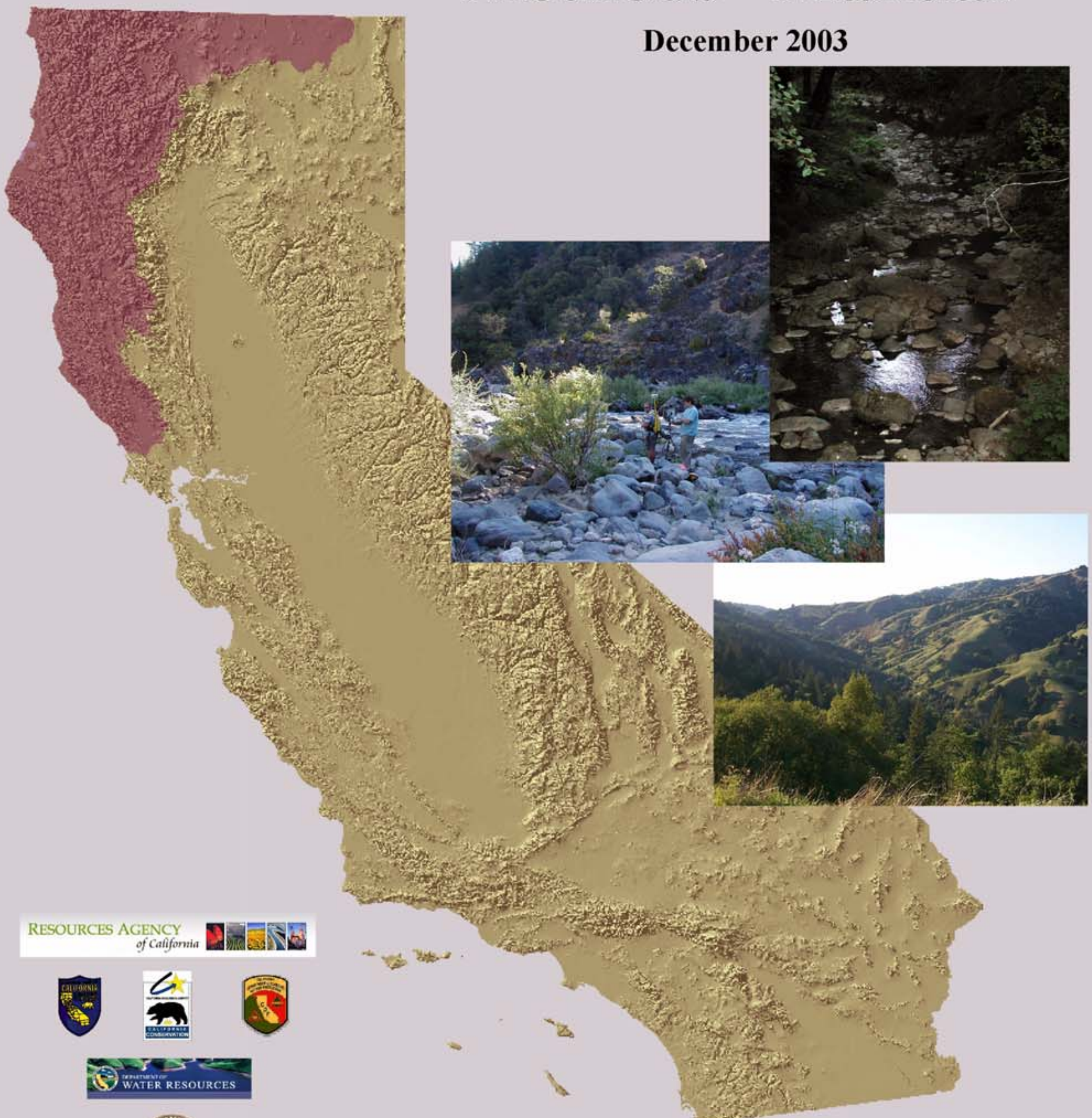
North Coast Watershed Assessment Program

Methods Manual

December 2003



State of California
Governor Arnold Schwarzenegger

California Resources Agency
Mike Chrisman Secretary

California Environmental Protection Agency
Terry Tamminen Secretary

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Suggested Citation:

Bleier, C., Downie, S., Cannata, S., Henly, R., Walker, R., Keithley, C., Scruggs, M.; Custis, K., Clements, J. and R. Klamt. 2003. North Coast Watershed Assessment Program Methods Manual. California Resources Agency and California Environmental Protection Agency, Sacramento, California. 191 pages.

Acknowledgments

We wish to thank the Center for Forestry, University of California, Berkeley, for its assistance in the development of our watershed assessment approaches and the watershed assessment reports completed to date. Dr. Richard B. Standiford, Director of the Center and Assistant Dean for Forestry, College of Natural Resources coordinated the Center's many efforts and also directed scientist and practitioner peer reviews of our assessment methods, EMDS model, draft assessment reports, and draft KRIS Gualala information system. Dr. Richard Harris, Extension Forestry Specialist, assisted in the development of our assessment methods and the first draft of our methods manual. Susie Kocher, Staff Research Associate, provided technical and editing assistance in the development of our first and final drafts of the assessment manual.

Additionally, we would like to thank the many watershed assessment scientists and practitioners who gave freely of their time and expertise to provide us with wise, substantive, and incisive feedback as we developed our assessment methods and reports. Their help added greatly to the quality of our work.

Finally, we would like to thank our most important partners, the many landowners and watershed community members who provided us with guidance and feedback during the course of our assessment efforts. We hope that our products will be useful in your watershed management and improvement activities.

Table of Contents

CHAPTER 1: THE NORTH COAST WATERSHED ASSESSMENT PROGRAM 1
1.1 BACKGROUND AND GOALS 1
1.2 ASSESSMENT AREA 1
1.3 PARTICIPATING AGENCIES 3
1.4 PUBLIC AND SCIENTIFIC INPUT 4
1.5 PROGRAM MANAGEMENT 7
1.6 NORTH COAST WATERSHED ASSESSMENT PROGRAM PRODUCTS 8
1.7 ACCESS TO NCWAP PRODUCTS 10
CHAPTER 2: CONCEPTUAL FRAMEWORK FOR WATERSHED ASSESSMENT 12
2.1 CURRENT APPROACHES TO WATERSHED ASSESSMENT AND ANALYSIS 12
2.2 NORTH COAST WATERSHED ASSESSMENT PROGRAM APPROACH 13
2.3 NORTH COAST WATERSHED ASSESSMENT PROCESS 17
CHAPTER 3: DATA COLLECTION AND ANALYSIS 21
3.1 GEOLOGY AND LANDSLIDE POTENTIAL 22
3.2 VEGETATION AND LAND USE ANALYSIS 29
3.3 FLUVIAL SEDIMENT MAPPING/SEDIMENT PRODUCTION AND TRANSPORT 39
3.4 RIPARIAN VEGETATION CONDITIONS 46
3.5 HYDROLOGY AND WATER QUANTITY 54
3.6 WATER QUALITY 59
3.7 FISH HABITAT 69
3.8 FISH HISTORY AND STATUS 78
3.9 DATA QUALITY CONTROL AND ASSURANCE 81
CHAPTER 4: INTERDISCIPLINARY ANALYSIS AND SYNTHESIS 86
4.1 ECOLOGICAL MANAGEMENT DECISION SUPPORT WATERSHED MODEL 86
4.2 LIMITING FACTORS ANALYSIS OF SALMONID POPULATIONS 99
4.3 METHOD FOR IDENTIFYING AND RATING REFUGIA AREAS 104
4.4 INTEGRATED ANALYSES OF GEOLOGY AND LAND USE DATA 112
4.5 MAPPING POTENTIAL RESTORATION SITES 122
4.6 USE OF 'WORKING HYPOTHESES' AND WEIGHT OF EVIDENCE 124
4.7 IDENTIFICATION OF RECOMMENDATIONS FOR WATERSHED IMPROVEMENT ACTIONS 126

APPENDICES **129**
APPENDIX A: DEFINITION OF TERMS 130
APPENDIX B: MANUAL FOR REGIONAL OR WATERSHED SCALE MAPPING OF LANDSLIDE AND FLUVIAL GEOMORPHIC CONDITIONS 138
APPENDIX C: LAND USE HISTORY DATA COLLECTION AND METHODS PROCEDURES 139
APPENDIX D: ORIGIN AND DESCRIPTION OF CALWATER 2.2 145
APPENDIX E: REGIONAL WATER QUALITY CONTROL BOARD METHODS MANUAL 146
APPENDIX F: CALIFORNIA SALMONID STREAM HABITAT RESTORATION MANUAL 147
APPENDIX G: STREAM REACH CONDITION EMDS MODEL 148
APPENDIX H: POTENTIAL SEDIMENT PRODUCTION EMDS MODEL 159
REFERENCES **175**

Table Of Figures

Figure 1. North Coast Watershed Assessment Area 2

Figure 2. NCWAP Management - Relationships and Responsibilities 8

Figure 3. Interactions Among Watershed Processes, Conditions and Activities 14

Figure 4. How NCWAP Integrates Disciplinary Data To Answer Critical Questions 17

Figure 5. North Coast Watershed Assessment Program Approach 18

Figure 6. Geologic and Geomorphic Features Related to Landsliding, North Fork Subbasin, Gualala Watershed, Sonoma and Mendocino Counties 25

Figure 7. Relative Landslide Potential with Geologic and Geomorphic Features. North Fork Gualala River Subbasin 27

Figure 8. Land Ownership on the Albion River Watershed 34

Figure 9. Vegetation by Cover Type, Albion Watershed 35

Figure 10. Fire Hazard Map for Albion River Watershed 36

Figure 11. Roads by Type Class in the Albion River Watershed. 37

Figure 12. Distribution of Channel Gradients in the Gualala River Watershed 43

Figure 13. Distribution of the Excess Sediment in the Gualala River Watershed in 2000 44

Figure 14. 1942 Stream Exposure (white) in the Gualala River Basin 50

Figure 15. 1968 Stream Exposure (white) in the Gualala River Basin 50

Figure 16. 1999-2000 Stream Exposure (white) in Gualala River Basin 51

Figure 17. Relationship of Water Temperature with Riparian Canopy 52

Figure 18. Mean, Maximum, And Minimum Daily Discharge For South Fork Gualala River Near Annapolis, USGS Station #11467500, Water Years 1951–1971 58

Figure 19. Summary of MWAT values for the North Fork Gualala River Subbasin 67

Figure 20. Raw Data Plot Of Continuous Water Temperatures With EMDS Ratings 67

Figure 21. Cumulative Distribution of Water Temperature Data from a Single Site With Example EMDS Ranges 68

Figure 22. Cobble Embeddedness Categories as Measured at Pool Tail Crests in Surveyed Streams 74

Figure 23. Percentage Of Pool Habitat, Flatwater Habitat, Riffle Habitat, And Dewatered Channel By Surveyed Length, Mattole River Northern Subbasin 75

Figure 24. Percent Length Of A Survey Composed Of Deeper, High Quality Pools, Mattole Northern Subbasin 75

Figure 25. Average Pool Shelter Ratings From CDFG Stream Surveys, Mattole River Northern Subbasin 76

Figure 26. NCWAP EMDS Anadromous Stream Reach Condition Model. 88
Figure 27. NCWAP EMDS Potential Sediment Production Model. 89
Figure 28. EMDS Reference Curve. 90
Figure 29. Normalized Cumulative Distribution Function. 91
Figure 30. EMDS Graphical Output. 92
Figure 31. Potential Restoration Sites And Limiting Factors For The Gualala Watershed........ 122
Figure 32. The Stream Reach Condition Model with Populated Habitat Factors 148
Figure 33. Breakpoints for 7DMAT Truth Values 150
Figure 34. Breakpoints for Canopy Density 151
Figure 35. Breakpoints for Percent Reach in Primary Pools 154
Figure 36. Breakpoints for Pool Shelter Complexity.. 155
Figure 37. Breakpoints for Percentage in Backwater Pools and Side Channel Habitat 156
Figure 38. Breakpoints for Embeddedness 157
Figure 39. Breakpoints for Percent Dry Weight of Fine Sediments <0.85mm 158
Figure 40. Breakpoints for Percent of Sediments <6.35mm.. 158
Figure 41. The Potential Sediment from Natural Processes section of the EMDS Model 161
Figure 42. The Potential Sediment from Management-related Sources section of the EMDS Model 165

Table Of Tables

Table 1. Summary of Historic Timber Harvest on the Albion River Watershed 33

Table 2. Timber Harvest by Silvicultural System and Yarding, Albion River Watershed........... 33

Table 3. Albion River Watershed Vegetation by Cover Type.. 35

Table 4. Summary Roads Information for the Albion River Watershed 37

Table 5. Database Dictionary for GIS: Mapped Channel Characteristics. 42

Table 6. Gualala River Watershed Stream Characteristics Representing Sediment Sources or Storage 44

Table 7. Riparian Forest Ecosystem Functions (Naiman 1998) 46

Table 8. Vegetation Cover Type: Summary For Different Buffer Widths. 49

Table 9. Vegetation Size Classes: Summary For Different Buffer Widths 49

Table 10. Canopy Density: Summary For Different Buffer Widths.. 49

Table 11. Summary Stream Flow Data for the South Fork Gualala River Gauge Station 57

Table 12. Summary of Current (1995, 1997, and 2001) Conditions Based Upon Habitat Inventory Surveys from the North Fork Subbasin, Gualala River Watershed, California 74

Table 13. Summary from Redwood Creek Upper Subbasin EMDS Stream Reach Evaluation... 93

Table 14. Reference Curve Metrics For EMDS Stream Reach Condition Model........................ 94

Table 15. Reference Curve Metrics For EMDS Sediment Production Risk Model, Version 1.0. 95

Table 16. Fish Habitat Components And Parameters Applicable For Limiting Factors Analysis 100

Table 17. Example Of DFG Habitat Inventory Data And Analysis 101

Table 18. EMDS Reach Model Scores for the North Fork Subbasin, Gualala Watershed......... 102

Table 19. Example of Limiting Factors Determination.. 103

Table 20. Refugia Rating Worksheet... 109

Table 21. Refugia Table.. 110

Table 22. Refugia Summary Table 111

Table 23. Vegetation Types Associated With Terrain Types In The Northern Subbasin. 113

Table 24. Land Use And Vegetation Type Associated With Relative Landslide Potential. 114

Table 25. Historically Active Landslide Features Associated with Land Type or Use............. 115

Table 26. Relative Landslide Potential and Land Use/Type Classes, Redwood Creek............. 117

Table 27. Relative Landslide Potential by Silvicultural System and Yarding Method 119

Table 28. Integrated Information for the Redwood Creek Watershed and Subbasins............... 120

Table 29. Information Sources For CDF's Land Use History Development 140
Table 30. Data Types, Status And Usage 143
Table 31. Weights Given To Land Use And Eras Of Timber Harvests 168
Table 32. Model Weights Of Eras Of Human Disturbance 170

CHAPTER 1: THE NORTH COAST WATERSHED ASSESSMENT PROGRAM

This manual describes the approach and methods used to conduct watershed assessments on the North Coast under the State of California's North Coast Watershed Assessment Program (NCWAP). NCWAP is an interagency program, developed by the California Resources Agency and the California Environmental Protection Agency (Cal/EPA). The missions of the two agencies include the protection, restoration and management of natural and cultural resources, and the restoration, protection and enhancement of human health, environmental quality and economic vitality, respectively. The Legislature established NCWAP to improve decision-making by landowners, watershed groups, agencies, and other stakeholders for the purposes of protecting, managing and restoring North Coast watersheds.

This manual provides a consistent framework for assessing North Coast watersheds. Methods focus on assessing watershed conditions for cold-water anadromous fisheries because this is a cross-cutting concern for agencies and the public. Individual assessments will vary somewhat from basin to basin as the result of differences in available information, issues, and assembled staff. Reports offer additional examples of how data can be analyzed and presented. These reports and this manual are available via the NCWAP website at http://www.ncwatershed.ca.gov/.

1.1 BACKGROUND AND GOALS

The North Coast Watershed Assessment Program's goals are to provide information:

- On baseline conditions at a watershed scale to improve our ability to evaluate the effectiveness of resource protection programs to promote watershed health;
- To help agencies focus watershed improvement programs and investments, and to assist landowners, local watershed groups, and individuals to develop successful projects;
- To help focus cooperative interagency, nonprofit and private sector approaches to protect the best watersheds and streams through watershed stewardship, conservation easements, and other incentive programs; and
- To help landowners, land managers, and agencies better implement laws that require watershed assessments such as the State Forest Practices Act, Clean Water Act, and State Lake and Streambed Alteration Agreement Act.

1.2 ASSESSMENT AREA

The NCWAP assessment area includes all coastal drainages from Sonoma County north to Oregon (See Figure 1). These drainages comprise over 12 million acres, approximately 6.5 million acres of which are private lands.

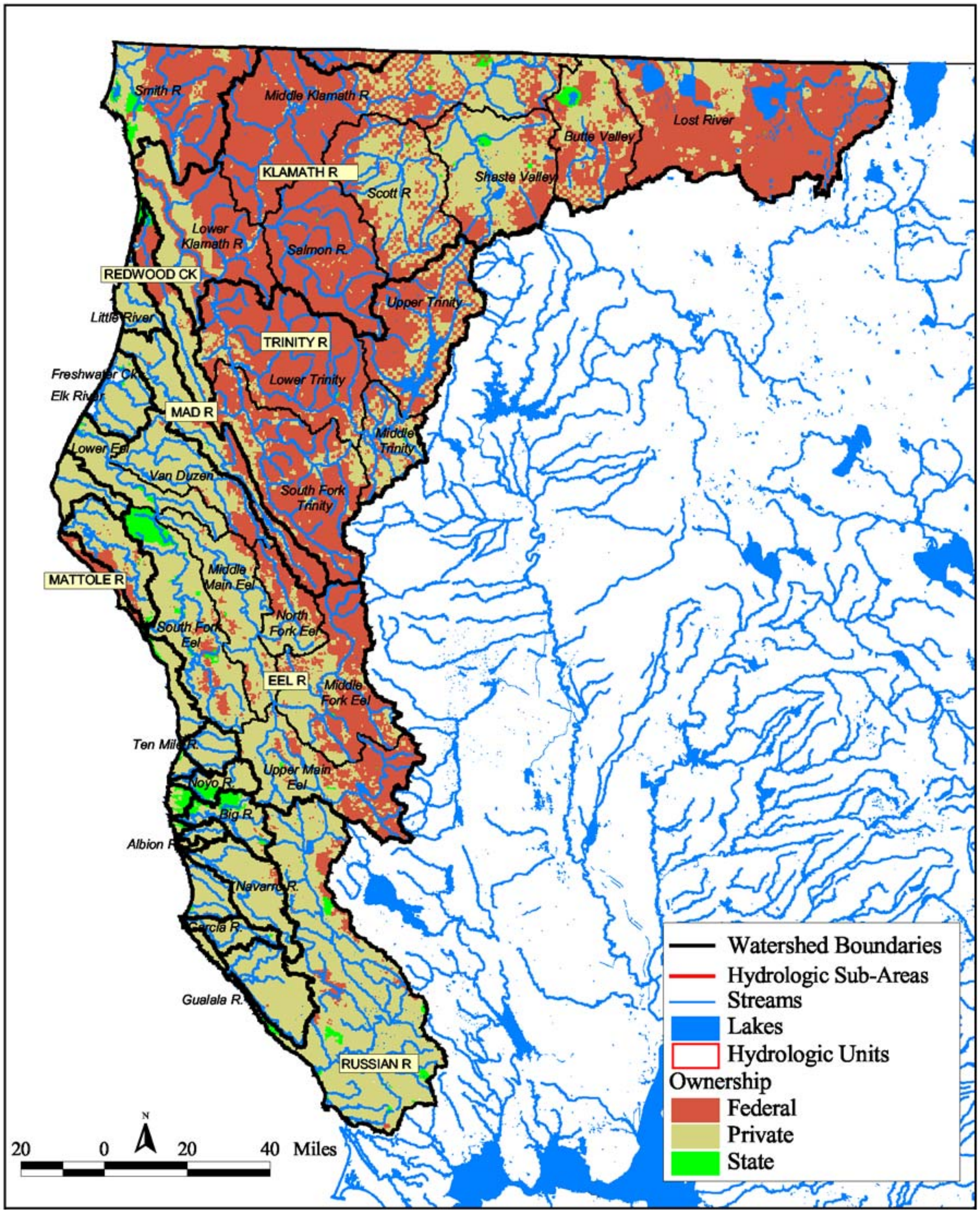


Figure 1. North Coast watershed assessment area

1.3 PARTICIPATING AGENCIES

The North Coast Watershed Assessment Program is conducted by the following agencies and departments:

- California Resources Agency
- California Environmental Protection Agency (CalEPA)
- California Department of Fish and Game (DFG)
- California Department of Forestry and Fire Protection (CDF)
- California Department of Conservation/California Geological Survey (DOC/CGS)
- California Department of Water Resources (DWR)
- North Coast Regional Water Quality Control Board (NCRWQCB) of the State Water Resources Control Board (SWRCB)

The major responsibilities of the agency and departments in the North Coast Watershed Assessment Program include:

California Resources Agency

The Agency serves as the administrative lead for the interagency program. It provides leadership for the Management Team, works with CalEPA and the State Water Resources Control Board, and reports to the Legislature, stakeholder groups, and others on program progress and results.

