creek Tributary #1			2	1		
Little North Fork		2		1		
Little North Fork Tributary #1		2		1		
Log Cabin Creek	3	2		1		
McGann Creek	2			1		
North Fork		2		1		
Robinson Creek		2	3	1		
Rockpile Subbasin						
Rockpile Creek	3	4	2	1		
Buckeye Subbasin						
Buckeye Creek		2	3	1		
Wheatfield Fork Subbasin						
Danfield Creek	2		3	4	1	
Fuller Creek	2	3	1	4		
Fuller Creek North Fork			1	2		
Fuller Creek South Fork			1	2		
Haupt Creek (*partial survey*)			1	2		
House Creek	5	4	2	3	1	?
Pepperwood Creek	4		2	3	1	

Table 4.4-2

Priorities for Restoration for the Gualala River Tributaries, Gualala River Watershed, California

(numbers indicate priority rating with one being the highest priority)

Stream	Bank Stabilization	Roads Repair or Removal	Riparian Canopy Development	Instream Structure Enhancement	Livestock or Feral Pig Exclusion	Barrier Removal
Sullivan Creek				1		
Tombs Creek	2		3	4	1	
Wheatfield Fork (*partial survey*)	2	3	4	1		
Main stem /South Fork Subbasin						
Camper Creek		2		1		
Carson Creek		2		1		
Marshall Creek (*partial survey*)	3	4	1	2		
McKenzie Creek		2		1		3
Palmer Canyon Creek (*partial survey*)		3	2			1
Upper South Fork (*partial survey*)		3	2	1		
Wild Hog Creek		3	2	1		

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. Project recommendations can be made in concurrence if 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. In these regards, NCWAP'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 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 logistical 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 also are factors in project selection for design and development.

4.4.3 GUALALA RIVER WATERSHED GENERAL HYDROLOGIC CHARACTERISTICS

Table 4.4-3 (Table 1 of Appendix 2) presents numerical watershed data at the planning watershed level that can be used as a first approximation of important hydrologic design criteria. The data presented is as follows: subbasin area and subbasin perimeter, upslope area, total stream length, maximum stream length; and bankfull width, bankfull depth, bankfull cross-sectional area, and bankfull discharge.

The units for each are shown on the table. Consideration of these variables is essential for the design of effective instream structures.

The data were developed from a 10-meter digital elevation model using RiverTools hydrologic modeling software, and applying regional hydrologic analysis. The results of this model correlated well with actual conditions during limited field checking. This modeled data can be used as a starting point but should be checked against actual field conditions prior to incorporation in any engineered design. California Department of Water Resources (DWR) installed several new stream gages in the watershed during the last two years. Flow data from those gages should be used to calibrate estimated bankfull discharge and bankfull geometry.

Table 4.4-3

Gualala River Watershed General Geomorphic Characteristics (Table 1 of Appendix 2)

HSA, SPWS, and PWS Name	Subbasin Area-m2	Subbasin Area, km2	Acres	Perimeter, m	Upslope Area km2	Total Stream length, km	Max. Stream Length, km	Width-BF^1 ft	Ave. Depth-BF^2 ft	X-Sec. Area-BF^3, ft^2	Discharge-BF^4 cfs
Buckeye Creek HSA											
Buckeye Creek SPWS											
North Fork Osser Creek	19,812,856	19.813	4,900	20,079	19.859	190	7.8	1012.1	29.83	23,942	219,091
Harpo Reach	11,008,003	11.008	2,722	15,793	30.832	283	13.4	908.2	27.17	19,698	177,142
Flat Ridge Creek	26,403,094	26.403	6,529	24,879	26.356	257	16.6	1114.8	32.41	28,499	264,876
Grasshopper Creek	23,319,840	23.320	5,767	25,432	80.522	748	18.5	1125.9	32.69	29,012	270,076
Little Creek	23,733,334	23.733	5,869	25,951	104.146	957	36.0	1136.2	32.95	29,492	274,947
Gualala River HSA											
Lower S. Fork Gualala R. SPWS											
Mouth of Gualala River	21,453,990	21.454	5,305	33,793	532.212	4,830	67.8	1279.9	36.50	36,552	347,349
Big Pepperwood Creek	26,412,790	26.413	6,532	29,055	772.850	6,901	77.7	1195.6	34.42	32,329	303,867
Marshall Creek SPWS											
Upper Marshall Creek	26,768,052	26.768	6,619	25,035	26.726	262	10.6	1118.0	32.49	28,644	266,341
Lower Marshall Creek	24,329,432	24.329	6,016	20,337	51.101	502	19.8	1017.9	29.97	24,192	221,583
Upper South Fork G.R.	33,980,743	33.981	8,403	44,637	33.950	331	25.0	1451.1	40.66	45,829	444,382
Middle South Fork G.R.	31,987,571	31.988	7,910	31,853	116.339	1,116	44.8	1246.2	35.67	34,837	329,636
North Fork Gualala R HSA											
North Fork SPWS											
Billings Creek	43,071,992	43.072	10,652	31,537	43.022	395	15.5	1240.6	35.53	34,556	326,737
Stewart Creek	26,630,261	26.630	6,586	26,775	69.733	598	28.1	1152.4	33.35	30,252	282,669
Robinson Creek	35,558,066	35.558	8,793	38,874	124.205	1,027	38.3	1363.4	38.54	40,959	393,200
Doty Creek	18,716,086	18.716	4,628	23,571	18.959	152	9.0	1088.0	31.74	27,275	252,510

Table 4.4-3

Gualala River Watershed General Geomorphic Characteristics (Table 1 of Appendix 2)

HSA, SPWS, and PWS Name	Subbasin Area-m2	Subbasin Area, km2	Acres	Perimeter, m	Upslope Area km2	Total Stream length, km	Max. Stream Length, km	Width-BF[1] ft	Ave. Depth-BF[2] ft	X-Sec. Area-BF[3], ft^2	Discharge-BF[4] cfs
Rockpile Creek HSA											
Rockpile Creek SPWS											
Upper Rockpile Creek	36,695,303	36.695	9,075	29,548	36.720	348	11.9	1204.7	34.65	32,774	308,431
Middle Rockpile Creek	33,021,154	33.021	8,166	28,326	69.783	639	26.8	1182.0	34.09	31,669	297,116
Red Rock	8,972,925	8.973	2,219	14,437	78.778	713	29.5	872.2	26.25	18,312	163,614
Lower Rockpile Creek	11,916,460	11.916	2,947	17,392	90.751	813	38.7	948.6	28.21	21,304	192,931
Wheatfield Fork HSA											
Hedgepeth Lake SPWS											
Britain Creek	27,128,844	27.129	6,709	28,610	27.177	237	14.6	1187.3	34.22	31,926	299,748
Pepperwood Creek	25,239,812	25.240	6,242	22,454	25.180	233	8.4	1064.4	31.15	26,220	241,885
House Creek	21,406,679	21.407	5,294	24,328	73.918	677	23.0	1103.6	32.13	27,984	259,671
Lower Wheatfield Fork SPWS											
Haupt Creek	24,439,940	24.440	6,044	23,167	24.869	222	11.2	1079.5	31.53	26,895	248,675
Tobacco Creek	32,599,136	32.599	8,061	31,631	230.421	2,065	46.8	1242.3	35.58	34,639	327,598
Flat Ridge Creek	28,467,315	28.467	7,040	26,959	28.439	247	14.9	1155.9	33.44	30,420	284,383
Annapolis	30,652,247	30.652	7,580	29,222	289.395	2,568	59.8	1198.7	34.50	32,479	305,412
Walters Ridge SPWS											
Buck Mountain	33,117,216	33.117	8,190	29,036	32.936	310	13.0	1195.3	34.41	32,311	303,692
Tombs Creek	25,225,115	25.225	6,238	25,810	25.206	235	12.8	1133.4	32.88	29,363	273,629
Wolf Creek	40,850,686	40.851	10,102	42,693	98.985	896	28.8	31429.0	39.96	44,200	427,202

Bankfull characteristics are based on north coast regional curves developed by Rosgen and Kurz (2000).

1. Bankfull width = $17.827*(Area_{sq.mi.})^{0.4251}$

2. Bankfull mean depth = $0.9253*(Area_{sq.mi.})^{0.3878}$

3. Bankfull cross-sectional area = $16.528*(Area_{sq.mi.})^{0.8127}$

4. Bankfull discharge = $79.013*(Area_{sq.mi.})^{0.8852}$

4.5 Potential Salmonid Refugia

The concept of refugia is based on the premise that patches of aquatic habitat provide the critical ecologic functions to support wild anadromous salmonids. 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 historical natural productivity, 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 salmonid conservation to ensure long-term survival of viable stocks and a critical element towards recovery of depressed salmonid populations (Sedell 1990; Moyle and Yoshiyama 1992; Frissell 1993, 2000). Refugia habitat is defined as: 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; refugia remains as a center from which dispersion may take place to re-colonize areas after climate readjustment.