California Department of Fish and Game

The Department compiles, develops, and analyzes data related to anadromous fisheries habitat and populations. It evaluates factors affecting anadromous fisheries production and participates in interdisciplinary synthesis and development of watershed recommendations for each watershed. DFG also coordinates data collection and shares results with other programs, including the Fishery Restoration Grants Program, Lake and Streambed Alteration Agreement Program, Basin Planning Program, Steelhead Research and Monitoring Program, Coho recovery planning, Habitat Conversation Planning, and Timber Harvest Plan review.

California Department of Forestry and Fire Protection

The Department compiles, develops, and analyzes historical and current land use data and develops spatial data for use in interdisciplinary analysis and cumulative impacts assessment. Staff participates in the interdisciplinary synthesis and development of watershed recommendations. CDF shares information among its Fire and Resource Assessment, Forest Practices, Fire Planning, Forestry Assistance Programs and others.

California Department of Conservation/California Geological Survey

The Department compiles, develops, and analyzes data related to geology and landslides, erosion potential, and sediment production and transport. Staff participates in the interdisciplinary synthesis and development of watershed recommendations. CGS shares information and expertise with its Timber Harvest Plan review program.

California Department of Water Resources

The Department installs and maintains stream gages to develop and analyze information on stream flow and water use. Staff participates in the interdisciplinary synthesis and development of watershed recommendations.

North Coast Regional Water Quality Control Board

The Board compiles, collects, and analyzes water quality data for the assessments. Staff participates in the interdisciplinary synthesis and development of watershed recommendations. The Board coordinates and shares data collection among its programs including the Surface Water Ambient Monitoring Program (SWAMP), Timber Harvest Plan review, watershed grants administration, and TMDL programs.

The Institute for Fisheries Resources (IFR) is also a partner and participant in this program. Its role is to develop KRIS (Klamath Resource Information System) for use with NCWAP watersheds. IFR enters NCWAP data into KRIS either directly or by training state employees.

1.4 PUBLIC AND SCIENTIFIC INPUT

To ensure that assessment methods, products, and results were understandable, useful, and scientifically credible, NCWAP conducted public and scientific peer reviews of the methodology, and of the draft reports of the first three watersheds assessed.

Public Input on NCWAP and Review of Draft Methods Manual

The Resources Agency met with landowner groups, fishery and environmental groups, restoration professionals, watershed councils, agencies, and others to discuss program goals and objectives. In April 2001, it released its Draft Methods Manual, soliciting public comments through email, workshops, announcements in the media, and list servers. Major themes that emerged from the comments included:

- Concerns or questions about data quality;
- Opportunities for input by landowners and local experts;
- The need for adequate public review;
- Recognition of the contributions of restoration projects to improving watershed health;
- The need to obtain permission to access private property;

- The potential use of data for regulation;
- The appropriate level of specificity for recommendations derived from coarse assessment; and
- Public access to data and opportunities to update assessments.

Scientific Peer Review of Draft Methods Manual

NCWAP provided for three scientific peer reviews of NCWAP products through the University of California at Berkeley's Center for Forestry (UCB). Each peer review was conducted by recognized experts in the field of watershed assessment and related disciplines.

The Draft Methods Manual review critiqued proposed methods, recommended improvements to the methodology, and made format and content suggestions for writing the manual. Comments focused on the need for clarification or further development of:

- Initial issue scoping with local stakeholders and the public;
- Inclusion of all beneficial uses in assessment;
- Challenges of using data from different sources;
- Limiting Factors Analysis (LFA);
- Stream gauges for headwaters and other stream flow analysis needs;
- Analysis of linkage between land use activities and instream conditions;
- Use of landslide maps for analyzing risk and cumulative effects;
- Ability to establish statistically valid baseline data for future monitoring;
- Synthesis of information among departments and disciplines to answer critical questions; and
- Program management structure.

A second scientific peer review focused on the design and use of its Ecosystem Management Decision System (EMDS) watershed model (described in Chapter 4). Major recommendations were to:

- Separate the model into pieces assessing current and potential conditions, risk, and potential future conditions;
- Create a model of current food availability;
- Incorporate passage barriers into the model as soon as possible;
- Include all relevant landslide information from the California Geological Survey;
- Use process-oriented models to fill key data gaps (e.g. stream temperature);

- Incorporate TMDLs and other ancillary data to weight road and land use factors;
- Use reference watersheds where possible for breakpoints in the model;
- Calibrate and validate the model; and
- Develop a stream sampling protocol geared specifically for EMDS data collection.

Scientific Peer Review of Individual Assessments

The third peer review looked at the first three draft watershed assessment reports (Gualala River, Mattole River, and Redwood Creek watersheds). Peer review comments specific to each watershed report are included in appendices of those reports. Comments included recommendations to:

- Describe data, explain why they were chosen and how they were used;
- Incorporate more statistically-based sampling;
- Improve analyses and discussions of historic versus current conditions, upland conditions, effects of timber harvest, and cumulative effects;
- Improve interdisciplinary analysis of geology, land use, sediment and fish habitat;
- Develop sediment budgets;
- Suggest monitoring to fill data gaps and promote adaptive management;
- Address limiting factors at the basin scale;
- Link recommendations to findings and data, and make them more specific to locations and land use practices; and
- Prioritize recommendations for cost-effectiveness.

NCWAP Response to Reviews

NCWAP refined its methods and developed additional analytical tools in response to reviews, incorporating these changes into the watershed assessments, final reports, and this manual. Public and science review comments, along with NCWAP responses, can be found on-line at the NCWAP website at http://www.ncwatershed.ca.gov. Public comments on the first three assessments are included as appendices of the reports and can also be found at the NCWAP website.

Ongoing Public Input to Watershed Assessments

NCWAP also developed a process for working with the public during each watershed assessment. This starts with initial "scoping" sessions and continues through the public review of draft reports at the end of the process. These activities include landowners, local agencies, local experts, watershed councils, and other interested parties. The objectives are to:

- Explain program goals and objectives;
- Describe methods and products, and explain access needs and constraints related to private property;
- Identify local watershed concerns, local information needs, and local watershed assessment or watershed planning efforts;
- Discuss which concerns, needs or efforts NCWAP might support;
- Identify data, reports, histories, etc. that local entities are willing to share;
- Identify opportunities for coordinated data collection or analysis; and
- Identify local sources of information and local experts with whom NCWAP should work, interview, etc.

NCWAP works with multi-stakeholder groups where possible to host or sponsor scoping activities, announcing them through local press and other means. The assessment team lead personally contacts key stakeholders if they can't be reached through public meetings.

During the assessment, the field team lead is responsible for communicating assessment progress, using email, websites, newsletters, meetings or workshops. He or she communicates data collection plans, timelines, and assessment results. In the course of completing the initial analyses, the team will provide opportunity for data contributors to review how their data were used, to ensure that the team didn't err in incorporating or interpreting those data.

When the Watershed Assessment Team completes its Public Review Draft Report of the assessment, public and stakeholder comments are solicited (the document is made available on-line and in hard copy). The team holds one or more workshops to explain the findings, identify additional potential recommendations, and answer any questions. At least one month is provided for comments.

1.5 PROGRAM MANAGEMENT

The interagency North Coast Watershed Assessment Program is managed through the NCWAP Management Team, which is led by the Resources Agency (See Figure 2). The Management Team consists of NCWAP leaders from each participating department. This team establishes policies, procedures, and timelines for NCWAP activities to ensure interdepartmental data access and use, consistent standards for fieldwork and analysis, adequacy of assessment products, coordinated management of field staff from different departments, and resolution of interdisciplinary disagreements. Each Management Team lead is responsible for supervising NCWAP staff from his or her Department, for leading one or more interdisciplinary field Watershed Assessment Teams, and for working with the Management Team to address problems brought up by Watershed Assessment Field Teams.

Watershed Assessment Field Teams are established for each watershed. Each team is responsible for compiling data; working with local stakeholders to collect or share field data; analyzing data and developing maps, databases and other products; and writing draft and final reports. The team is led by one of the department leaders from the Management Team and consists of technical staff from each department. The Watershed Assessment Team leader is responsible for scheduling assessment production, coordinating work among team members, leading interdisciplinary analysis, communicating progress to the Management Team, and conducting public outreach.

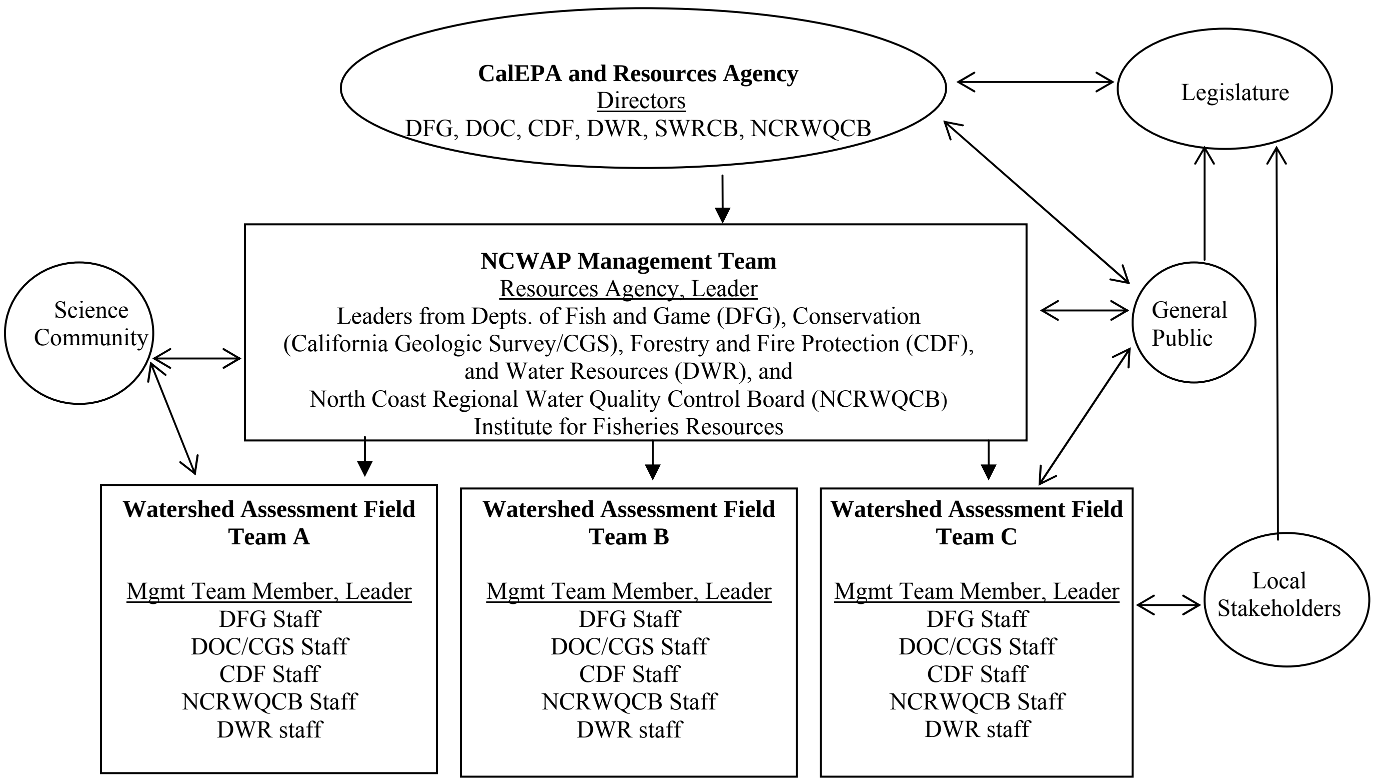


Figure 2. NCWAP management - relationships and responsibilities

1.6 NORTH COAST WATERSHED ASSESSMENT PROGRAM PRODUCTS

The North Coast Watershed Assessment Program has produced and made available to the public a consistent set of products for each basin assessed. Each final Watershed Assessment includes:

- New geology information:
    - Maps of landslides and geomorphic features related to landsliding;
    - Relative landslide potential maps;

    - Maps or spatial data of instream features indicating excess sediment production, transport, and/or deposition; and
    - Maps or spatial data of stream reaches classified by gradient and by Rosgen stream type.
- New or compiled fish habitat information
- New digital Timber Harvest Plan data and a summary of timber harvest by decades
- New or compiled water quality information
- Land use, vegetation and road digital data
- Streamflow, precipitation and water rights information
- Ecological Management Decision Support system (EMDS) model and map products that integrate different types of data on instream and upslope conditions
- A basin level Synthesis Report that includes:
    - Descriptions, analyses and discussions of current and historic conditions (if known) of fisheries, vegetation, land use, geology and fluvial geomorphology, water quality, stream flow, water use, and instream habitat;
    - Interdisciplinary analysis of interactions among watershed processes, land and water use, and water quality and fish habitat conditions, including various types of maps, tables or other products;
    - Identification of habitat condition factors that are likely limiting salmonid production;
    - Interdisciplinary analysis of the suitability of stream reaches and the watershed for salmonid production and refugia areas;
    - Weight-of-evidence evaluation of "working hypotheses" about instream and watershed conditions that affect salmonids and potentially limit production;
    - Tributary and watershed recommendations for management, refugia protection, and restoration activities to address limiting factors and to improve conditions for salmonid productivity;
    - Monitoring recommendations to fill data gaps and improve adaptive management efforts;
    - Appendices for more comprehensive information by discipline or Department;
    - Appendices for more detail about interdisciplinary analytical tools;
    - Appendices for bibliography and a catalogue of data considered for use in the assessment; and
    - Appendix of public and peer review comments on draft report.
- Databases of field data used and collected;
- Data catalogue of information reviewed for use in assessment;
- Bibliography;

- Klamath Resources Information System (KRIS) tool, available as a Web-based compact Disk (CD) and on-line.

1.7 ACCESS TO NCWAP PRODUCTS

Web Sites And Compact Disks (CDs)

NCWAP products described above are available primarily as electronic files. One way to access these is through the NCWAP web site at www.ncwatershed.ca.gov. The web site provides synthesis reports, including a searchable bibliography and data catalogue, a description of the EMDS model, and a complete set of spatial data, as well as data analyses and summaries

An interactive Internet Map Service (IMS) site has been created for viewing and manipulating spatial data developed as part of the NCWAP project. To get to the interactive map site, simply access the NCWAP web site, select a watershed, then select the "Interactive map" link.

NCWAP synthesis reports and spatial data are available for each assessment on compact disks (CDs) from the Department of Fish and Game. The report and the data are put on separate disks due to the size of the files. To receive these products, you may contact:

California Department of Fish and Game
1487 Sandy Prairie Ct. Suite A
Fortuna, California 95540
Phone: 707-725-1070

DFG Wildlife and Habitat Data Analysis Branch
1807 13th Street, Suite 202
Sacramento, CA 95814
Phone: 916-324-9265

California Dept. of Forestry and Fire Protection
1300 U Street
Sacramento, CA 95818
Phone: (916) 327-3939

North Coast Regional Water Quality Control Board
5550 Skylane Boulevard
Santa Rosa, CA
Phone: 707-576-2693

Paper Copies of Reports and Maps

Limited quantities of the assessment reports and appendices are available on paper. These are provided to local libraries and selected local or state agency sites so that landowners, local stakeholders, and the general public can access them.

Individual landslide and landslide potential maps can also be purchased from the Department of Conservation's California Geologic Survey Publications Sales Office (916-324-5644 and 324-5644 fax) or Publications Information and Sales Office (916-445-5716 and 916-324-5644 fax) in Sacramento; the Bay Area Regional Office in San Francisco (415-904-7707); and the Southern California Regional Office in Los Angeles (213-239-0878). Order forms can be downloaded from the Department's web site at:
www.consrv.ca.gov/cgs/information/publications/ordering.htm.

The Klamath Resource Information System

Klamath Resource Information System (KRIS) products have been developed for watersheds assessed by NCWAP. Use of KRIS allows integration and presentation of NCWAP watershed information for participating agencies and watershed-interested communities. KRIS was developed to support watershed assessment, protection, and restoration planning. The system integrates datasets, charts, graphs, map images and GIS data, photographs and bibliographic resources including reports, manuals and relevant correspondence. KRIS assimilates datasets in any standard format and uses ArcView™ software for viewing and updating map data.

KRIS has been designed with watershed analysts and restoration workers specifically in mind. Users can add information easily by cloning existing charts or slide tours. Any of its charts, photos, datasets, maps or document narratives can be cut and pasted easily from KRIS into reports or Power Point projects. KRIS has specialized functions such as the ability to download data directly from automated data probes or to reorganize its data contents through the use of Build Table functions. KRIS has a full help system and tutorials to guide users in all commonly used applications and routines.

KRIS includes a number of tools useful for data analysis and presentation. The HOBO Temp logger import utility, for example, makes the processing of data from stream temperature recorders extremely easy. Recent improvements to KRIS enable the dynamic display of maps from existing spatial data, in addition to the ArcView™ maps that accompany KRIS projects. Recent improvements include:

- KRIS/NCWAP provides shells that can be populated with information.
- KRIS now maintains a website, www.krisweb.com, to provide Internet access to its projects.

Watershed assessment products, as they become available, can be incorporated into watershed-specific KRIS projects. The ability to add information to KRIS promotes on-going watershed monitoring, evaluation, and adaptive management.

Copies of CD versions of the KRIS Noyo, Ten Mile, Gualala, Mattole, Redwood, and Big River projects can be ordered free of charge from the Department of Forestry and Fire Protection by calling (916) 327-3939 or e-mailing FRAP@fire.ca.gov.

CHAPTER 2: CONCEPTUAL FRAMEWORK FOR WATERSHED ASSESSMENT

2.1 CURRENT APPROACHES TO WATERSHED ASSESSMENT AND ANALYSIS

Various programs for watershed assessment and analysis have been established across the country, all of which have somewhat different goals, users, and methods. In the Pacific Northwest, the best-known methods for watershed assessment are those used by the states of Washington and Oregon, and by the USDA Forest Service.

Washington Forest Practices Board Manual

The State of Washington developed a voluntary watershed analysis procedure (Washington Forest Practices Board 1997) for use by natural resource professionals for the purpose of developing site-specific forest management prescriptions. The program provides an approach for identifying regions within a watershed that may be sensitive to forest practices using hazard and vulnerability ratings. The incentive for the landowner to conduct this assessment was streamlined approval of management under some watershed conditions and an increased level of certainty about what practices are appropriate. The process provides for two scales of data development and analysis. The state conducted Level One analyses using remote imagery or other "reconnaissance" level data. Landowners conducted the more detailed Level Two analyses using field level data. The Washington methodology was designed to be adapted with monitoring, but was criticized for not effectively applying this element. Modules included hydrology, mass wasting, erosion, riparian function, fish habitat, channel conditions, water quality and public works. The state conducted only a few Level 1 analyses; several large landowners participated in Level 2 analyses.

The Oregon Watershed Assessment Manual

The Oregon Watershed Assessment Manual (Oregon Governor's Office 1997) was developed for use by non-technical local watershed councils to guide watershed restoration. (Salminen et al. 1999). The objectives are to identify problem areas and prioritize potential restoration opportunities; it is not intended to provide the detail needed for project design. This method uses historical conditions and channel habitat types as a framework for assessing processes and resources. Assessment categories are similar to Washington's analytical modules, except that there is no public works module. The program uses existing data such as maps, reports, aerial photographs, and historical accounts. A method for development of a monitoring plan is included.

The Federal Guide for Watershed Analysis

The Federal Guide for Watershed Analysis (Regional Interagency Executive Committee 1995) is used on much of the federally managed public land in the Pacific Northwest. The approach uses a six-step process framed around a series of "core" topics (erosion, hydrology, vegetation, stream channel, water quality, species and habitats, human uses) to describe the condition of a watershed and to address issues of concern. Its goals are to guide program development and provide a consistent watershed context for environmental analysis of management activities. Analyses also provide recommendations for management, research, and monitoring.

California Efforts

In California, several large timberland owners have adapted some of Washington's methods for use in timber harvest planning. On the central and south coast, watershed and stakeholder groups have begun using the Oregon manual. More recently the State of California has begun developing the California Watershed Assessment Manual to provide a toolbox of approaches and protocols for analyzing a variety of natural resource issues in creek and river basins. It is designed for watershed groups and the general public, and will initially focus on the North and Central Coasts, and Central Valley (including the west-side Sierra Nevada). It will be adapted for other areas as funding becomes available.

2.2 NORTH COAST WATERSHED ASSESSMENT PROGRAM APPROACH

The North Coast Watershed Assessment Program is designed for agencies to conduct relatively coarse watershed assessments over a large region. It is intended to provide information for landowners, watershed groups, agencies and other stakeholders about watershed conditions and limiting factors for salmonids to guide restoration and conservation planning, to assist cumulative effects analysis, and to clarify additional analysis needs. Assessment modules are similar to those of other states, although NCWAP also uses an additional model that integrates information from each discipline to evaluate conditions for anadromous salmonids. NCWAP uses existing information, relies heavily on remotely sensed data for new information, and collects new field data for fish habitat and water quality where landowners allow access. Recommendations are focused at the watershed and subbasin scale, and the level of detail is not generally sufficient for project design. NCWAP works closely with local stakeholders and provides several opportunities for public and scientific review.

Conceptual Model and Critical Questions

Watershed assessment must consider interactions among natural processes, human activities, and resource conditions to assess watershed health. NCWAP recognizes that these watershed interactions are numerous, complex, non-linear, and may occur over extended periods of time and space. Furthermore, the forces or systems that drive or affect these factors may lie outside the watershed or occur at a much larger scale. As a result, single cause-and-effect relationships may be difficult to pinpoint. Figure 3 highlights interactions among key factors in North Coast watersheds.

Natural events and human land use activities can cause significant disturbances that affect both watershed conditions and processes. Their effects may, in turn, affect other processes, including those needed for recovery. For example, sediment from a road failure may take decades to work its way down many miles of stream, affecting fluvial processes, impacting water quality conditions, and altering stream substrate as it moves. As the sediment transports down stream, it can cause spatial and temporal changes in channel conditions through initial aggradation, possible lateral migration that undercuts channel banks, and eventual degradation as the channel attempts to reach its initial base level. Thus, this additional sediment may alter channel and channel bank structures, flow hydraulics and impede riparian vegetation re-establishment.

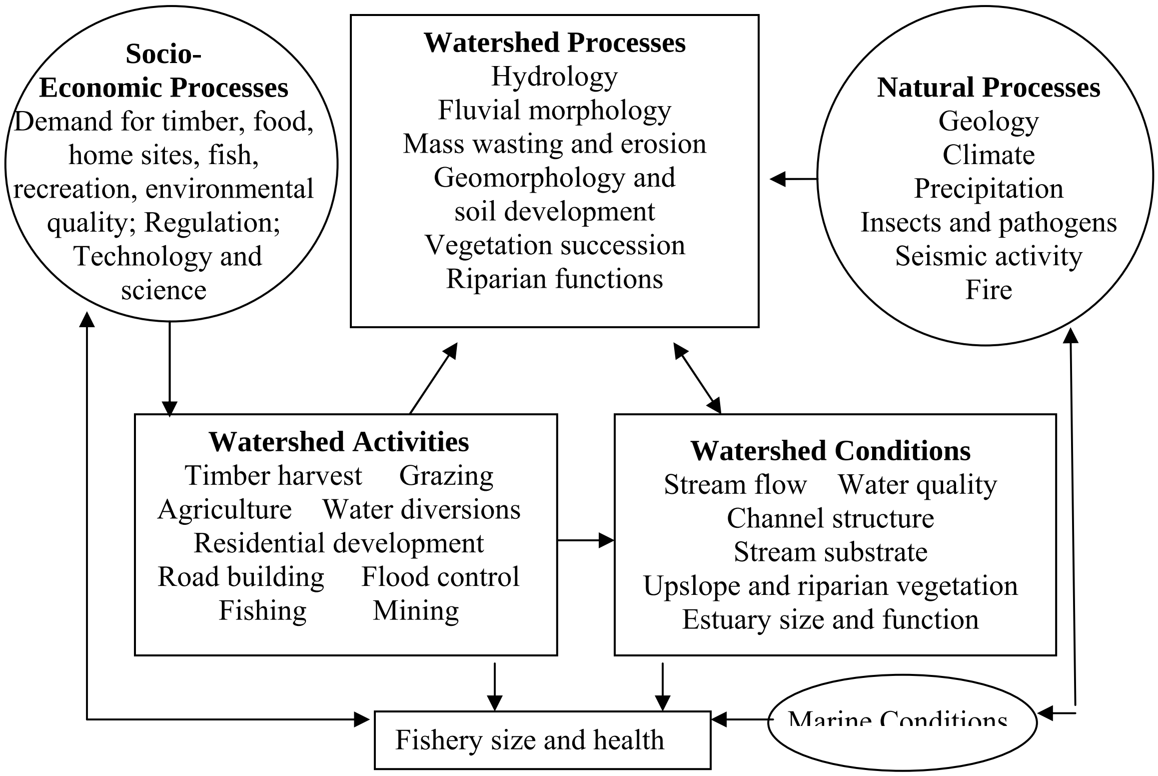


Figure 3. Interactions among watershed processes, conditions, activities and fisheries

Most North Coast stakeholders agree that the interaction of intensive timber harvest activities and flood events in the last century caused significant impacts to salmonid habitat and that some of these impacts persist today. There is less agreement about whether or how much current activities impact watershed conditions or impede recovery. While it is beyond the scope of NCWAP to conduct controlled experiments of these interactions or to implement complex risk models, the program uses existing information, new data, and a number of new analytical tools attempts to answer the following questions:

- What are the history and trends of the sizes, distribution, and relative health and diversity of salmonid populations within this subbasin?
- What are the current salmonid habitat conditions in this subbasin? How do these conditions compare to desired conditions?
- What are the relationships of geologic, vegetative, and fluvial processes to natural events and land use history?
- How has land use affected these natural processes?
- Based upon these conditions, trends, and relationships, are there elements that could be considered to be limiting factors for salmon and steelhead production?

- What habitat improvement activities would most likely lead toward more desirable conditions in a timely, cost effective manner?

These questions guide data compilation, collection and analysis for NCWAP and are the basis for developing conservation, protection, and restoration recommendations.

Spatial Scale of Assessment

Watersheds consist of hierarchical structures of spatial units ranging from the stream channel habitat unit (e.g., pool, riffle, etc.) to the stream reach to the subwatershed and finally whole watershed (Frissell et al. 1986). Although watershed assessment seeks to integrate information at the whole watershed scale, there is a need to gather and analyze data at multiple scales.

Watershed terminology often becomes confusing when discussing the scale of watersheds involved in planning and assessment activities. The conventions used in the North Coast watershed assessments follow the guidelines established by the Pacific Rivers Council. The descending order of scale is from the basin level (e.g., Gualala Watershed); subbasin level (this corresponds in many cases to the "super planning watershed" level in Calwater 2.2a, e.g., North Fork Gualala); watershed level (e.g., Little North Fork); and subwatershed level (e.g., Doty Creek). In the NCWAP approach, the finest level of resolution is the stream reach scale, on the order of 1-10 kilometers in length.

The subbasin scale is used in NCWAP as the basic summary framework for findings and recommendations. These incorporate information and recommendations developed at finer scales, such as sub-watershed, planning watershed, and stream reaches. More generalized findings and recommendations are also provided at the basin scale.

The North Coast Watershed Assessment Program uses the California Watershed Map (Calwater version 2.2a) to delineate watershed units. Calwater is a set of standardized watershed boundaries meeting standardized delineation criteria. The hierarchy of watershed designations consists of six levels of increasing specificity: Hydrologic Region (HR), Hydrologic Unit (HU), Hydrologic Area (HA), Hydrologic Sub-area (HSA), Super Planning Watershed (SPWS), and Planning Watershed (PWS). The primary purpose of Calwater is the assignment of a single, unique identifier code to a specific watershed polygon. The Calwater Planning Watersheds are generally from 3,000–10,000 acres in size.

Temporal Scales for Assessment

The North Coast Watershed Assessment Program develops measures of landscape change over time and links them to changes that have occurred in streams. Within this context the program looks at changes in watersheds during critical periods defined by major natural perturbations, changing levels and technologies of land use, and evolving government policies. Although natural processes have been at work shaping North Coast watersheds since they were formed millions of years ago, NCWAP focuses assessment on the past 150 years. This is because changes have intensified since about 1850 as a result of the interplay between natural factors and increasing human uses. While some processes work slowly over many years, others can reshape the environment radically during infrequent high-impact events. Recent history has shown that several key episodes have been especially important in reshaping watersheds. These punctuating phenomena include major floods, earthquakes and fires (e.g., the flood of 1955, the earthquake of 1906, etc.). While human activities can exacerbate their impacts, these events are precipitated by nature.

The past 150 years has also witnessed profound changes in human technology. The adoption of inventions in the late 1800s (such as the Dolbeer steam donkey), and the post-WW II use of crawler tractors for logging, greatly increased our efficiency at resource extraction. However, these innovations often resulted in accelerated rates of key watershed processes, particularly hillslope erosion and stream deposition, which have in turn adversely influenced stream turbidity, temperature, overbank flooding and fish habitat. More recent decades have seen the development of equipment and techniques that have tended to result in a lesser level of impact on watershed processes. The dates of major technology changes are milestones in the histories of North Coast watersheds, as they are often turning points in the rates of critical processes affecting stream structure and salmonid habitat.

Administrative policies of the government and of private companies have also affected watershed conditions. Changes in the statutes governing development, timber, and other land uses, large-scale changes in land tenure, and new management directives have affected trajectories in human alteration of the landscape. As an example, California’s 1973 Forest Practice Act significantly altered timber harvesting practices in North Coast watersheds. In addition, until the early 1990s stream structure was greatly affected in the region by government-sponsored programs to remove woody debris from stream channels. The dates associated with important managerial changes serve as critical points in understanding trends in the watersheds.

Importance of Interdisciplinary Analysis

NCWAP provides data and information by individual agencies that can be used alone, as well as interdisciplinary products that provide an integrated watershed perspective. The disciplinary analyses (described in Chapter 3) intentionally draw on existing data and use standard data collection methods, already familiar to the public and other agencies, to fill critical gaps. The interdisciplinary analyses utilize tools or approaches developed specifically for NCWAP.

Interdisciplinary analysis is conducted using the Ecosystem Management Decision System (EMDS), a model adapted by NCWAP staff in collaboration with consulting scientists. NCWAP also establishes a process for identifying refugia and conducting GIS-based analyses of interactions among land use activities, geology, sediment, and fish habitat. Each report contains various tabular presentations of spatial associations developed through GIS analysis. In addition, the Gualala assessment team developed a map showing adverse instream sediment accumulations, roads, geologic features, and limiting factors for fish.

Both disciplinary and interdisciplinary products are then considered by the team during the synthesis phase in order to answer questions and develop recommendations. Figure 4 provides a detailed explanation of the disciplinary analysis, interdisciplinary analysis, and synthesis phases.

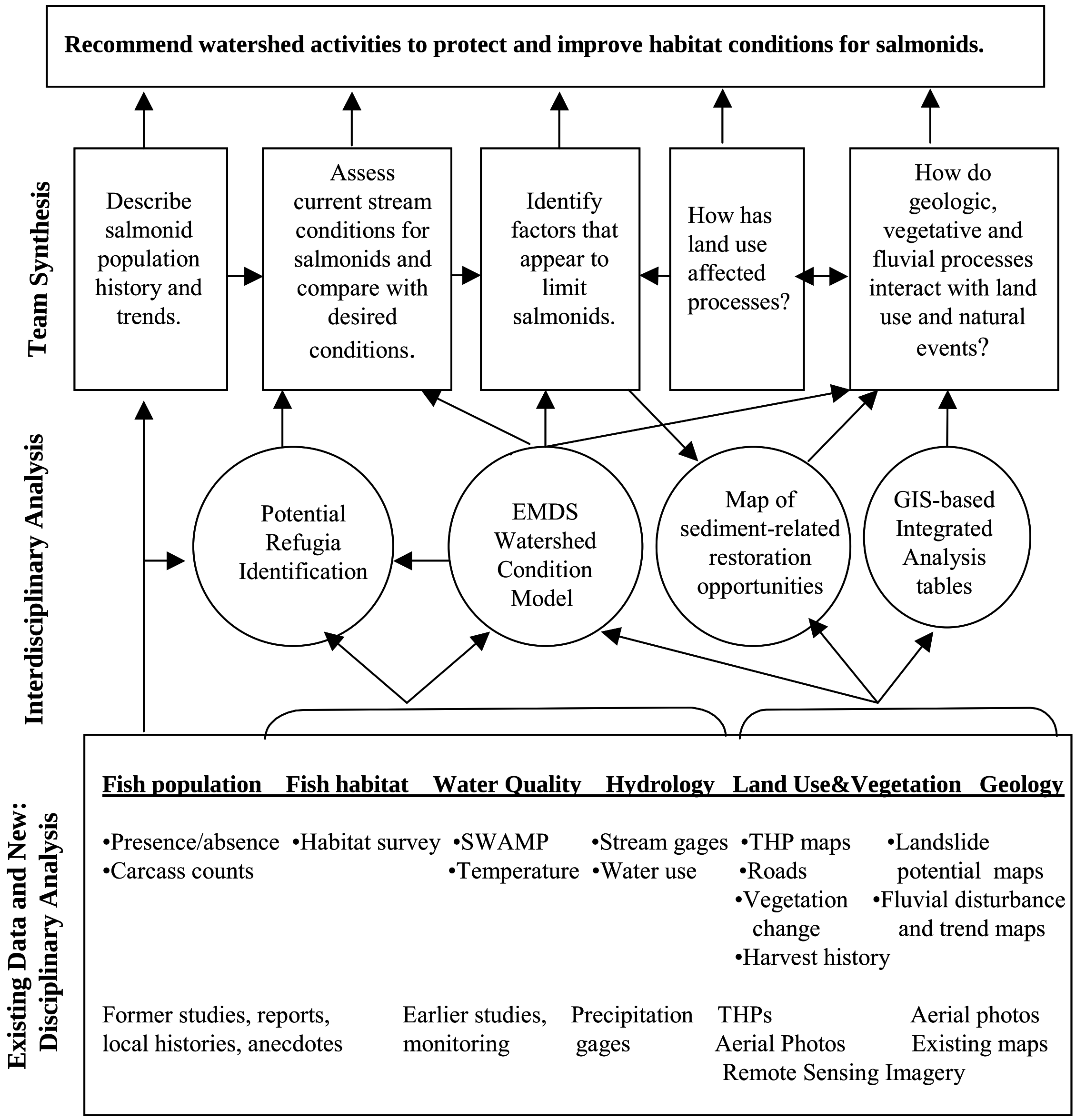


Figure 4. How NCWAP integrates disciplinary data to answer critical questions

2.3 NORTH COAST WATERSHED ASSESSMENT PROCESS

In order to answer the assessment questions above for a watershed, North Coast Watershed Assessment Program participants employ a six-step process for working with local stakeholders, the general public, the scientific community, and each other. The major opportunities for public input are during scoping, data compilation and review of the draft synthesis report, although stakeholders may also work with NCWAP to collect data and to review the NCWAP analysis of their data. Figure 5 depicts the steps taken by the assessment team.

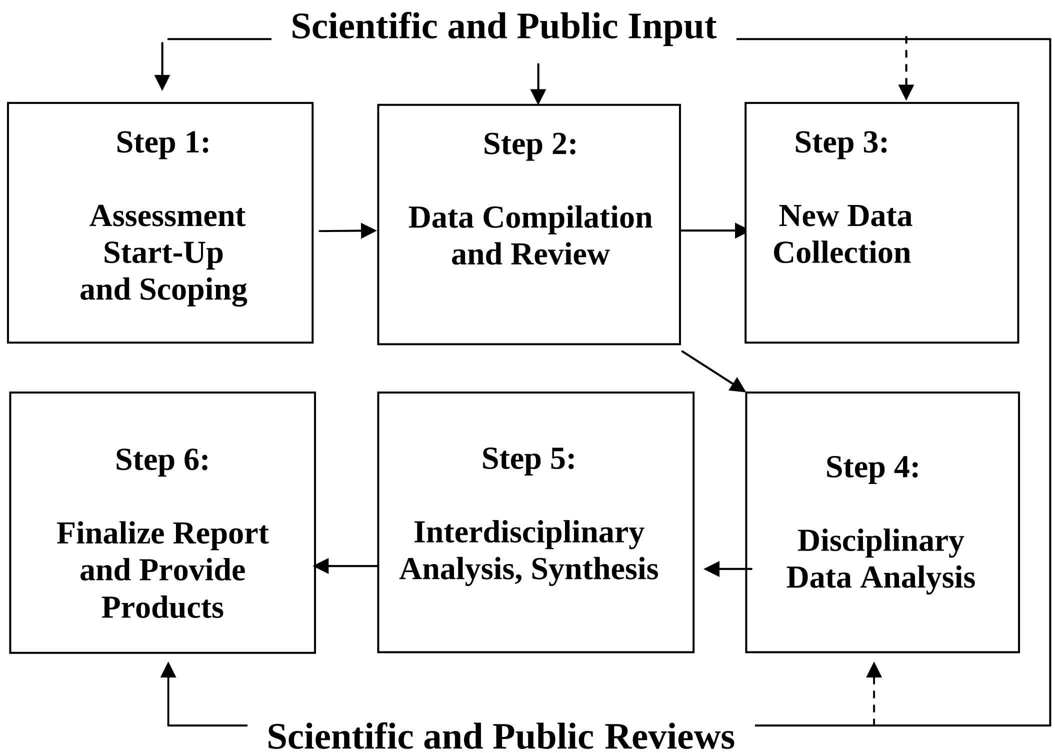


Figure 5. North Coast Watershed Assessment Program approach

Step One: Start-up and scoping.

- The team meets with stakeholders to explain program goals, objectives and critical questions, methodology, and products.
- The team asks stakeholders to identify local watershed concerns, assessment activities and interests, local data or information, and local sources of expertise.
- The team explores opportunities to work with local landowners and other groups to share information, collect new data, access private lands for field data, and review assessment products and drafts.
- The team establishes a means of communicating ongoing team activities.

Step Two: Data compilation and review.

- The team obtains information that may be useful for answering critical questions about current and past watershed uses, conditions, and processes. These include aerial photos, maps, surveys, reports, studies, Timber Harvest Plans, local and regional histories, and other information.
- Team members review and screen the information for use in the assessment according to a quality control processes described in Chapter 3.9.

- Team members describe the information considered in a data catalogue.

Step Three: New data collection.

- NCWAP agencies prioritize new data collection based on adequacy of existing information to answer critical questions.
- Agencies request permission from landowners to conduct fieldwork to fill critical data gaps, validate existing data, and/or verify imagery or photo-based analyses.
- Agencies collect new data or contract/cooperate with local groups or landowners to do so, using preferred data collection methods. They coordinate access among agencies whenever possible to minimize disturbance to landowners.

Step Four: Disciplinary data analysis.

- Individual departments analyze data specific to their discipline using standardized methods described or referenced in Chapter 3.
- Agencies develop products including summaries, maps, and charts to characterize watershed history, conditions and trends.
- The team shares this information to begin answering critical questions at the watershed scale.

Step Five: Interdisciplinary analysis and synthesis of Public Review Draft.

- The Watershed Assessment Team uses several GIS-based analyses, developed for NCWAP and described in Chapter 4, to integrate data from all disciplines.
- The team uses disciplinary findings, interdisciplinary analyses, and best professional judgment in a final synthesis process to answer critical questions and develop recommendations.
- Team members use a weight-of-evidence to document key findings about limiting factors and the processes and activities that contribute to them, treating them as "working hypotheses" to encourage monitoring and adaptive management.
- The team uses conclusions about limiting factors to help prioritize recommendations about management, restoration and monitoring.
- The team develops draft assessment report for public review.

Step Six: Finalize watershed assessment reports and products.

- The team conducts local workshops to explain and discuss draft synthesis report, and solicits comments from the public at large.
- The program conducts peer review of assessment.
- The team uses public and peer review comments to add information, improve analysis and discussions, and improve recommendations, as needed.

- The team finalizes synthesis report and all related data and products.
- Reports, maps and data are made available on-line at website (www.ncwatershed.ca.gov), on CD, and through KRIS tool.

Evaluating Watershed Recovery

The determination of a healthy watershed for salmon and steelhead populations is based upon the status of several habitat conditions that directly affect the fish, as well as an assessment of the watershed processes and their trends that affect those conditions. Further, the several variables must be considered in the aggregate to estimate "health" or "state of recovery" relative to management efforts.

That detection and evaluation of watershed condition recovery depends on the choice of endpoints, time frame, and geographic scale. While improvements in a condition or set of conditions may indicate progress toward better watershed health, the rate or achievement of recovery must be evaluated relative to desired endpoints. In the case of a "recovered watershed," the endpoint must be based upon an in-balance set of conditions and processes that are able to withstand perturbations without large fluctuations. These are difficult to define or evaluate at the large watershed scale (basin level).

These assessments focus primarily on watershed conditions and their suitability for supporting native salmon and steelhead, and consider instream condition indicators, such as water supply and quality, positive channel characteristics, and complex fish habitat elements as endpoints. Desirable conditions standards are based upon historic, supportive local conditions, peer reviewed literature, DFG manuals, and / or the NCRWQCB's Basin Plans. Upslope conditions and erosion processes, ranked by our erosion potential EMDS model, are also considered. These are combined through the Integrated Analysis process. However, changes in these criteria have to be compared and considered within the context and time frames of other watershed processes, such as hydrologic cycles, fluvial processes, and fish population biology, as well as ocean conditions, which are subject to broad fluctuations and even long-term cycles.

It is difficult, therefore, to declare basin recovery status based on a single criterion, or even several of them. Thus, in these large-scale watershed assessments, we do not draw conclusions about basin level recovery status, although we may discuss trends toward, or away from recovery of various conditions, such as vegetation canopy or channel sediment features, relative to a given benchmark. For example, the Gualala assessment discusses stream canopy status relative to 1942 conditions, and the Mattole report discusses trends in channel characteristics from 1984 to 2000. Hence, the individual assessment reports discuss these factors and others as indicators of relative recovery, estimating percent change in disturbance features over one or more decades, but do not make conclusions about overall basin recovery status other than inferences that can be drawn relative to one another.

CHAPTER 3: DATA COLLECTION AND ANALYSIS

This chapter presents key components of the technical core of the watershed assessment work to be performed by the North Coast Watershed Assessment Program. The data collection and analysis procedures discussed here respond to the critical questions presented in Chapter 2 and provide the information and analytical basis needed to conduct the limiting factors analysis and produce the synthesis report described in the previous chapter.

The chapter describes data needs, collection methods, and analysis by the following disciplines or topics: geology and landslides, vegetation and land use, fluvial sediment production and transport, riparian conditions, water quality, hydrology and water quantity, fish habitat, and fish history and status.