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

The NCWAP interdisciplinary team identified and categorized refugia habitat by using professional judgment and criteria developed for north coast watersheds. The criteria considered different values of watershed and stream ecosystem processes, the presence and status of fishery resources, forestry and other land uses, land ownership, potential risk from sediment delivery, water quality, and other factors that may affect refugia productivity. Information from CDFG's habitat inventory surveys, NCWAP's EMDS stream reach, professional judgment, and local Gualala expertise were used to assess streams as potential refugia.

NCWAP Refugia Categories and Criteria:

Five categories of refugia were described: (1) High Quality Refugia; (2) High Potential Refugia; (3) Medium Potential Refugia; (4) Low Quality Habitat; and (5) Critical Contributing Areas. Medium Potential Refugia were identified in the Little North Fork and North Fork. The potential refugia identified on the Little North Fork were related to shade canopy and water temperature. The potential refugia identified on the North Fork were related to shade canopy and pool depth. No other refugia were identified in the watershed (Table 4.5-1).

The Gualala North Coast Watershed Assessment Program (NCWAP) team used various methods and models to assess relationships between fish habitat and landscape processes and conditions as follows: (1) geographic information system (GIS) data from the California Department of Forestry and Fire Protection (CDF), the California Geologic Survey (CGS), the California Department of Fish and Game (CDFG) were composited through a series of database queries intended to reveal relationships; (2) the output of the queries was used to build tables (Integrated Data Tables) and maps; and (3) the Ecological Management Decision Support (EMDS) model was used to create maps of reach conditions based on

CDFG raw data and additional maps showing road density and position on hillslope by Planning Watershed.

A map and three tables were developed to help guide future stream restoration activities in the Gualala River Watershed and are illustrated below. The tables shown here are copied from the Appendix 2 and Appendix 5 where in-depth discussion is found. A reduced version of the map is shown for illustration purposes. The full size map is Plate 3. The map and tables represent the results of the NCWAP watershed assessment and provide a starting point for future work. These are not a substitute for on-site analysis and design. The recommendations shown on the map and in the table were developed independently by California Geologic Survey (CGS) and CDFG respectively. Some differences exist for numerous reasons. For example, the map was developed from aerial photo analysis, whereas, CDFG observations were made on the ground. Another example is that the map considers the entire watershed; whereas, habitat inventories were limited to portions of tributaries. Prioritization of restoration efforts involves many factors that beyond the scope of this work; however, the map and tables can be used as building blocks.

Table 4.5-1

Potential Salmonid Refugia Based Upon Habitat Inventory Survey, EMDS Stream Reach, Professional Judgment, and Local Expertise

in the Gualala River Watershed, California

Subbasin Stream Name Stream	NCWAP Refugia Categories	Shade Canopy Overstream	Embeddedness Related to Spawning Suitability	Pool Depth Related Summer Conditions	Pool Shelter Related to Escape and Cover	Thermal Refugia Based Upon MWAT Data from 2001
North Fork Subbasin						
Doty Creek	Potential	**---**				
Dry Creek	Potential					---
Dry Creek Tributary #1	Potential	---	---			
Little North Fork	High Potential	---	---		---	---
Little North Fork Tributary Tributary #1	Potential	---	---			
Log Cabin Creek	Potential	---	---			
McGann Creek	Potential	---				
North Fork	High Potential	---	---	---		**Undetermined**
Robinson Creek	Potential				--	
Rockpile Subbasin						
Rockpile Creek	Low Quality					
Buckeye Subbasin Subbasin Score						
Buckeye Creek	Potential		--			
Wheatfield Fork Subbasin						
Danfield Creek	Low Quality					
House Creek	Potential		---			
Pepperwood Creek	Low Quality		--			
Tombs Creek	Low Quality					

Table 4.5-1
Potential Salmonid Refugia Based Upon Habitat Inventory Survey, EMDS Stream Reach, Professional Judgment, and Local Expertise

in the Gualala River Watershed, California

Subbasin Stream Name Stream	NCWAP Refugia Categories	Shade Canopy Overstream	Embeddedness Related to Spawning Suitability	Pool Depth Related Summer Conditions	Pool Shelter Related to Escape and Cover	Thermal Refugia Based Upon MWAT Data from 2001
Wheatfield Fork *(partial survey)*	Potential			---		
Mainstem/South Fork Subbasin						
Camper Creek 1999	Potential	---				
Carson Creek 1999	Potential	---				
Marshall Creek	Potential		---			
McKenzie Creek 1999	Potential	---				
Palmer Canyon Creek	Potential	---	--			
Upper South Fork	Potential	--	--			
Wild Hog Creek 1999	Potential	--				

(---) =great to (-) = good