While these sections are presented individually for clarity of discussion, NCWAP recognizes that there is significant overlap. Therefore, the NCWAP technical team uses methods acceptable to all members and determines primary leaders for specific data. When employing more than one agency to collect data useful for a basin, staff is jointly trained to ensure consistency. While this chapter describes core data collection and assessment activities, basin assessment teams may collect additional data by working with local efforts or leveraging resources through other programs. Those efforts will also be conducted using existing methods and protocols whenever possible.

North Coast Watershed Assessment Program team members also work in a collaborative, interagency fashion to analyze data and to complete the assessment. Chapter 4 discusses how different areas of assessment are integrated through the limiting factors analysis process.

The latter part of this chapter discusses quality control and assurance issues for data. This is important because NCWAP relies on various types of watershed data for its work. Therefore, it includes an explanation of the quality control and assurance procedures used by NCWAP for existing information and for GIS and field data.

3.1 GEOLOGY AND LANDSLIDE POTENTIAL

The California Geological Survey provides baseline, regional-scale geologic and geomorphic information, and geologic expertise to interpret the relationships between the dynamics of landsliding, sediment transport into and through stream channels, and potential impacts to fish habitat. Sediment sources include surface erosion (splash, sheet, rill, and gully erosion) and mass wasting (landslides, soil creep, and debris flows). These erosion processes are often interrelated. For example, earth materials displaced by mass wasting processes such as landslides are often modified and reworked by surface erosion. Sediment produced by these processes may be deposited directly into a stream through bank slumping, or may be transported to a stream by mechanisms such as surface runoff or debris flow torrents.

Geology, seismicity, topography, and climate combine to influence erosion rates and mass wasting in Northern California. Natural factors affecting sediment production and transport include: bedrock type, strength of the bedrock, degree of disruption by mass wasting and/or faulting, soil composition (depth, permeability, cohesion, and structure), slope steepness and length, aspect, ground water levels, amount and type of vegetation on the slopes, recent and current rainfall intensity and duration, and fire.

Geologically unstable areas are more likely to produce sediment. Therefore the spatial and temporal distribution of landslides provide a conceptual framework to better understand how natural phenomena and land use practices may interact to impact slope stability and sediment production.

Land use practices can increase slope failure, alter fluvial processes, and produce sediment. Human related factors include vegetation removal (livestock grazing, agricultural clearing, development, or timber harvesting), surface disturbance and modification (road construction and drainage, ground-based timber operations, and watercourse diversions.)

Studies have suggested that the majority of erosion from management related activities occur in a small portion of the total managed area (Rice and Lewis 1991). Road-related sediment is a major factor in most North Coast watersheds because most forest and range roads are not paved or hard-surfaced. The location of roads on slopes (near stream, mid-slope, and ridge top) affects road stability, drainage and sediment yield (Cafferata and Spittler 1998, Jones et al. 2000).

Approach

Mapping and data collection in each watershed is separated into a landslide component and a stream channel component. Given the relationship between hillslope and fluvial sediment processes, the two components are evaluated concurrently and interactively. Data and maps generated are used in the assessment of streams and fish habitat.

The landslide component of this assessment includes two basic products: 1) a geologic and geomorphic features map which includes landslides and other features related to slope stability; and 2) a Relative Landslide Potential map which integrates geologic and slope data in conjunction with landslides and other geomorphic features affecting slope stability.

Questions and Issues

Existing data, newly collected data, and field observations are used to assess the following:

Existing Conditions:

- What is the spatial distribution of landslides in each watershed?
- What are the dominant landslide features in each watershed?
- What are the primary geologic controls on landslides?
- Which geologic formations or groups of formations are susceptible to various types of landsliding?
- What areas are most (and/or least) susceptible to landsliding and associated sediment production?

Ancillary information:

- What are the dates of past significant earthquake and meteorological events?
- What flood events are recorded by stream gauges or otherwise?
- What is the spatial relationship between land use practices and mass wasting?

System Response:

- Historically, how have hillsides responded to natural and anthropogenic perturbations?
- What are the likely responses of hillsides to potential changes in existing conditions such as runoff, vegetation, and land use?
- Where is sediment delivery to streams from landslides and other geomorphic features observed?

Data Sources and Gaps

Readily available geologic maps and literature pertinent to a watershed are reviewed early in the assessment process. The majority of the geologic and geomorphologic interpretations are through the examination of one or more sets of stereo-paired aerial photographs. Photographic coverage available for various portions of North Coast watersheds consists of about a dozen sets of photographs, from the early-mid 1940s until the most recent taken in 2000. However, individual watersheds often have only a few sets of complete coverage, and some of the sets (i.e., 1940s) may be extremely difficult to obtain. Data derived from the California Geological Survey review of the available aerial photos are incorporated and stored in GIS.

Limited fieldwork is conducted to verify mapping derived from aerial photographs. CGS fieldwork is focused on confirming features observed on the aerial photographs and investigating features of uncertain origin in the upland areas as well as lower stream reaches.

Slope stability and stream channel characteristics are related to fish habitat quality and habitat forming processes, and the link between hillslope and stream processes is evaluated.

Data Collection

The landslide-mapping component builds upon and updates landslide mapping conducted by the Department of Mines and Geology (DMG) in the early to mid-1980s. Mapping is performed at a reconnaissance scale of 1:24,000 with more detailed assessment conducted at key locations for calibration and quality control purposes. CGS interprets aerial photographs for large-scale (greater than 1/5 acre) landslide and geomorphic features that affect sediment generation, transport, and deposition.

Multiple sets of aerial photos are used to allow detection of changes over time and observation of multiple features. Cruden and Varnes (1996) describe the typical morphology of various landslides, while Keaton and Degraff (1996) provide a scheme to understand the relative degree of activity of the landslide. Geomorphic features related to landsliding are also important to note as these features (inner gorges, debris slide slopes and disrupted ground) indicate an increased probability of sediment production within the watershed (California Department of Conservation 1997).

Once a set of aerial photos has been interpreted and draft landslide, geology, and fluvial geomorphology maps have been created, limited field inspections are conducted. Field studies are conducted to confirm aerial photograph interpretation and mapping and to improve the development and analysis of hillside and channel data. The accuracy of data (i.e., maps, GIS layers) borrowed from other sources is also reviewed in the field. Several factors including resources, access, weather conditions, and mapping scale affect the amount of field verification. In general on watershed scale projects, CGS tries to incorporate approximately two weeks of field time per 7.5-minute quadrangle.

A variety of physical, temporal, and spatial data are collected for each feature of interest and entered into the digital layer. For example, the data for specific landslides includes such items as type, relative age, approximate depth and whether it appeared to have delivered sediment to the stream.

Data Analysis

CGS conducted new mapping for NCWAP Arcview and ArcInfo™ platforms in a GIS. The process of superimposing maps of various terrain information helps identify those relationships otherwise difficult to recognize landslide layers are overlain on slope maps, various geology, soils, orthophotoquarter-quadrangles, and topographic maps. GIS can also be used to generate stream profiles, drainage network diagrams, slope maps, and landslide potential models.

Geologic and Geomorphic Features Map

Landslide type, other geomorphic features, landslide activity classes, and other attributes are mapped. Mapped features include rockslides, earthflows, debris slides, debris flows, torrent tracks, small landslides too small to delineate at 1:24,000 scale, disrupted ground, debris slide, slope, inner gorge and gullies. The landslide features are also categorized as historically active or dormant based on features seen in the aerial photos and/or field reconnaissance. Complete descriptions and symbols used are included in the CGS *Manual for Regional or Watershed Scale Mapping of Landslide and Fluvial Geomorphic Conditions* located on the CGS website, http://www.consrv.ca.gov/cgs/ncwap/index.htm. Figure 6 is an example of a landslide map from the Gualala report.

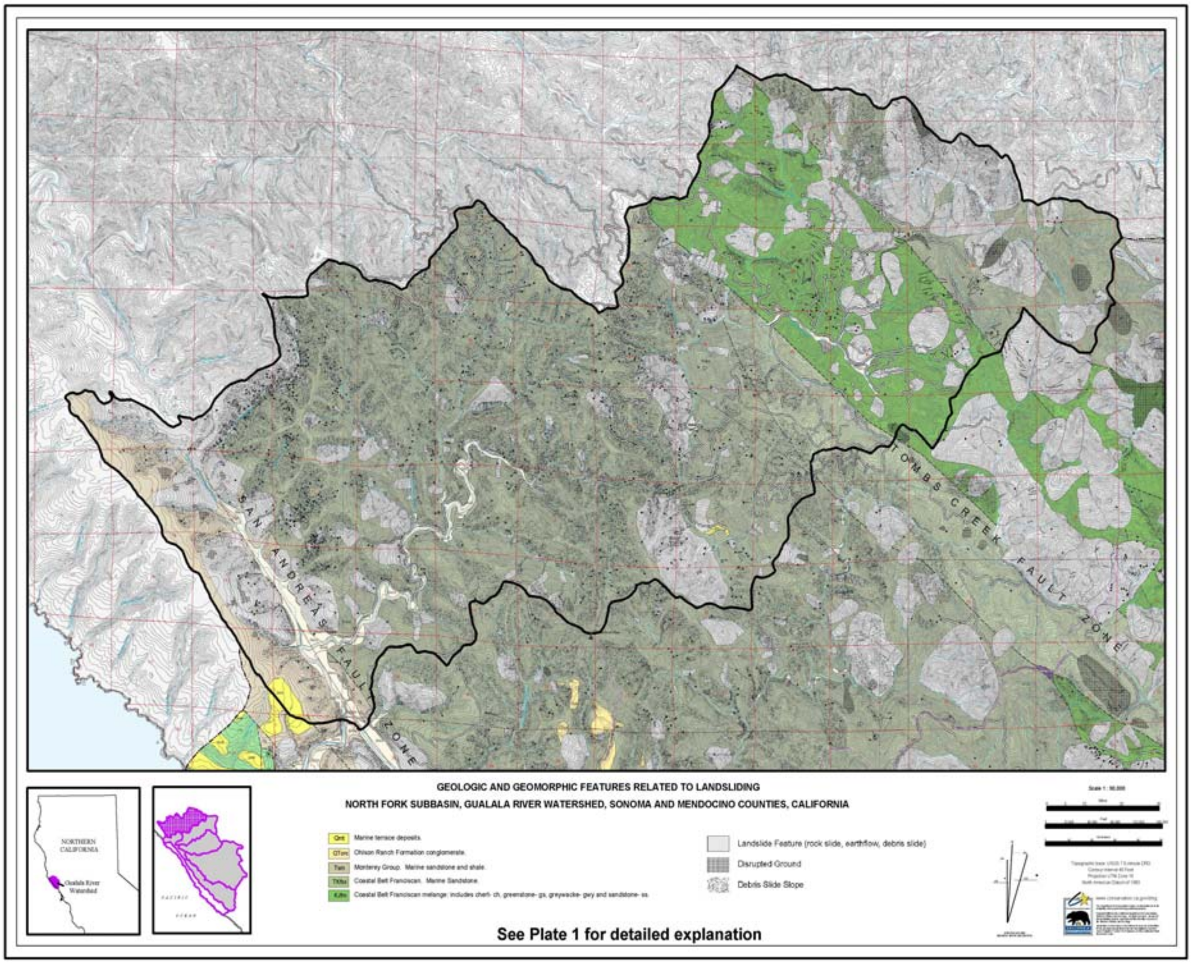


Figure 6. Geologic and geomorphic features related to landsliding, North Fork Subbasin, Gualala Watershed, Sonoma and Mendocino counties

Features affecting landslide potential (including landslide type, active or dormant, geologic material, slope, etc.) are combined using a matrix developed by the California Geological Survey to assess relative landsliding potential. The GIS layer is also used to combine complex geologic relationships into a more simplified system based on inherent strength and susceptibility to landsliding (and therefore sediment production). It is also then used to examine the relationships between landsliding and fluvial features indicative of sediment production, transport and/or deposition. The California Geological Survey's *Regional and Watershed Landslide and Stream Channel Mapping Methods Manual* located on the CGS website, http://www.consrv.ca.gov/CGS provides a more detailed discussion of the procedures followed to assess sediment production and transport.

Relative Landslide Potential Maps

Once relevant relationships between geology and landsliding are recognized, a landslide potential map is created in GIS. The landslide potential map is compared with the slope maps, landslide density thematic map, and other available slope models for important variations. Any important variations are interpreted and classified. The relative landslide potential is divided into five categories from 1 (most stable) to 5 (least stable). Additional modifiers, which supplement the primary definitions, are added as relevant.

The assignment of the categories is an interpretative process and based on relations drawn from the Landslide and Geomorphic Features Related to Landsliding map, statistical analysis, and general field observations. The five categories of relative landslide potential are as follows:

1. ***Very Low Landslide Potential.*** Landslides and other features related to slope instability are very rare to non-existent within this area.

2. ***Low Landslide Potential.*** This area includes gentle to moderate slopes underlain by relatively competent material that is considered unlikely to mobilize under natural conditions. Landsliding in these areas is not common.

3. ***Moderate Landslide Potential***. Moderate to moderately steep, relatively uniform slopes that are generally underlain by competent bedrock, may also include older dormant landslides. Some slopes within this area may be at or near their stability limits due to weaker materials, steeper slopes, or combination of these factors.

4. ***High Landslide Potential***. This area is characterized by moderately steep to steep slopes that include many dormant landslides in upslope areas and slopes upon which there is substantial evidence of downslope creep of surface materials.

5. ***Very High Landslide Potential***. Areas include historically active landslides and inner gorges, as well as areas of debris slide/flow source areas on steep to very steep slopes and areas of "disrupted ground".

Additional descriptors can be added to the above categories. Figure 7 is an example of a Landslide Potential map from the North Fork Gualala River Subbasin.

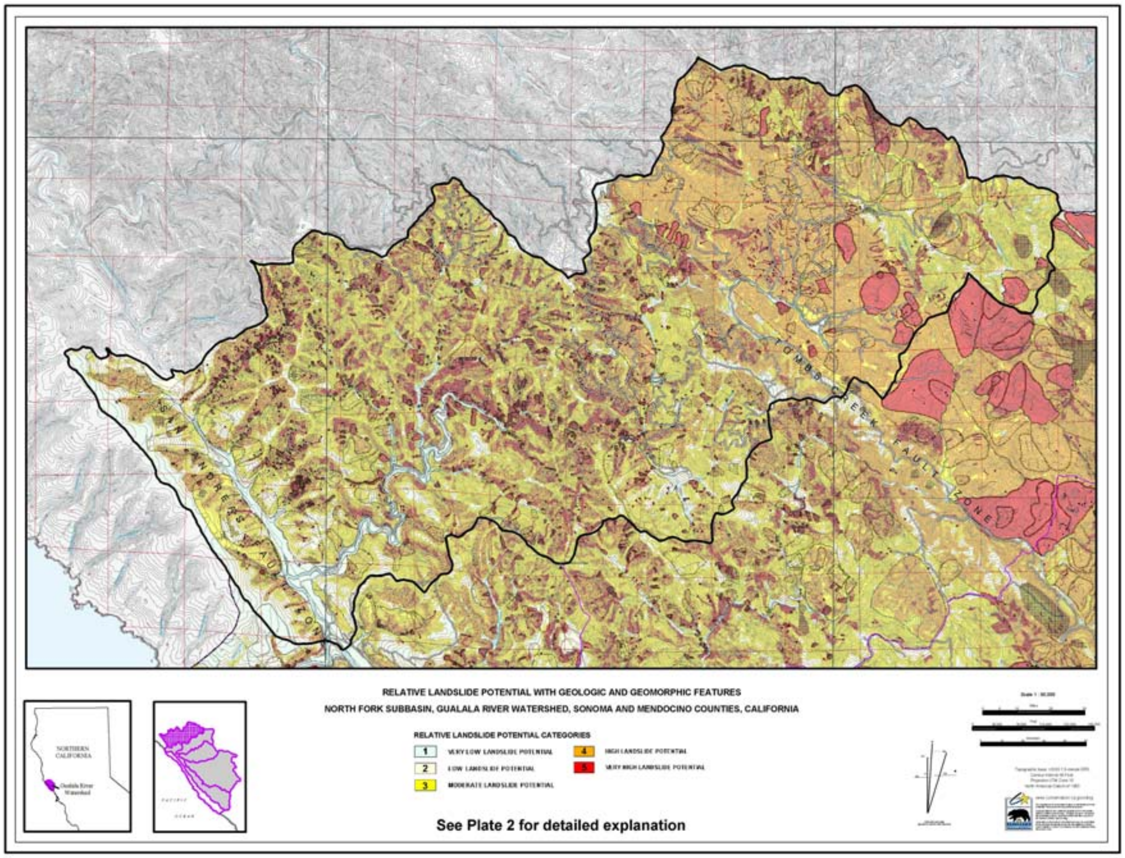


Figure 7. Relative landslide potential with geologic and geomorphic features. North Fork Gualala River Subbasin

Limitations

There are limitations in aerial photograph coverage and some scale constraints. Vegetation cover, soil moisture, sun angle, photo scale and quality change with each set of photos. Depending on numerous factors, interpretation of a given set of photographs may fail to reveal mappable landslides that are ambiguous, more recent than the photos, or hidden beneath heavy forest. This underscores the necessity to interpret multiple sets of photos. Field review therefore greatly enhances mapping.

Mapping at a scale of 1:24,000 may not allow full identification of features smaller than 30 meters in greatest dimension. Vegetation cover impairs mapping of these small features from aerial photographs. Limited aerial photo coverage may not occur before and after important watershed events such as major floods, and the effects of such events may not be fully evident in photos taken years later.

The amount of field verification of features is directly related to the accuracy of the mapping. Limited field verification results in lower confidence in mapped features that appear questionable or are not observable in aerial photographs. As a ground rule, CGS tries to spend approximately two weeks field checking per 7.5- minute quadrangle. In some cases, field checking is limited.

In addition to the interpretation issues above, it is initially assumed that ten-meter resolution digital elevation models closely match actual topography. That may not prove to be true. The landslide potential map is a derivative map and therefore includes all the limitations of the several maps from which it was derived, including the spatial averages of the digital elevation model and the assumption that existing geologic maps are relatively close to actual geologic conditions.

3.2 VEGETATION AND LAND USE ANALYSIS

The Department of Forestry and Fire Protection (CDF) leads the assessment of vegetation and land use for NCWAP. Staff conducting the assessment includes Registered Professional Foresters with significant field experience.

Over the past two centuries, cumulative impacts from human land use activities coupled with natural events have caused significant impacts on floodplain and stream conditions. These impacts influence the ability of streams to support salmonid populations. Recent efforts to improve land use practices and stream habitat conditions are key elements in the recovery of salmonid populations.

A broad array of upland conditions influence watershed processes with numerous interactions over space and time among natural and anthropogenic processes. Reconstructing the European-American history of land use and resource extraction is important to understanding current conditions of North Coast watersheds. While it is not possible to determine strict causality between historic land use and current watershed conditions, assessment can assist in relating stream and salmonid problems to their probable causes, both in type (natural vs. human, relative magnitude) and timing.

Identifying high-impact natural historical events such as major floods, fires and earthquakes, as well as coincident land use activities, helps define the necessary timeframe for examining trends in stream and upland conditions. Of special importance to the North Coast Watershed Assessment Program is documenting historical human activities that are typically known to have high impacts on watersheds. These activities may have large effects either because of the type of disturbance, location (e.g., proximity to stream), the size of the area disturbed, coincidence with natural process drivers such as flooding, or some combination thereof.

Taken together, the above factors can provide an index of watershed disturbance over time and context for understanding the state of the watershed today. In addition to supporting an overall watershed assessment, such an index is useful for future work by the California Department of Forestry and Fire Protection (CDF) to develop risk assessment approaches to cumulative effects analysis.

Approach

Using a variety of data sources, quantitative and qualitative timelines of important historical events and land use trends are established for each watershed. To the extent possible, data are spatially explicit (i.e., points and areas geo-referenced) and digitized to allow assessment within a geographic information system (GIS). The assessment focus includes several key factors in the watershed, such as the timing, locations and extent of: 1) major timber harvesting, as well as predominant silvicultural and yarding practices; 2) land use and conversions related to agricultural practices (row crops, vineyards, grazing, etc.) and development of towns; and 3) roads and other development in the watershed.

The approach uses existing digital data and develops new digital data to the greatest extent possible within each study basin. This approach provides for spatially located, quantifiable data that can be summarized in individual topics and integrated into the Ecological Management Decision Support system (EMDS), limiting factors assessment, and other synthesis efforts.

The most complete and readily available information available for watershed assessment is based on current conditions. Watershed and planning watershed scale information available in digital form includes CalVeg2000, 1:24,000 scale stream and roads layers, 10-meter digital elevation model, topographic maps and ortho-photographic quadrangles. General landownership pattern information and wildfire history are available. Many of the North Coast watersheds have GIS-based timber harvest plan information.

Other sources of digital information are evaluated and incorporated into data sets as appropriate. These additional data sets include county parcel maps, roads layers developed by landowners for resource management purposes or as part of restoration grant products, and digital information developed as part of historical or scientific research.

New digital data development by the California Department of Forestry and Fire Protection emphasizes acquisition of data on land use activities, particularly timber harvest and roads from aerial photos and timber harvesting plans.

Questions And Issues

Information on land use history on the North Coast is collected to answer a number of disciplinary and interdisciplinary questions:

Disciplinary

- What has been the history of land use on the watershed?
- What are current vegetation types and structures (e.g., tree diameter and canopy closure) on the watershed in general and along streams in particular?
- What are the locations and conditions of roads on the watershed?

Interdisciplinary

- What are the general relationships between historic land use, its changes over time, and the current condition of a given watershed?
- What do the relationships among land use, vegetation, and watershed processes indicate about cumulative watershed effects on salmonids and their habitat?
- Is there a relationship between natural stressing events such as major floods and land uses in terms of watershed effects?

Data Sources And Gaps

Data sources include photographic records, current and historic maps, published and unpublished reports by both agencies and landowners, digitized timber harvest plans (THPs) and other digitized data, satellite images, literature sources, and personal interviews. The type of data used within a given watershed depends largely on availability and extent. Researching, locating and accessing (and in some cases reproducing) the data takes considerable effort.

Historic written accounts related to salmonids (runs, harvest, etc.), major flood events and other watershed-related phenomena have been collected from local sources for some North Coast watersheds. While descriptive in nature, these are often the only information available for the earliest period of post-European-American colonization. They have proven valuable in indicating a watershed's character before the major alteration of stream characteristics associated with subsequent dam construction and channelization, intensive agriculture, development and resource extraction activities.

Oral accounts may be obtained from interviews with persons knowledgeable about the watershed and its history. Input from local watershed councils is also important. As with many written accounts, the information is anecdotal and qualitative in nature, and varies between individuals interviewed. However, such information helps to focus research on a previously overlooked events or activities in the watershed.

Historic maps, public land survey data, tax ledgers, and other systematically recorded data also serve to recreate land use scenarios from past decades (Sisk 1998). While precise locations and areas might be difficult to determine, these records help provide information on the relative magnitudes of various activities in the watershed.

Photographic evidence, including historic photos from the ground and aerial photographs taken from aircraft, is some of the most useful information available to establish prior watershed conditions and human activities. The ground photograph record can in some cases extend nearly to the beginning of the period of European-American colonization, circa 1850. Aerial photographs extend into the 1930s, limiting their use to the past 70 or so years. These are not available for all watersheds. With time series photos of the same area, the timing of important changes in the watershed can be observed to yield insight into the relationship between land use activities, major natural events (e.g., floods, earthquakes), and apparent stream structure and processes (e.g., Gruell 1983).

Digital data layers are available from a variety of sources. Government agencies have developed many state and county-wide coverages. Many landowners, both government and private, have developed digital data for their management needs. Landowner response to requests for electronic data is generally positive.

The earth resources (LANDSAT) satellite data record begins in the early 1970s. Through digital image processing change detection techniques, the approximate timing and areal extent of higher impact land use changes, as well as recovery rates, can be quantified for all North Coast watersheds (Sample 1994).

Little information is available on the type and prevalence of non-permitted activities. For example, livestock numbers are reported on a by-county basis. Residential or ranch road construction, use, current condition and upgrading have recently become subject to some oversight by counties that have grading ordinances, but baseline data is limited. Even with existing data sets, information, though adequate for its original purposes, may not be sufficient to answer the questions posed by the assessment.

Data Collection

Researching the existence and whereabouts of historical data requires significant effort. Some of the data needed for the land use analysis are readily available e.g., LANDSAT images, while other data are located in public agency files, private and corporate ownership files, museums and university collections.

For each land use history polygon digitized into a geographic information system, the set of attributes entered includes:

- Approximate date of activity (if episodic)
- Areal extent (i.e., how many acres were in this land use? Implicit in GIS polygon)
- Type of activity (cropland, grazing, timber harvest, building development, existing or new road)
- Degree of impact (i.e., how impacting is this practice?)
- Permanency of the conversion (e.g., temporary timber harvest vs. permanent conversion to pasture land)
- Observable proximate impacts that may be ascribed to particular area of given land use
- Source of data
- Level of observer confidence in determining process at work

Roads are important in watershed assessments. Roads are a special case of land use since they are linear features that remain on the landscape indefinitely. Additional roads information is captured in a parallel effort to the polygon-based land use history data. GIS attributes for the roads coverages include the following:

- Type (skid trail, haul roads, dirt, two-lane, county road, state highway, etc.)
- Surface
- Road width
- Date or era of construction (if known)
- Apparent road condition (state of repair/disrepair from aerial photos)
- Apparent stream crossings (type, if discernible)

Data Analysis

Land Use

The data compiled for historical land use is used to reconstruct terrestrial watershed conditions over the past 150 years. For the period predating aerial photography (before 1940), other records are synthesized into a historical narrative. The narrative includes major disturbance events such as floods and fires and their effects, episodes of land clearing, timber harvesting, road building, and other eras of land ownership and management practices. This information is presented along with other relevant data, such as the status of the local fisheries at the time and any changes in laws governing resource extraction practices. Table 1 provides an example of how historic timber harvest data were summarized for the Albion River watershed.

Table 2 shows historic harvests by three classes that indicate different levels of inferred disturbance (Category 1 = highest disturbance, Category 3 = lowest) associated with the silvicultural systems applied.

Table 1. Summary of historic timber harvest on the Albion River Watershed

TIMBER HARVEST HISTORY - ENTIRE WATERSHED			
	Total Acres	Percent of Watershed	Percent Watershed Cut Annually
Harvested ~1930 - 1936	149	< 1	<1
Harvested 1937 - 1952	2023	7	<1
Harvested 1953 - 1963	1236	4.5	<1
Harvested 1964-1972	2223	8	1
Harvested 1973-1987	4760	17	1.2
Harvested 1986 – 1989, THP data	1,928	7	1.8
Harvested 1990 – 1999, THP data	10,392	38	3.8
Harvested 2000 – 2002, THP data	4,450	16	5.4
Not Harvested:			
Approved THPs, THP data	3,793	14	Not applicable
Non-commercial vegetation & parkland (grass, brush, etc.)	3,500	13	Not applicable

Table 2. Timber harvest by silvicultural system and yarding, Albion River Watershed

Harvesting Categories - Albion Watershed (27,511 acres)					
Harvest time period	Category 1 (acres) Includes clear-cut and seed tree seed step	Category 2 (acres) Includes shelterwood prep / removal step, and alternative prescriptions	Category 3 (acres) Includes selection and commercial thin	Total harvest by time period	Percentage Cable or helicopter-yarded
1973-1987	596	1,004	3,159	4,759	29%
1987-1989	521	1,132	273	1,926	49%

Harvesting Categories - Albion Watershed (27,511 acres)					
1990-1999	1,307	4,263	4,744	10,314	43%
2000-2002	309	783	3,288	4,380	40%
Open 2002	0	403	3,048	3,451	36%
Total by System	2,733	7,585	14,512		

For the period from 1940 to the present, data on the percentage of the landscape impacted by various types of land use and management, density of roads, and locations of past fires is compiled using Calwater planning watersheds. These data are distilled from existing and GIS data layers created using sequential aerial photographs and satellite images, timber harvest plan maps, and other spatial data sources. These data show larger area and higher impact changes in the watershed.

Since land ownership can have significant implications for land use (e.g., small land owners are generally less aggressive timber managers than industrial owners), land ownership is captured from existing GIS coverages and county parcel data. Figure 8 provides an example of landownership display for the Albion watershed.

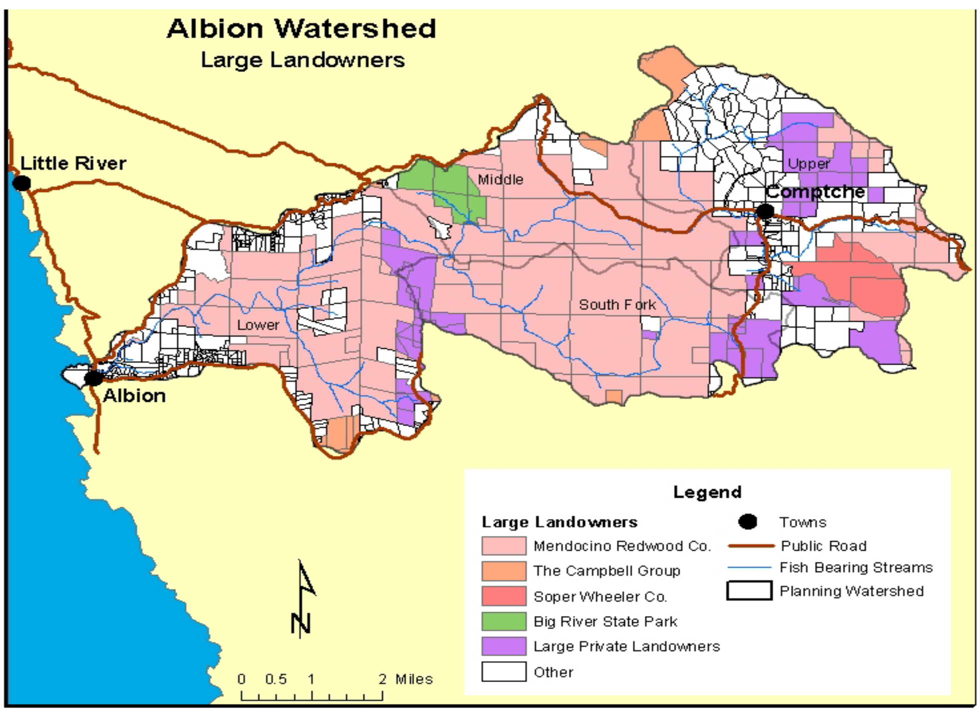


Figure 8. Land ownership on the Albion River Watershed

Vegetation

For an entire watershed, a first approximation of current conditions is made using existing vegetation maps and digital spatial data (CalVeg2000). Maps from the USDA Forest Service and the California Department of Forestry and Fire Protection include the following attributes derived from LANDSAT imagery: species, canopy cover, and tree size. These data represent forest condition as of 1998. Vegetation data are used to infer broad seral stage classes, based on species, size, and canopy cover for both upland and riparian vegetation. The data are not specific enough to describe micro-sites such as the species composition of the canopy directly impinging on streams, but can be used as one criterion for considering future large woody debris recruitment and stream shading potential.

Table 3 provides an example of how vegetation data can be presented in a tabular format. Figure 9 shows this information in a graphical presentation.

Table 3. Albion River Watershed Vegetation by Cover Type

Vegetation Type-Entire Albion Watershed		
	Total Acreage	Percent of Total Area (%)
Conifer	16,137	59
Mixed Forest	8,152	30
Herbaceous	1,614	6
Hardwood	1,215	4
Shrub	147	1
Barren	81	<1
Agricultural	27	<1
Urban	12	<1
Water	117	<1

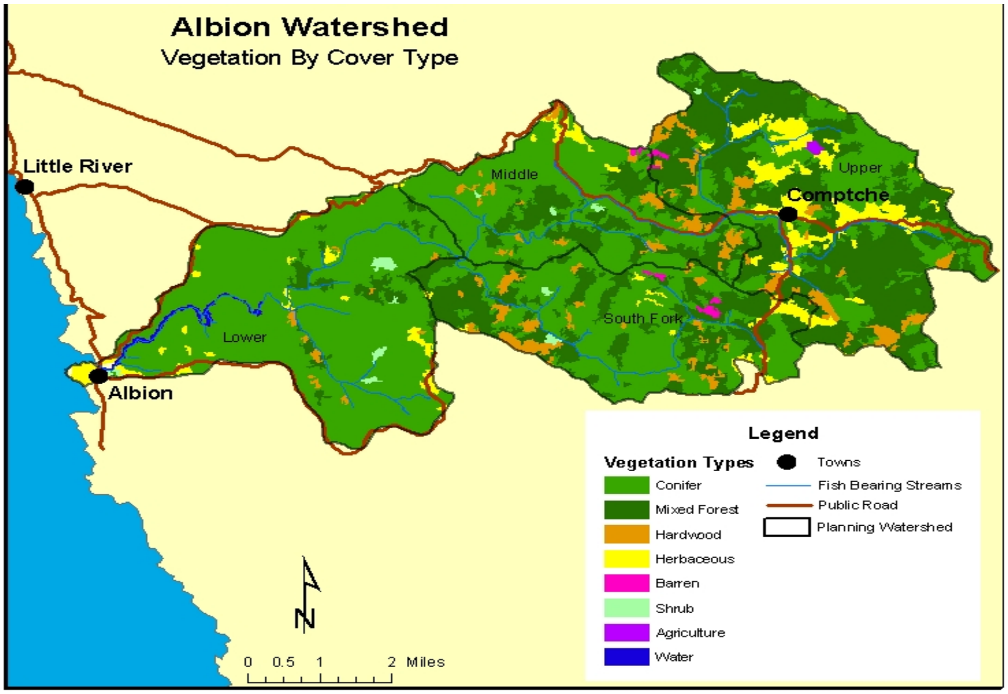


Figure 9. Vegetation by cover type, Albion Watershed

CDF's Fire and Resource Assessment Program (FRAP) has a standard business process for using vegetation data in GIS in conjunction with fuels and fire behavior models to generate a fire hazard map. This information is developed for each NCWAP watershed (see Figure 10).

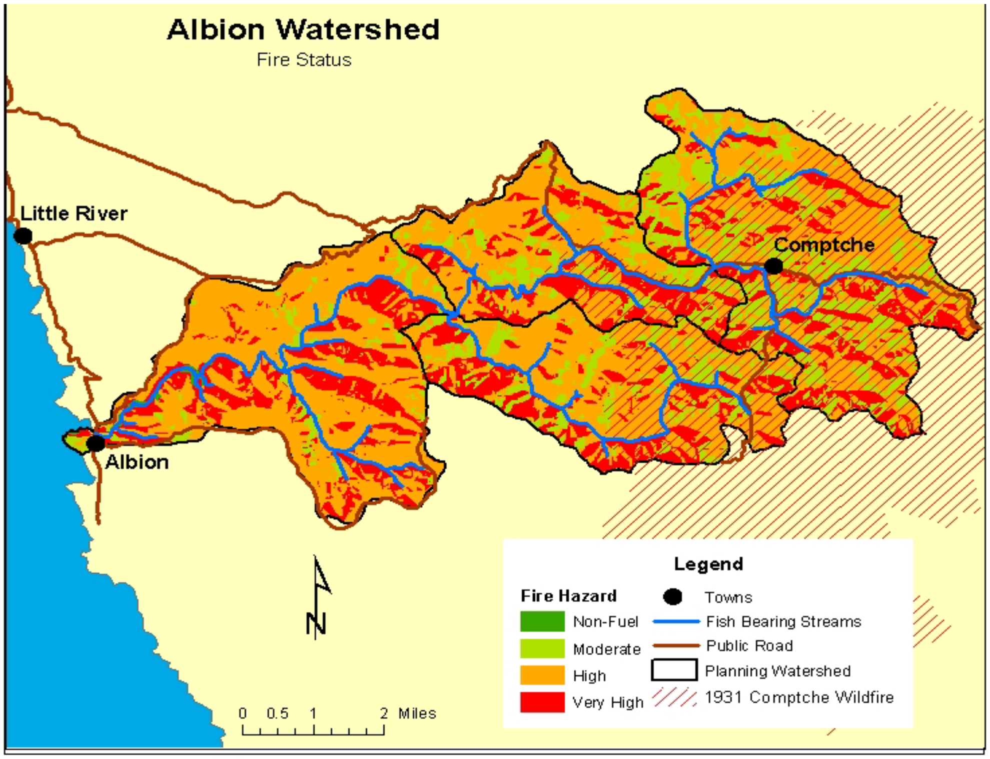


Figure 10. Fire hazard map for Albion River Watershed

Roads and Streams

The position of a road in a watershed (i.e., near stream, mid-slope, ridge top) and style of construction (outsloping, use of rolling dips, back-up drainage structures) can determine the extent to which the road network modifies the existing hydrologic network. The relationships between roads and streams are analyzed using a combination of spatially explicit models and metrics derived through GIS. Simple GIS analyses are run to estimate numbers of road stream crossings, miles of roads in close proximity to streams, and other areas of disturbance in proximity to streams. GIS analyses are run to estimate the relationship between roads, location on slope, and location on areas of low to very high relative landslide potential (developed by the California Geologic Survey).

Figure 11 and Table 4 provide examples of summary roads information from the Albion watershed.

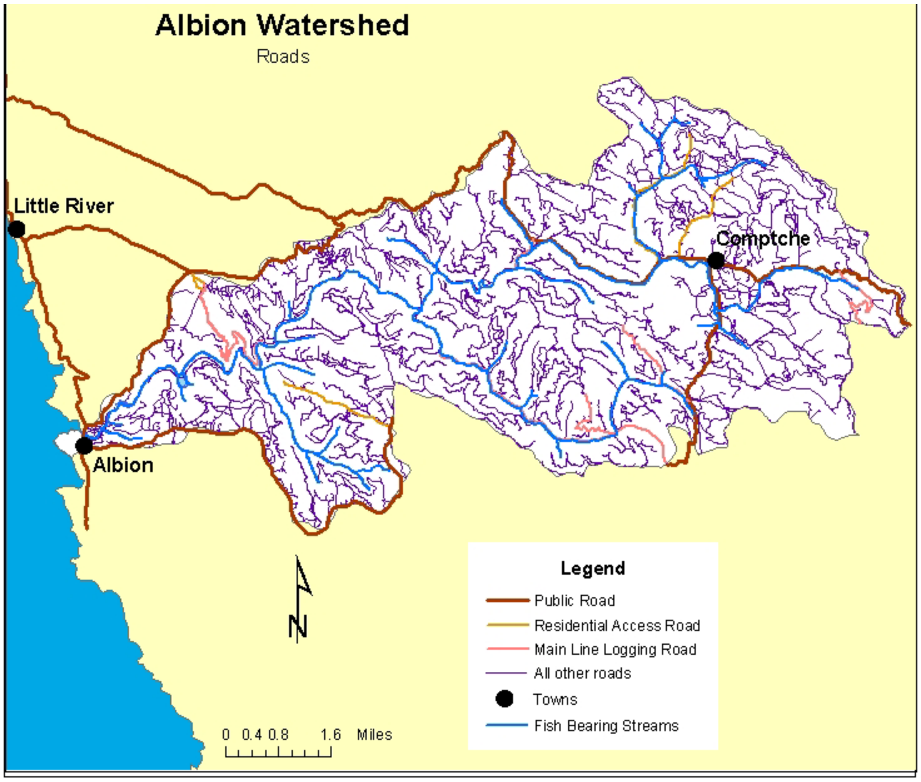


Figure 11. Roads by type class in the Albion River Watershed.

Table 4. Summary roads information for the Albion River Watershed

Roads			
	Miles (of road)	**Square miles (of land)**	**Road Density (miles per sq. mile)**
Albion Watershed	396	42.98	9.2
Lower Albion PWS:	123	12.61	9.8
Middle Albion PWS:	62	7.62	8.1
South Fork Albion PWS:	83	9.11	9.1
Upper Albion PWS:	128	13.64	9.4

Limitations

Watershed level data may be general and often are not site-specific. For example, existing roads information generally contains only the main roads currently used and often does not indicate road surfacing, construction type, or road width. CalVeg2000 data are derived from satellite remote sensing with a minimum mapping size of 2 ½ acres, which limits its usefulness for describing riparian vegetation in small order streams. The large size of the watersheds, varied ownership, and limited staff time do not allow for a systematic sampling design to validate the completeness, accuracy, or precision of existing data sets.

Robust historical analysis of any process is difficult and prone to the vagaries of existing and accessible data. The highest quality land use data is sought. But since it is difficult to attain the necessary level of information to support quantitative analyses of cause and effect within a watershed, results must of necessity be qualitative. The central challenge of the assessment's land use change characterization is to document and present the best evidence of the timing and magnitudes of human activities in the watershed and to provide historical context for other aspects of the assessments. The benefits in this regard should far outweigh the qualifications and limitations.

The same level of data is not available for all assessment areas. The use of different qualities and quantities of data limits the direct comparison of the assessment results from one watershed to another.

3.3 FLUVIAL SEDIMENT MAPPING/SEDIMENT PRODUCTION AND TRANSPORT

The California Geological Survey provides an analysis of sediment related fluvial features in order to assess stream conditions for fish habitat and to evaluate potential recovery. Fluvial geomorphic features recorded during the assessment are indicative of sediment production, load, transport and/or deposition. Given the relationship between unstable hillslope and fluvial sediment processes, the two components are mapped concurrently and interactively during the NCWAP process. Detailed descriptions are provided in Appendix B.

Geology and Landslide Potential

Section 3.1 describes NCWAP analysis of geology and landslide potential components of sediment production and transport. The California Geological Survey's *Manual for Regional or Watershed Scale Mapping of Landslide and Fluvial Geomorphic Conditions* located on the CGS website, http://www.consrv.ca.gov/cgs/ncwap/index.htm provides a more detailed discussion of the procedures followed to assess sediment production and transport.

Factors affecting sediment production and transport include natural factors such as susceptibility to landsliding, strength properties of the bedrock, slope steepness and length, soil composition (depth, permeability, cohesion, and structure), ground water levels, amount and type of vegetation on the slopes, rainfall intensity and duration, and fire. In Northern California, geology, pre-existing landslides, tectonics, seismicity, topography, and climate primarily determine erosion rates and mass wasting.

Land use practices have the potential to increase slope failure, alter fluvial processes and increase bedload and suspended sediment. These may include vegetation removal (livestock grazing, agriculture clearing, development, timber harvesting), and surface disturbance and modification (road construction and drainage, ground-based timber operations, and watercourse diversions.)

Sediment and fluvial processes

Sediments are composed of particles that range in size from fine organic matter, silt and sand, to large boulders. Sediment sources are often interrelated. For example, earth materials displaced by mass wasting processes such as landslides are often modified and reworked by surface erosion. Sediment sources include surface (splash, sheet, rill, and gully) erosion and mass wasting (landslides, soil creep, debris flows).

Sediment produced by these processes may be directly deposited into a stream by processes such as a bank slumping or by transport mechanisms such as surface runoff or debris flow/torrents. Alternatively, sediment may be retained by vegetation on benches or hillslopes, or above the river on terraces and floodplains, and only be delivered to the stream during flood events. Sediment generation and transport into streams is generally measured in units of tons or cubic yards, or as rates of delivery such as cubic yards generated per square mile of area per year.

Natural stream channel stability occurs when a river develops a stable plan and profile, such that, over time, channel features are maintained and the stream neither aggrades or degrades. Stable streams can consistently transport the sediment load, both in size and quantity, with only local deposition and scour (Rosgen, 1996).

Stream systems can be viewed as out of balance if sediment deposition or erosion is excessive or when natural sources of sediment input are lacking or exceed the stream's transport capacity. These situations may be reflected in stream channel changes such as channel aggradation or down-cutting, channel widening, and accelerated stream bank erosion.

While sediments are important components of aquatic ecosystems, providing the substrate for salmonid spawning, aquatic insect production, and nutrient storage, excess sediment can fill pool habitats and clog spawning gravels. Factors relating to sediment sources and their likelihood to affect stream fish habitats are considered in the fluvial assessment.

Approach

The California Geological Survey evaluates, compiles and maps channel fluvial characteristics. Mapping focused primarily on stream features associated with sediment source, transport and response (depositional) areas within the watershed. Mapping is performed at a reconnaissance level with more detailed assessment conducted at key locations for calibration and quality control purposes.

Stream features that may indicate excess sediment production or transport for the purpose of the NCWAP assessment are identified as "negative mapped channel characteristics". These were mapped for at least two periods of time in the first NCWAP assessment report. Time-series mapping allows for evaluation of changes in channel geomorphology and is used as an indicator of disturbance, sediment source, or stored sediment in the river system.

The stream channel-mapping component is GIS-based using an ArcInfo™ platform.
The digital layers contain a variety of physical, temporal, and spatial data collected for each feature of interest. For example, the data for a specific mapped channel includes the length, width and thickness of the feature. Results of the fluvial geomorphic assessment are presented as numerous shape files/coverages within GIS. These can be viewed directly or downloaded as maps or profiles of key stream channel characteristics.

Questions and Issues

Existing data, newly collected data, and field observations are used to complete an integrated analysis of the following:

Stream Features Existing Conditions:

- What is the spatial distribution of fluvial features in each watershed?
- What are the dominant fluvial geomorphic features in each watershed?
- How has the distribution and extent of fluvial geomorphic features changed over time?
- What are the primary geologic controls on these fluvial geomorphic features?

- Which geologic formations or groups of formations are likely progenitors of the various types of fluvial features?

Ancillary Information:

- What are the dates of past significant meteorological events?
- What peak flow events are recorded by stream gauges or otherwise?
- What is the history of land use, seismicity, and wildfire and their proximity to streams?
- What is the spatial relationship between land use practices and fluvial geomorphic features?

System Response:

- Where was sediment delivery to streams from landslides and other geomorphic features observed?

Stream Channels:

- What is the spatial distribution of channel types, as classified by gradient and confinement?
- What role does the geology of the watershed have in spatial distribution channel types?
- What is the evidence of historic channel changes from both anthropogenic and natural causes?
- What do existing conditions indicate about the present geomorphic stability of the channel network?
- What can be said about the likely responses of channel reaches to potential changes in input factors such as sediment delivered, stream flows, woody debris?
- What role does large woody debris have within the watershed in forming fish habitat and determining channel class and storing sediment?
- What are the dominant channel- and habitat-forming processes in different portions of the watershed?
- What portions of the channel network are prone to aggradation or degradation in response to variations in erosion rates and sediment delivery potential?
- What is the character and magnitude of local channel response to recent sediment input from hillslopes, e.g., landslides?

Data Sources and Gaps

All available relevant and current geologic literature regarding each watershed is reviewed early in the assessment process. The vast majority of the geologic and geomorphologic interpretations is made through the examination of several sets of stereo-paired aerial photographs.

Photographic coverage available for various portions of North Coast watersheds consists of about a dozen sets of photographs, from the early-mid 1940's until the most recent taken in 2000. However, individual watersheds often have only a few sets of complete coverage, and some of the early sets may be extremely difficult to obtain. Data derived from review of the available aerial photos by the California Geological Survey is incorporated and stored in the GIS.

Limited fieldwork is conducted to verify mapping derived from aerial photographs. CGS fieldwork is focused on confirming features observed on aerial photographs and investigating features of uncertain origin in the upland areas and lower stream reaches.

Data Collection

Stream channel conditions, and other geomorphic characteristics throughout selected North Coast watersheds are mapped at a scale of 1:24,000. Multiple sets of aerial photos are used to allow detection of changes over time and observation of multiple features.

Channel types are characterized within the study area using a reconnaissance-level interpretation based on Rosgen (1996) channel type. Fluvial geomorphic feature mapping is conducted using a methodology adapted after the RAPID technique (Grant 1988) for evaluating downstream effects of forest practices on riparian zones.

Thirty-two types of stream characteristics ("mapped channel characteristics") are considered in the aerial photograph review, and added to the fluvial database where observed (See Table 5). This includes features that are indicative of channel instability (e.g., eroding banks) and sediment storage (e.g., mid-channel bars), as well as other general channel attributes such as pools or riffles. Those that may be indicative of excess sediment production, transport, and/or response (deposition) are referred to as "negative" mapped channel characteristics within this report and are shown in boldface type on Table 5.

Table 5. Database dictionary for GIS: mapped channel characteristics.

sed_type1 – primary* channel characteristic
sed_type2,3,4 – secondary* channel characteristic (if noted)

wc - wide channel	**ag – aggrading**
br – braided channel	**dg – degrading**
rf – riffle	**in – incised**
po – pool ox – oxbow meander	
fl – falls	ab – abandoned channel
uf – uniform flow	am – abandoned meander
tf – turbulent flow	**cc – cutoff chute**
bw – backwater	**tr – tributary fan**
pb - point bar	lj - log jam
lb - lateral bar	**ig - inner gorge**
mb – mid-channel bar	**el - eroding left bank** (facing downstream)
jb - bar at junction of channels	**er - eroding right bank** (facing downstream)
tb - transverse bar	**la - active landslide deposit**
vb - vegetated bar	**lo - older landslide deposit**
vp - partially vegetated bar	**dr – displaced riparian**
bc – blocked channel	ms – man-made structure

Note: Features in bold represent channel characteristics indicative of excess sediment in the channel.

Once a set of aerial photos has been interpreted and draft fluvial geomorphology maps have been created, field inspections are conducted to confirm or clarify interpretations and to improve the development and analysis of channel data. The accuracy of data (i.e., maps, GIS layers) borrowed from other sources is also reviewed in the field. CGS suggests two weeks of field verification for every 7.5-minute quad.

Data Analysis

The spatial distribution of source, transport, and response reaches are analyzed (see Figure 12); these govern the distribution of potential impacts and recovery times for the stream system. Channel slope is used to classify stream sections as source (>20%), transport (4-20%), or response (<4%). The areas of greatest susceptibility are those where higher gradient reaches transition into low gradient reaches.

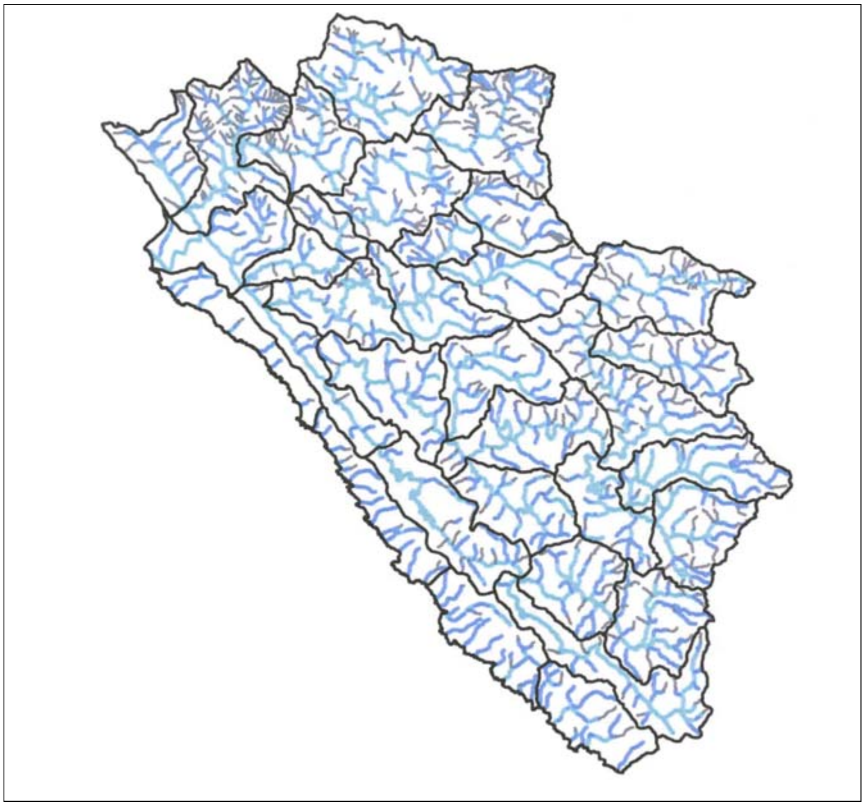


Figure 12. Distribution of channel gradients in the Gualala River Watershed
Response channel (light blue), transport channel (violet), source channel (gray)

In the Gualala and Mattole River assessments, changes and trends are analyzed in channel conditions between 1984 and 2000. Maps are developed of individual characteristics or of groups of characteristics. Figure 13 is an example of a map of all negative mapped channel characteristics in a basin.

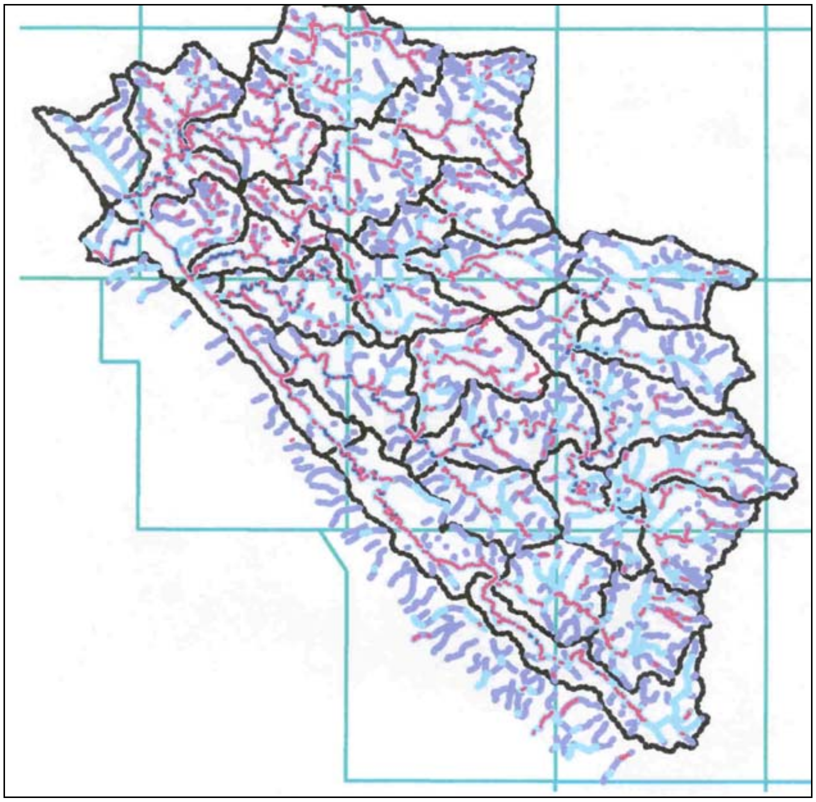


Figure 13. Distribution of the excess sediment in the Gualala River Watershed in 2000 Channel characteristics that suggest excess deposition or sediment delivery are red, and other mapped channel sediment deposits are blue.

Comparisons between dates of the proportion of stream occupied by negative mapped channel characteristics (NMCC) versus other channel characteristics are provided in Table 6. Quantitative analysis of NMCCs are conducted only on data assigned to the primary characteristic of the field which best reflects conditions through the entire channel reach. Trends can be looked at by stream and also by percentage of streams within subbasins.

Table 6. Gualala River stream characteristics representing sediment sources or storage

Subbasin	Year 2000		Year 1984		1984 to 2000	1:24K Streams
	Disturbed Channel Length (miles)	% Total Stream for Entire Watershed or Subbasin	Disturbed Channel Length (miles)	% Total Stream for Entire Watershed or Subbasin	Percent Length Change	Total Stream Length (miles)
Gualala River Watershed	***156.8***	***21.0***	***297.8***	***39.9***	***-47.3***	***745.8***
North Fork Subbasin	29.2	23.0	48.3	38.1	-39.5	126.7
Rockpile Creek Subbasin	19.8	22.4	32.0	36.3	-38.3	88.2
Buckeye Creek Subbasin	17.9	19.8	41.6	46.0	-56.9	90.4
Wheatfield Fork Subbasin	56.7	18.9	118.9	39.6	-52.3	300.6
Gualala Subbasin	33.2	23.7	57.0	40.8	-41.8	140.0

Geographic information systems can also be used to generate stream profiles, drainage network diagrams, slope maps, and landslide potential models. Fluvial features can be overlain on: slope maps; maps of geology, landslides, soils; vegetation type and timber harvesting history; detailed stream habitat surveys; orthophoto-quarterquadrangles; and topographic maps. The nature and extent of fluvial features can be related to geologic bedrock, extent of dormant or active landslides, and varying degrees of landslide susceptibility. Chapter 4 describes interdisciplinary analyses using this CGS data.

Limitations

Limited aerial photo coverage may not occur before and after important watershed events such as major floods, and the effects of such events may not be fully evident in photos taken years later.

It is initially assumed that ten-meter resolution digital elevation models closely match actual topography. That may not prove to be true, and may affect the stream's Rosgen classification.

The assumption that existing geologic maps are relatively close to actual geologic conditions may not always hold true, particularly at a local scale when the geology is compiled from larger scale historical mapping.

Sediment generation and transport volumes are not included.

3.4 RIPARIAN VEGETATION CONDITIONS

The Department of Forestry and Fire Protection worked closely with other NCWAP team members to develop and apply approaches to assessing riparian vegetation conditions. Riparian zones are transitional areas between terrestrial and aquatic ecosystems. Riparian forests influence sediment delivery and transport processes, the amount of light reaching the stream, water temperature and productivity. They provide nutrients, stream bank cohesion, a metering of sediment from upslope areas, flood plain storage of sediment, and large woody debris, all of which are important to the health of salmonid populations. The North Coast Watershed Assessment Program approach to riparian forest assessment is described in this section.

Riparian forests may be defined as the area of land located immediately adjacent to streams, lakes, or other surface waters, including the floodplain and terraces. The spatial extent of riparian areas varies laterally throughout the channel network and is strongly influenced by geomorphology (Naiman 1998). The boundary (i.e., ecotone) of the riparian area and the adjoining uplands is not always well defined, but there are often strong differences in microclimate within it (Brosofoske et al. 1997). Riparian areas differ from the uplands because of high levels of soil moisture, frequent flooding, and the unique assemblage of plant and animal communities found there. Riparian vegetation influences stream ecosystems by contributing wood and organic material to streams, providing shade, and regulating microclimates (Welsh 2000).

Riparian areas are also defined by process. Riparian forests develop in response to disturbance. Flooding, fire, mass wasting and disease are all natural disturbance processes that affect riparian vegetation (Naiman 1998). The variability in disturbance processes among different stream types results in distinct differences in vegetation patterns. Table 7 summarizes many of the functions performed by riparian forests.

Table 7. Riparian forest ecosystem functions (Naiman 1998)

Scale/Element	Structure	Functions
Instream habitat	Large Woody Debris - recruited from hillslope and floodplain forests	Controls routing of water and sediment. Controls aquatic habitat dynamics: pools, riffles, cover. Provides wildlife habitat. Source of scour pools
Stream banks	Roots	Increased bank stability. Create overhanging bank cover. Nutrient uptake.
Floodplain	Stems and low-lying canopy	Retard movement of sediment, water and transported woody debris.
Above-ground or above-stream	Canopy and stems	Shade control of temperature and stream primary productivity. Source of large and fine plant detritus. Provides wildlife habitat.
Stream reach	Corridor	Movement of fish and wildlife.

In addition to natural controls such as soils and geology, forest practices, agriculture, development and other land uses have the potential to affect many riparian processes and functions (Gregory 1997). There was little or no protection given to riparian forests in California prior to 1970. As a result, riparian forests on the North Coast tend to lack old mature forest stands and reflect the legacy of past forest practices. Since the passage of the Forest Practice Act in 1973, and especially over the past decade, riparian buffers have been required in areas subject to timber harvesting to maintain ecosystem processes and promote the development of riparian forest conditions.

Approach

The function and health of riparian forests are related to the following parameters: water temperature, air temperature, canopy, large woody debris (LWD), forest condition (type and size), and bank stability.

On North Coast streams, riparian issues are focused on large woody debris (LWD) and stream shade. Historical forest practices and wood removal projects have left streams deficient in LWD. The purpose of the riparian analysis is to evaluate the riparian zone, and its potential to contribute wood to streams and to provide stream shade.

A multi-disciplinary approach is applied to investigate the following factors within each watershed:

- Forest canopy and stream shade
- Riparian vegetation: Size and type of vegetation are analyzed to determine recruitment potential
- Large woody debris
- Stream temperature
- Channel characteristics

Questions And Issues

Questions and issues to be addressed on riparian vegetation condition vary by scale: landscape, whole watershed, sub-watershed or stream reach.

Landscape, whole watershed or sub-watershed:

- What is the distribution of vegetation types and structure within the riparian zone across the watershed?
- What is the status of canopy cover and the potential implications for stream shade across the watershed?
- What is the potential for LWD recruitment?

Stream reach:

- What is the role and status of instream LWD?
- Have historic practices modified current channel conditions (i.e., stream clearing, changes in channel form)?

Data Sources And Gaps

Riparian condition assessment is undertaken in close coordination with stream channel classification and fish habitat assessments, and relies on some of the same data sources. Additional data sources are USDA Forest Service and California Department of Forestry and Fire Protection vegetation type maps and aerial photos.

- *Riparian Vegetation*: Derived from USFS/CDF vegetation maps and aerial photos
- *Fluvial Geomorphology*: (Bank stability, channel changes, etc.)
- *Aquatic Habitat*: Department of Fish and Game stream habitat surveys
- *Water Temperature:* Data collected by and/or provided to the North Coast Regional Water Quality Control Board by landowners and watershed groups.

Data Collection

Interpretation of riparian forest condition requires a multi-scale approach. For an entire watershed, a first approximation of conditions can be made using existing vegetation maps. Where DFG stream habitat survey data exist, reach-level riparian conditions are also addressed.

Riparian vegetation at the stand level:

USDA Forest Service and CDF maps include the following attributes: species, canopy cover, and tree size. These data represent forest conditions as of 1998. The vegetation data were updated to current conditions and revisions made to improve canopy cover and size estimates. Where several photos are available, data represents conditions before major human disturbance (e.g. logging) and current conditions.

1) *Bank cover*. Reach level riparian conditions are assessed in the field using DFG stream habitat survey data when private lands can be accessed.
2) *Large Woody Debris (LWD).* LWD is characterized using data collected as part of the in-stream surveys conducted by Department of Fish and Game.
3) *Water Temperature.* Instantaneous water temperature data were collected from streams as a part of DFG stream surveys. Agencies and landowners provided water temperature statistics from continuous monitoring devices to the North Coast Regional Water Quality Control Board.
4) *Fluvial geomorphic features*. Features such as eroding banks, displaced riparian vegetation and wide channels are denoted on California Geological Survey maps.

Data Analysis

Data analysis is done by integrating information from vegetation maps (type and structural attributes) in riparian zones, stream habitat surveys, and water quality and fluvial geomorphology data (i.e. channel feature maps).

Vegetation characteristics in the riparian zone (CDF). Vegetation across the riparian zone is analyzed using both aerial photography and vegetation maps derived from satellite imagery. The USDA FS/CDF GIS layer is used to assess the area and type of vegetation (Table 8), tree size (Table 9), and canopy cover (Table 10). The riparian zone is defined by stream buffers based on a 1:24,000 scale stream network. The data are then summarized for multiple buffer widths ranging from 50 to 90 meters. Buffer widths are based on Forest Practice Rules (50 and 150 feet) and Northwest Forest Plan guidelines (90 meters or 295 feet).

Table 8. Vegetation cover type: summary for different buffer widths.

Vegetation Cover Type	**Acres and Percent by Buffer Zone**					
	50 feet		**150 feet**		**90 meter**	
	Acres	Percent	Acres	Percent	Acres	Percent
Agriculture						
Barren						
Conifer						
Hardwood						
Grassland						
Mixed Conifer/Hardwood						
Shrub						
Urban						
Water						
Total						

Table 9. Vegetation size classes: summary for different buffer widths

Vegetation Size Class	**Tree Diameter Class**	**Acres & Percent of Area by Buffer Zone**					
		50 feet		**150 feet**		**90 meter**	
		Acres	Percent	Acres	Percent	Acres	Percent
0	Sapling						
1	< 6 inches						
2	6 to 11 inches						
3	12 to 23 inches						
4	24 to 40 inches						
5	> 40 inches						

Table 10. Canopy density: summary for different buffer widths.

Density Class	**Canopy Closure Class**	**Acres & Percent of Area by Buffer Zone**					
		50 feet		**150 feet**		**90 meters**	
		Acres	Percent	Acres	Percent	Acres	Percent
1	10-20%						
2	20-30%						
3	30-40%						
4	40-50%						
5	50-60%						
6	60-70%						
7	70-80%						
8	80-90%						
9	90-100%						
Total							

Riparian canopy cover change (CDF). In watersheds where several sets of aerial photos are available, changes in riparian canopy over time are mapped. These changes are then used to identify land use impacts. The three time periods used for riparian canopy cover maps on the Gualala watershed are described below. Somewhat different time periods may be appropriate on other watersheds depending upon their land use history and available aerial photography. The following example describes the approach to historical riparian canopy cover applied on the Gualala River watershed.

<u>Time 1: 1936 – 1942.</u> This period, after the Great Depression, showed little activity. The first aerial photo sets date back to this time (see Figure 14). Major portions of North Coast watersheds consisted of undisturbed old growth timber stands in central and upper basin reaches.

<u>Time 2: 1965 – 1973.</u> This period denotes the end of the tractor-logging era after large areas of the old growth timber base had been harvested (see Figure 15). Timber operations and ranchland conversions were concentrated in riparian areas containing the largest and highest valued trees, and typically involved building roads, skid trails, and landings in or adjacent to watercourses. Entire canopy removal left streambanks exposed on both sides of the watercourse.

<u>Time 3: Current conditions (2000).</u> There is a sharp contrast in the effects of contemporary regulatory policies and land management practices with effects of earlier policies that provided little regulation of harvesting practices. Buffer zones around watercourses are more apparent in the aerial photos taken since the mid 1990s when larger second growth conifers were retained to provide riparian habitat corridors and canopy closure. These riparian buffer strips have generally become incrementally wider and denser by 2001.

Aerial photo mapping of current canopy conditions incorporates DFG ground habitat inventory surveys and private landowner stream cover measurements where available. Digital LANDSAT-derived vegetation imagery is also used to quantify percent canopy cover (see Figure 16).

Figure 14. 1942 stream exposure (white) in the Gualala River Basin

Figure 15. 1968 stream exposure (white) in the Gualala River Basin

Figure 16. 1999-2000 stream exposure (white) in Gualala River Basin

This method maps stream reaches with the same aerial photos used to develop land use maps. Photos taken during summer low flows are preferred. Stream reaches with banks exposed on each side of the channel are mapped. Only blue line streams with exposed banks along the immediate stream channel are included, not those with exposure only along the vegetation transition line or the flood line. Stream segments that were partially or entirely covered with a canopy are not included. Reaches with the stream channel exposed on both banks are traced onto Mylar overlays from the photo interpretations and then digitized using Arc View software.

Stream Habitat Surveys (DFG): At the reach level, stream surveys can be used to evaluate the functional use of wood to form pools, create habitat, and regulate fine sediment. Where available, stream habitat data are used to describe riparian habitat conditions at the reach level. To the extent possible, stream survey data are used to evaluate aquatic habitat and make predictions about community structure as it varies throughout the stream network.

Large woody debris (LWD) inventories and canopy density measurements are part of the stream habitat survey and are used as a measure of riparian condition. LWD and cover data are analyzed separately. These are evaluated explicitly in the reach level Ecological Management Decision Support system (EMDS) model. For more information see Chapter 3.7: Fish Habitat and Flosi et al., 1998 (Appendix F).

Fluvial Geomorphic Mapping (CGS). The California Geologic Survey maps characteristics of stream channels, documenting changes in channel characteristics and allowing analyses of trends in channel width, sediment production, and riparian vegetation displacement. Methods developed by CGS for mapping fluvial geomorphic features are modified from the RAPID technique (Grant 1988) for evaluating downstream effects of forest practices on riparian zones. Both methods use the same basic technique to map channel changes. However, RAPID methods for measuring patterns of riparian canopy disturbance are expanded to include additional information on channel geomorphic characteristics visible on aerial photos. These features are then attributed in the GIS database for map preparation and data analysis.

Fluvial geomorphic maps developed by CGS identify 32 features indicative of stored channel sediment or sources of sediment visible on available aerial photographs. The attributes in bold in Table 5 in bold are those that may indicate excess sediment in storage or sediment sources detrimental to optimum habitats for anadromous salmonids. 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.

Water Quality (NCRWQCB). Regional Water Board staff compiled water temperature data from landowners and watershed groups in all watersheds assessed. Water quality samples were obtained when and where possible, mostly limited by access. Sample collection and analysis is in accordance with methods used by the US Geological Survey and the US Environmental Protection Agency, further explained in NCRWQCB (2003). Water temperature data collected by landowners and local watershed groups is reviewed for adequacy and used if appropriate.

The data were computerized into formats appropriate for the information, e.g., spreadsheets for dissolved oxygen, flow, and temperature. Analysis of the data was specific to the data type and its quality. Data collected on stream temperature supported the analysis of canopy cover in riparian areas (Figure 17).

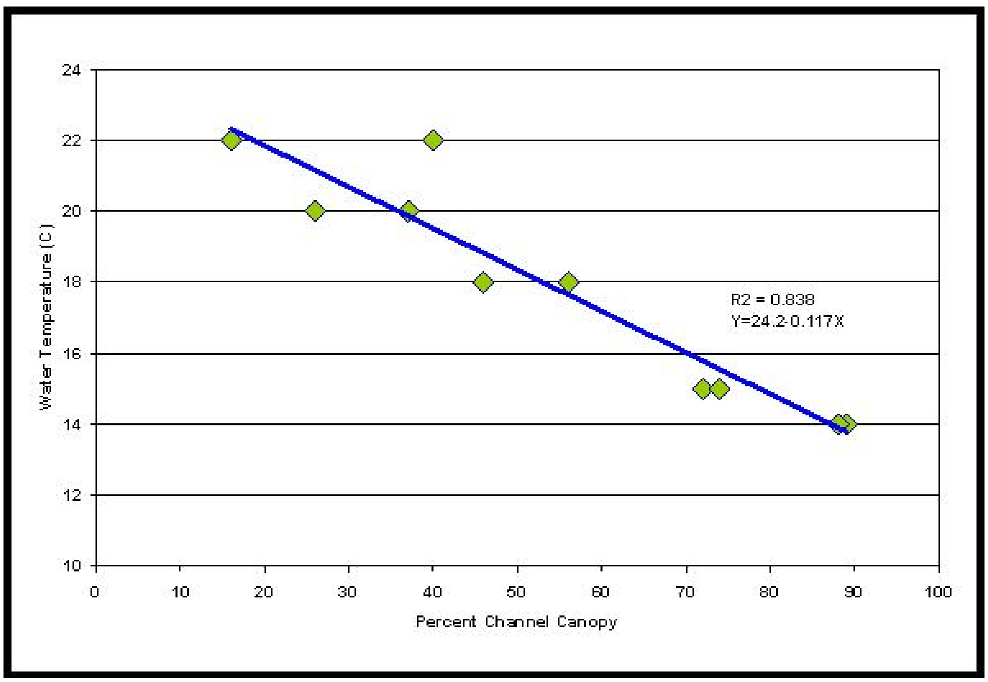


Figure 17. Relationship of water temperature with riparian canopy

Linear regression is based on 11 sites within the Gualala watershed, using data collected by Gualala Redwoods Inc. and Gualala River Watershed Council (Klamt et al. 2003).

Limitations

The primary assumption used in this analysis is that existing vegetation maps provide the information necessary for characterizing riparian conditions at the watershed and sub-watershed scales. There is limited information on historic or reference riparian or LWD conditions, which impairs our ability to assess current conditions relative to historical conditions. In the absence of DFG stream habitat data, there may be limitations to the amount of detail that can be provided through aerial photograph and limited fieldwork.

3.5 HYDROLOGY AND WATER QUANTITY

Water quantity or stream flow data are important for determining the existing conditions in North Coast watersheds and assisting in assessment, restoration, and management activities. Insufficient stream flow can limit anadromous fisheries by affecting migration and the quantity and quality of spawning, rearing and nesting areas and other indirect factors such as water temperature, dissolved oxygen, and sediment and chemical transport. Stream flow data are required to quantify total stream sediment and chemical transport loads. This information is needed for floodplain management, instream structural design and installation projects, and State Water Resources Control Board water rights applications, license reviews and judicial water supply allocations.

Stream flow data are sparse for North Coast watersheds. Stream flow gauging programs by federal and state agencies have been severely reduced over the last three decades. Many streams are currently without stream gauging stations. NCWAP funded the installation and operation of ten stream flow gages in the Gualala, Albion, Big, Mattole, and Scott River watersheds. In addition, NCWAP funding was used for operation of some gauges subject to discontinuation. With the defunding of NCWAP in FY 2003-04, agencies and watershed groups are making a concerted effort to find alternate funding sources to keep the gauges operating. Many years of contiguous data are needed for hydrologic analyses, and the loss of the gauges that are currently operating would preclude much detailed hydrologic analysis in the future.

Approach

The role of the Department of Water Resources (DWR) in the North Coast Watershed Assessment Program is to provide new stream flow data, compile historic stream flow data, and assist in compiling water rights information. NCWAP has provided for continued operation of selected stream flow gauging stations subject to discontinuation due to funding reductions. Additional support for installation and operation of new stream gauging stations on North Coast watersheds has been provided by the Surface Water Ambient Monitoring Program (SWAMP).

All new stream flow gauging stations are equipped with water temperature sensors. Some stations have other water quality sensors for measuring turbidity, dissolved oxygen, pH, and conductance. Selected stations are equipped with telemetry to provide a portion of the collected data on a real-time basis via the California Data Exchange Center (CDEC) web site. Real-time stream flow and water quality data assist in notifying this and other data collection efforts of event sampling opportunities or hazardous conditions for fish survival. Flood forecasters and emergency response personnel also benefit.

Selection of sites, type of data collection, and period of station operation is based on available funding, existing stations, resumption of discontinued stations for historic comparisons, access, favorable site conditions, and identified NCWAP or SWAMP needs. Stations located at the terminus of the watersheds or major sub-basins where none currently exist are a priority. Some stations are operated for the long term for trend and base correlation analysis, while others are operated for short periods. These sites also provide an opportunity for others to place multiple parameter electronic data loggers to collect highly detailed time series data for temperature, dissolved oxygen, turbidity, conductance, pH, etc.

Historical stream flow and water rights data are compiled from existing DWR, State Water Resources Board, and US Geological Survey information. Current water rights information is compiled from DWR and State Water Resources Board files. The North Coast Regional Water Quality Control Board assists in that compilation as well.

Questions And Issues

Flow data collection is a long-term project by its very nature. Flows vary due to yearly precipitation differences, land use changes, and water withdrawals. Data must be collected for years, preferably decades, to develop patterns and reach conclusions about frequency of events.

New data support limiting factors analyses and point out the possible need for instream flow minimums or augmentation. New data also assist in identifying additional stream flow monitoring needs and provide information for comparison with historic data and a baseline from which to measure changes in future stream flow. For instance, the ratio of long-term precipitation to runoff assists in determining the affect of historic land use on stream flow. Although extensive compilation of riparian and appropriative water rights information and monitoring of actual diversion amounts are beyond the scope of the assessment, new stream flow data assist in identifying additional monitoring needs in these areas as well.

While new data must be collected for a long period to provide definitive answers, new data assist in addressing the following questions regarding water quantity issues:

- What are the current stream flow conditions relative to the life history requirements of salmonid species?
- Have significant changes in climate, land use, or water diversions and use adversely affected stream flow quantity relative to salmonid fish survival?

Data Sources and Gaps

Sources of historic and current stream flow data are limited. The U.S. Geological Survey and the Department of Water Resources are the primary agencies collecting stream flow data within North Coast watersheds. Historic average daily and instantaneous minimum and maximum stream flow data can be found in the agencies' published reports or web sites. NCWAP compiled these data for North Coast watersheds. Some industrial timber landowners and local watershed groups have recently begun to collect stream flow data, but these data are very sparse and need to be reviewed for quality assurance.

Data Collection

DWR and the USGS worked cooperatively to install and operate the new stream flow gauging stations using USGS methods, including data quality assurance and control techniques.

The stations are constructed to withstand substantial flood events and incidental vandalism. Stations installed for short-term operation are constructed with the assumption that data collection may be resumed at a later date. About 9 to 12 direct stream discharge measurements along with simultaneous water stage (elevation) data over a wide range of water stages are normally performed at each station annually. High discharge measurements may require the installation of cableway systems, if bridges are not located nearby or if measurements by boat are impractical. Multiple direct field measurements of water stage and water quality also are performed to verify and calibrate the station sensors.

Data Analysis

Water stage and quality time series data are downloaded on a monthly basis from the station data loggers and then uploaded into a database where they are reviewed and edited for accuracy. Time series stream flow data are determined by correlating the direct discharge measurements with the simultaneous water stage data. This stage vs. discharge relationship or rating curve is then applied to the stage recordings from the station's stage sensor and data logger to compute stream flow for the same time series interval as water stage, normally every 15 minutes.

Once the rating curves are developed, real-time flow data are provided through the Internet via the CDEC web site from those stations equipped with telemetry. Real-time telemetry also allows the station's operator to monitor operation of the station remotely and to respond quickly to station malfunctions. Real-time data are normally not reviewed and edited for inaccuracies such as telemetry transmission error, sensor drift or malfunction, or discharge rating curve shift and are considered preliminary and subject to revision. Data that have been reviewed and finalized for the October through September water year are available about three to six months after the end of the water year.

The finalized base recording interval data are collated to produce daily average, minimum, and maximum values for each station parameter for the entire water year in comma-delimited text and graphical formats. These data are made available via the California Environmental Resources Environmental System (CERES) web site. Some statistical analysis of the new flow data such as for distribution, frequency, and duration also are provided. Additional data collations and formats are provided as needed by NCWAP.

Summary data by water year for a long-term gauge are provided in a format similar to Table 11, below. In addition, instantaneous discharge may be plotted for a water year (Figure 18).

Table 11. Summary stream flow data for the South Fork Gualala River Gauge Station

SOUTH FORK GUALALA RIVER NEAR ANNAPOLIS
USGS STATION #11467500
MEAN MONTHLY DISCHARGE AND ANNUAL YIELD
WATER YEARS 1951-1971 AND 1991-1994
(units in cfs, NR = no record)

Water Year	Month															WY Total	Yield (ac-ft)
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Min	Max	Aug		
1951	NR	NR	1343	1420	1280	747	98	159	28	12	4	2	NR	NR	NR	NR	NR
1952	21	312	2343	2111	1140	905	167	89	34	17	7	4	4	2343	596	7150	434,118
1953	4	18	1847	2501	135	481	362	163	53	19	9	7	4	2501	466	5597	342,446
1954	14	343	270	2165	863	843	983	109	40	14	25	11	11	2165	473	5680	341,394
1955	15	375	782	588	147	83	658	135	33	13	5	4	4	782	237	2839	171,556
1956	6	88	3060	2367	1650	273	102	78	27	11	5	5	5	3060	639	7671	464,709
1957	38	24	15	482	1039	943	309	660	103	24	9	90	9	1039	311	3735	222,413
1958	736	225	577	1322	4407	870	1256	98	61	20	9	6	6	4407	799	9587	560,214
1959	7	20	22	1134	1533	164	88	33	14	4	3	36	3	1533	255	3057	178,536
1960	11	8	13	510	1713	1188	188	78	31	13	6	5	5	1713	314	3765	224,221
1961	8	87	979	586	1586	1034	172	68	30	9	5	4	4	1586	381	4569	270,907
1962	6	266	417	260	2385	1023	119	52	21	11	5	6	4	2385	381	4572	266,079
1963	434	71	560	663	1144	643	1401	152	47	21	11	7	7	1401	430	5154	307,082
1964	37	879	146	820	150	135	56	32	18	8	4	3	3	879	190	2285	138,031
1965	22	481	2276	1589	273	162	955	118	44	18	10	6	6	2276	496	5954	361,541
1966	7	461	544	1312	906	448	151	51	22	12	6	2	2	1312	327	3922	234,512
1967	1	556	1028	1909	390	905	866	159	77	21	8	5	1	1909	494	5925	359,023
1968	13	36	338	972	1043	632	124	52	21	9	9	7	7	1043	271	3256	195,696
1969	24	61	1284	2677	1798	488	240	66	31	12	5	4	4	2657	558	6690	400,006
1970	15	25	1445	4152	613	314	73	33	14	3	2	2	2	4152	558	6691	407,564
1971	8	395	2259	1357	132	858	244	72	29	11	5	4	4	2259	448	5375	328,354
1991	NR	NR	NR	NR	NR	NR	NR	NR	12	5	2	1	NR	NR	NR	NR	NR
1992	13	22	NR	183	NR	NR	182	45	20	11	3	2	NR	NR	NR	NR	NR
1993	12	16	NR	NR	NR	NR	337	196	197	42	14	6	NR	NR	NR	NR	NR
1994	5	21	NR	NR	NR	117	61	35	12	NR	NR	NR	NR	NR	NR	NR	NR
Min	1	8	13	183	132	83	56	32	12	3	2	1	1	782	190	2285	138,031
Max	736	839	3060	4152	4407	1188	1401	660	197	42	25	90	11	4407	799	9587	560,214
Avg	63	208	1026	1413	1159	603	383	114	41	14	7	9	5	2071	431	5174	310,420

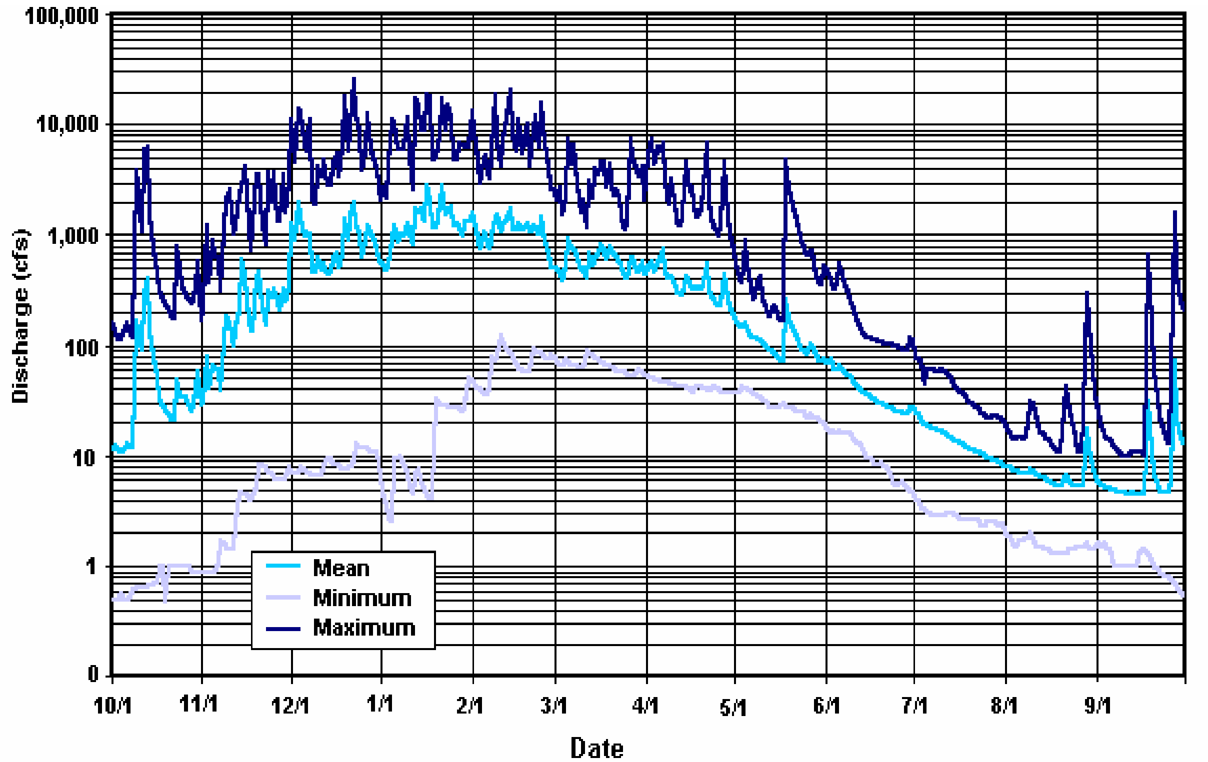


Figure 18. Mean, maximum, and minimum daily discharge for South Fork Gualala River Near Annapolis, USGS Station #11467500, water years 1951–1971.

Limitations

Detailed spatial and temporal stream flow data are not available for many watersheds. Only limited new data from NCWAP and SWAMP, intended to partially fill data gaps, are available for watersheds scheduled for NCWAP assessment the first few years. Two or three years of stream flow data may not be adequate for certain watershed assessment tasks. Consequently, some flow data may need to be estimated by using various mathematical methods. Those "synthetic data" are evaluated for quality and utility.

Data collection should normally precede any assessment analysis, but this is not possible for some watersheds where gages are installed the same year as the assessment is conducted. Therefore, the program installs gages a year or more ahead of the assessment schedule where possible. Collecting new data now also provides historic data for the future.

3.6 WATER QUALITY

The North Coast Regional Water Quality Control Board (NCRWQCB) compiles, analyzes, and presents water quality information from their own files, other agencies, landowners, and watershed groups. Whenever possible, the NCRWQCB collects additional new field data to supplement those existing data and provide current information.

While it is difficult in many situations to identify specific causes of watershed impairment, collection of water quality, biological, and related sediment parameters provides a perspective on watershed health. Assessing water quality and comparing it to baseline conditions is a useful way to gauge success of management practices designed to reduce human impact on the watershed. Likewise, it is useful for pointing out problem areas to address, and properly functioning areas to protect.

Water temperature, dissolved oxygen, turbidity, suspended and bedload sediment, nutrients, and chemical pollutants are important components of water quality that affect fish. Water quality affects all salmonid life stages and influences growth, behavior, and disease resistance.

Water quantity may affect water quality in a variety of ways, including changes in chemistry, water temperature, and sediment transport dynamics. Chemical changes are not expected to be a major factor in most coastal watersheds. However, the amount of water available to the stream affects the water chemistry when land uses produce nutrient and other chemical inputs. Stream flow, in addition to air temperature and solar radiation, may also affect water temperatures. Alterations in the flow regime during winter periods may have a profound effect on sediment transport dynamics as well, since stream flow in large part determines the power applied to the channel.

Water quality data are sparse for most North Coast watersheds. Routine sampling occurred decades ago in some watersheds, but only occasional observations are available for the last 15 years or so. Exceptions apply where local watershed groups or industrial timber companies have conducted sampling. The NCRWQCB collected field data where possible, and relied heavily on landowners and watershed groups for additional information, especially water temperature data.

Approach

A basic assumption used in assessment is that watershed conditions are integrated at the stream reach or sub-watershed level. Experience has shown that water quality and biological parameters are often useful in developing a perspective on watershed conditions. It is important to note that water quality and biological parameters include physical as well as chemical characteristics of water column quality, streambed substrate quality, and assemblages of aquatic life.

New water quality data collection for NCWAP occurs primarily through the North Coast Regional Water Quality Control Board's Surface Water Ambient Monitoring Program (NCRWQCB 2003). The schedule for the Surface Water Ambient Monitoring Program (SWAMP) is coordinated with NCWAP to provide additional and current information on water quality for watershed assessments. Access to private lands in many cases restricts the extent to which field data are collected.

The SWAMP sampling design is stratified by sub-watershed and tempered by local knowledge and access concerns. Site selection is based on SWAMP needs and goals as well as any special identified NCWAP needs. The goal is to characterize water quality at the sub-watershed level. Generally, data collection stations are at the terminus of a sub-watershed or in conjunction with other NCWAP reach surveys. Station locations are documented for use by all NCWAP personnel and for possible subsequent use by landowners and groups.

SWAMP parameters include: macroinvertebrates, water chemistry, pesticides, heavy metals, channel geometry, sediment transport, turbidity, and bacterial analyses. Dissolved oxygen, pH, conductance, and temperature are monitored "around-the-clock" by data loggers at selected sites.

Data from other agencies, landowners, and watershed groups are evaluated for their utility to the assessment by employing the concepts presented in Section 3.9, Data Quality Control and Assurance. Those data deemed appropriate for use are incorporated into the assessment.

Questions And Issues

New data will update existing older data, as well as improve our understanding of how well existing water quality meets objectives for the protection of beneficial uses. Current data support the limiting factors analysis, provide some idea of any identified trends, and point out areas for riparian evaluations and rehabilitation.

Currently, assessments of instream sediment conditions are based on aerial photo interpretations of geomorphology and on professional judgment. Collection of up to date information on instream channel characteristics provides a basis on which to make more informed judgments. Water quality data are compared to water quality objectives. Areas with anomalous results are reassessed to determine if unique conditions exist, or if problems are occurring from natural or human influences. New data provide information for comparison to older data, and a baseline from which to measure changes in the future.

New field data will assist in addressing water quality assessment questions:

- Is basic water column chemistry meeting Basin Plan water quality objectives and otherwise supportive of beneficial uses, especially drinking water supplies, cold water fishes, and contact and non-contact recreation?
- In a general sense, what are the current water temperature conditions relative to life history requirements of salmonid species?
- Is excessive sediment impairing coldwater fish habitat or otherwise compromising beneficial uses?
- Are there specific water quality problems identified by the data?
- Are there specific temporal trends in water quality?

The level detail of answers to these questions is variable, depending on the spatial and temporal distribution of temperature sites. Input from local landowners and watershed groups may modify the above questions, or add to them, allowing the assessment to be tailored to the specific watershed. This sensitivity to local issues and needs allows NCWAP to adapt to local conditions and new information. When local issues are beyond the scope of NCWAP, future studies are recommended.

Data Sources And Gaps

Sources of current water quality data are limited, but include agencies, large industrial timber landowners, and local watershed groups. Gathering these data and evaluating their utility in watershed assessment identifies numerous gaps, both temporally and spatially. New data collection is aimed at filling those gaps. To the degree that programs like SWAMP and local watershed groups continue data collection after a NCWAP assessment, data can be collected into the future, creating fewer temporal and spatial gaps and enhancing future assessments.

Data collected under the SWAMP program provides NCWAP with a more current assessment of conditions. The degree to which SWAMP data is available depends on SWAMP program staffing and laboratory resources. Field sampling is dependent on landowner access to a large degree.

Data Collection

NCRWQCB staff collects field samples to fill gaps in the spatial and temporal extent of historic data or to provide current information using the following methods. When staff is provided data from other agencies, landowners, and watershed groups, we use the methods described below to evaluate those data for their relative quality and usefulness. NCRWQCB was not able to field sample all watersheds due to access constraints.

Water Chemistry: Data quality assurance and control techniques common to water quality data collection are employed during collection of new water chemistry data. The SWAMP Quality Assurance Plan details the specific protocols and procedures for water chemistry sampling. It can be downloaded from the State Water Board's website at: http://www.swrcb.ca.gov/swamp/qapp.html.

Grab Sampling Collection: Water quality samples are obtained from the centroid of flow, if at all possible, as grab samples following U.S. Geological Survey protocols (USGS 1999b). When flows are too high for wading, a thief-type sampler (Kemmerer bottle or equivalent) is suspended into the centroid of flow from bridge crossings or from shore (in well mixed locations). Grab samples to be analyzed by contract laboratories are collected in appropriate containers prepared by the laboratory. They are labeled, preserved, transported, and analyzed according to USEPA and USGS protocols. Field parameters (dissolved oxygen, temperature, pH, conductance) are measured on site using portable field meters.

Site conditions including location, access, special considerations, photos, and sampling point location(s), as well as climatic and hydrologic variables are documented on waterproof forms. This allows standardization of information, and ensures that all variables are recorded (NCRWQCB 2003). Flow measurements are obtained when possible and according to the methods described by USGS (1999a).

Strict QA/QC procedures call for pre- and post-run calibration and routine precision checks. Meters are calibrated prior to sampling. Accuracy is checked at the end of a sampling run or every five samples, whichever is more frequent. A duplicate sample is collected at the first station in a sampling run and analyzed for pH, conductance, and turbidity at the end of the run, to provide information on overall precision. All data are recorded on waterproof data sheets. Meter calibrations, precision checks and accuracy checks are documented. In the event a measurement exceeds a QC warning or control limit, re-analysis procedures outlined in NCRWQCB (2003) are followed.

Automated Sample Collection: Data loggers are effective in collecting physico-chemical measurements on short time intervals over many days without constant staff oversight. Data are stored on internal memory chips and downloaded to a computer in the field or office for further data analysis.

> Temperature: Temperature loggers manufactured by Onset® Corp., programmed to sample at least every 96 minutes are used. With 8K of internal memory, a full summer of data can be collected. Additionally, the 96-minute sampling interval is the minimum specified in the cooperative effort developed by the Forest Science Project (FSP 1998) to detect daily maxima. A multi-agency temperature monitoring consortium in the Russian River watershed modified the FSP protocol and standardized data downloading from remote loggers.
>
> Basic considerations for site selection are presented in the modified protocol. Since the primary use of the data at this point is to characterize a stream reach, placement is in a well-mixed flowing section of the stream representative of the reach. Data sheets for calibration, deployment, and site conditions accompany the data for each deployment (NCRWQCB 2003).
>
> Multi-parameter: The loggers are calibrated and pre-programmed to collect conductance, pH, dissolved oxygen, temperature, depth, and other parameters on a predetermined interval, placed in the water body, and left to record the data on internal memory. Once the sampling period is complete, they are returned to the lab for post-calibration checks, and the data downloaded and imported into a spreadsheet for analysis. Typically, the probes need servicing every three or four days, depending on the water body. A four-day deployment can accommodate sampling at 15-minute intervals, providing a dense data set around the clock.
>
> The manufacturer's instructions are used to calibrate, program, deploy, service, retrieve, download, and post-calibrate for the particular instrument. Data sheets for calibration, deployment, and site conditions accompany the data for each deployment.
>
> Actual deployment on a site takes into account a combination of factors, placing the instrument in a well-mixed flowing section of stream, while protecting it from vandalism. As much as feasible, locations are representative of a stream reach and uninfluenced by local anomalies. Deployment on or in close proximity to patches of algae, sandy areas, or other micro-habitat influences is avoided.

Instream channel characteristics: Stream channel and streambed metrics, such as V*, D50, substrate cores, etc. have utility in describing channel conditions, sediment movement, and recent events, ultimately helping to describe the quality of cold water fish habitat. Analysis of those data with other watershed-level data is useful to NCWAP as well as sediment TMDL development efforts.

The following descriptions are summaries of the protocols with reference to specific literature. Detailed methods and the actual references for these metrics are presented in NCRWQCB (2003).

<u>Percentage of Residual Pool Volume Occupied by Fine Sediment Deposition (V-star/V*):</u> Pool volume has consistently been identified as an important aspect of pool habitat and appears to be vulnerable to increased sediment loads from watershed disturbances. Reductions in pool volumes reduce summer and winter holding capacities for salmonids (Stuehrenberg 1975, Klamt 1976, Bjornn et al. 1977). Bjornn et al. (1977) found that the effect of introducing enough fine sand into a third order stream pool to reduce its volume by half (a V* of 0.5) and to reduce fish numbers by two-thirds. Since pool habitat has often been correlated with the size and volume of pools (Heifetz et al. 1986 and Lau 1994), it follows that decreasing a pool's volume by introducing excess sediment will simplify pool habitat, also resulting in decreased substrate diversity.

V*, the volume of sediment in residual pools divided by the residual scoured pool volume, was developed to assess the supply of fine sediments being transported in a stream system (Lisle and Hilton 1992). The method uses cross-section measurements to define the area and depth of the pool, probing the sediment in the pool to determine both the existing water depth and the depth to the residual pool (the pool without the sediment). The resulting metric is a decimal between 0 and 100, with 0 being no sediment, and 100 being 100% of the residual pool volume occupied by fresh sediment.

Sampling protocols on the North Coast for selection of V* pools target pool-rifle channels with a 2-4% gradient in Rosgen B-3 channel types. These criteria were selected because they provide much of the spawning and rearing habitat for anadromous fish (Knopp 1993). V* was also found to have utility in other Rosgen B and C gravel channel types. Bedrock-boulder channels give mixed results and may not be reflective of upslope land use and natural disturbance activities in a particular watershed (Hilton and Lisle 1993).

<u>Channel Cross-sections:</u> Channel cross-section measurements provide valuable information on the shape and dimension of a stream channel and its relationship to the flood plain. Coupled with other measurements, cross-sections provide valuable information on transport and storage of sediment in the stream channel. Common parameters include width/depth ratio, gradient (slope), bankfull depth, flood prone area, and sinuosity.

Monitoring the long term changes in cross sectional data can provide insights into channel bed and bank stability, and relationships between sediment transport and discharge (Beschta and Platts 1986). Shifts, such as decreasing cross sectional area, are often associated with decreasing thalweg depth, increasing channel width, increasing bed elevations, and overall streambed aggradation. Channel incision and downcutting may be indicative of a return to more "natural" conditions from previous management and/or natural catastrophically related impacts (McDonald et al. 1991).

A typical study design can have as few as three, or as many as 15-20 cross sections located in a study reach. A reach has been variously defined as 20-50 bankfull flow widths (Kondolf and Micheli 1995), a thousand meters (Knopp 1993), or a predetermined length based on the geomorphic characteristics of the watercourse under study. For example, Madej and Ozaki (1996) defined a 26-kilometer long study area on Redwood Creek from its confluence with the Pacific Ocean to a slope-determined end point. Within the study area, the 26-kilometer stream segment was divided into three interconnected reaches: upper, middle, and lower. A total of 58 cross sections were nested within the three reaches, with the end points of each reach determined by major breaks in stream gradient.

The cross sectional profile is measured along a tape stretched across the stream. Distance, surface water, and streambed elevations at each specific point along the tape are recorded. Streambed characteristics, such as changes in bottom elevations, the position of the field-estimated bankfull height, riffle crests, breaks in slope, and the deepest points in the particular channel feature are recorded. The end points of the cross section are arbitrary, but should extend at least above the estimated bankfull stage and preferably beyond the current floodplain.

<u>Thalweg profiles:</u> Pools, logs, boulders, riffles, etc. add complexity to the channel that affect sediment transport, channel form, and fish habitat. The variability of the thalweg along a longitudinal axis in the stream is a good measure of complexity of the wetted stream channel. Changes in the thalweg profile reflect overall changes in the channel complexity, which result from channel-forming forces. Reduction of complexity occurs with excessive sediment introduction. Increased complexity indicates a recovery from such a condition. Thalweg profiles provide information on existing conditions, but are also useful in trend analysis over the long term.

Strictly implemented, a thalweg profile or survey measures the elevations along the water surface and the thalweg of the stream. Particular care is taken to measure all breaks-in-slope, riffle crests, maximum pool depths, and pool tail-outs. Concurrently, while the tapes, levels, etc., are set up for measuring thalweg profiles, the locations of transects for cross sections are also usually documented and measured (Madej and Ozaki 1996, Ramos 1996). Since it is practically impossible to uniformly arrange the longitudinal tape exactly over the thalweg, measurements are perpendicularly referenced to the centerline tape, and read to the closest one-tenth meter. Ramos suggests that when intersections occur, the thalweg should be measured first then the cross section before proceeding upstream. Other variables such as bar height, substrate size, high water marks, and comments on local channel features such as pools, riffles, runs, and the presence or absence of large woody debris are also recorded. Subsequent analysis of the profile allows the detection of changes in the vertical dimensions of channel features.

Depending on the data obtained from the thalweg survey, standard parametric and non-parametric statistical methods can be applied to more fully interpret survey results.

The reach length surveyed in a thalweg profile varies from 20 to 50 channel widths depending on the study's intent. Rather than channel widths, surveys can also be modeled around a specific number of meander segments, generally three to four, within a reach (Madej and Ozaki 1996, Trush 1997, Rosgen 1996). The important consideration in selecting a length is the ability of the study design to answer any questions or hypotheses proposed, such as changes in channel aggradation or degradation, or available pool and riffle habitat for salmonids and other instream biota.

Pebble counts: One of the most widely used methods of sampling grain size from a streambed is the pebble count technique (Wolman 1954). It can be used as a simple and rapid stream assessment method to help determine if land use activities or natural land disturbances are introducing fine sediment into streams (Potyondy and Hardy 1994). Pebble counts are routinely used by geomorphologists, hydrologists, and others to characterize the bed material particle size distributions of wadeable, gravel bedded streams. The procedures have been adapted in fisheries studies as a preferred alternative to visually characterizing surface particle sizes commonly used during instream flow studies (Kondolf and Li 1992). The methodology is best applied in gravel and cobble streams with a single channel. It is not applicable to lower gradient, sand-bed dominated channels.

Pebble counts are conducted by randomly collecting, counting and measuring the intermediate diameter (b-axis) of 100 to 200 (Kappesser 1993) particles from the surface of a given streambed. Riffles deemed suitable for spawning salmonids are the preferred location for sampling efforts (Schuett-Hames et al. 1999). Pebbles are collected along transects following a predetermined grid pattern, or by walking the streambed and picking up individual pebbles at the toe of a boot along a zigzag pattern. Whether the structured grid pattern or the toe method is used, all transects should traverse the stream channel from the estimated bankfull to bankfull stage.

Cumulative size distribution curves are developed from at a sample size of at least 100 pebbles, and the D_{50} (median particle size, the diameter at which 50% of the particles are finer), and the D_{16} and D_{84} calculated. Other analyses that may be applied are the geometric mean diameter: $dg = D_{84} \times (D_{16})^{0.5}$ and the geometric sorting coefficient: $sg = (D_{84}/D_{16})^{0.5}$ (Kondolf and Li 1992). As mentioned, it has been shown that shifts toward the lower end of the pebble count cumulative frequency curves may be indicative of significant increases in streambed fines from accelerated natural and or land-use disturbances. Conversely, a progressive coarsening of streambed surface particles may indicate improving conditions from past upstream and/or upslope disturbances.

Streambed Cores: The only way to determine the composition of the streambed below the surface is to remove a core and analyze it for particle size distribution. Methods of core sampling include McNeil style core samplers, freeze-core samplers, and shovels. Basically, a sample is removed from the streambed and run through sieves to determine the amount of material within particle size categories. When done in the field, samples usually are wet-sieved and the fractions are measured by volumetric displacement. A set of samples is also taken back to the lab for drying and analysis by weight to provide conversion factors for volume to weight for the particular geologic type. Samples also can be removed wet to the laboratory, dried, and analyzed by weight.

Data are expressed as percent of the core within different size classes, allowing one to characterize the streambed particle distribution and relate it to sediment transport mechanisms and suitability for salmonid spawning and egg incubation. We use the methods described in Valentine (1995).

Biological sampling: Macroinvertebrate samples are obtained using "D" nets per the California Stream Bioassessment Procedure (CDFG 1999, NCRWQCB 2003). Sampling sites are selected according to guidance provided in those protocols as well as knowledge of the watershed and land uses upstream of the site.

Qualitative observations of algal growths are supplemented by grab samples. Identification of algal assemblages is performed at the Regional Water Board laboratory, and relative abundance is delineated.

Other interesting, descriptive, or unusual biota is noted at the time of sampling to provide additional qualitative information on the relative health of the water body.

Data Analysis

Data obtained from other sources most often are provided in summary format. For instance, water temperatures are commonly collected from temperature loggers as described above. Data loggers take temperature readings many times during a day (often exceeding 24 times per day). However, the component data (hourly readings) usually are not made available. Instead, we most often are provided with summary statistics, such as maximum, mean, minimum, and maximum weekly average temperature (MWAT) for the data collection period. In these cases, we are unable to evaluate the data as described below. Instead data quality is evaluated and summary statistics are used. Figure 19 is an example of a summary plot for water temperatures in the North Fork Gualala River.

Data that are collected or provided to the NCRWQCB are treated as follows:

Data are entered into a database and converted to formats appropriate for analysis of the information, e.g., spreadsheets for dissolved oxygen, flow, and temperature. Data analysis is tailored to data type and quality. For example, water temperature data from continuous data loggers is evaluated using raw data plots over time and cumulative distribution plots against water quality criteria, TMDL targets, or water quality objectives (WQOs). This allows determination of the frequency of exceedances (percent of observations and number of days), duration of exceedances (how many hours was a particular standard exceeded in a day), and maximum daily excursions. For example, Figure 20 is a raw data plot of continuous water temperatures graphed with the EMDS temperature ratings.

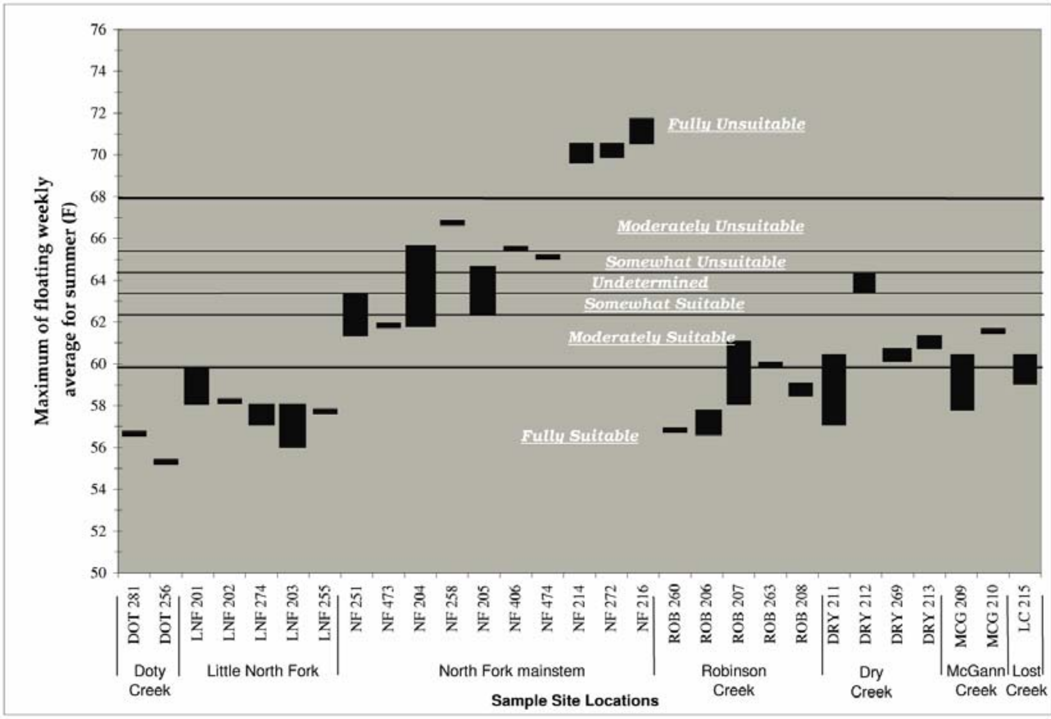


Figure 19. Summary of MWAT values for the North Fork Gualala River Subbasin

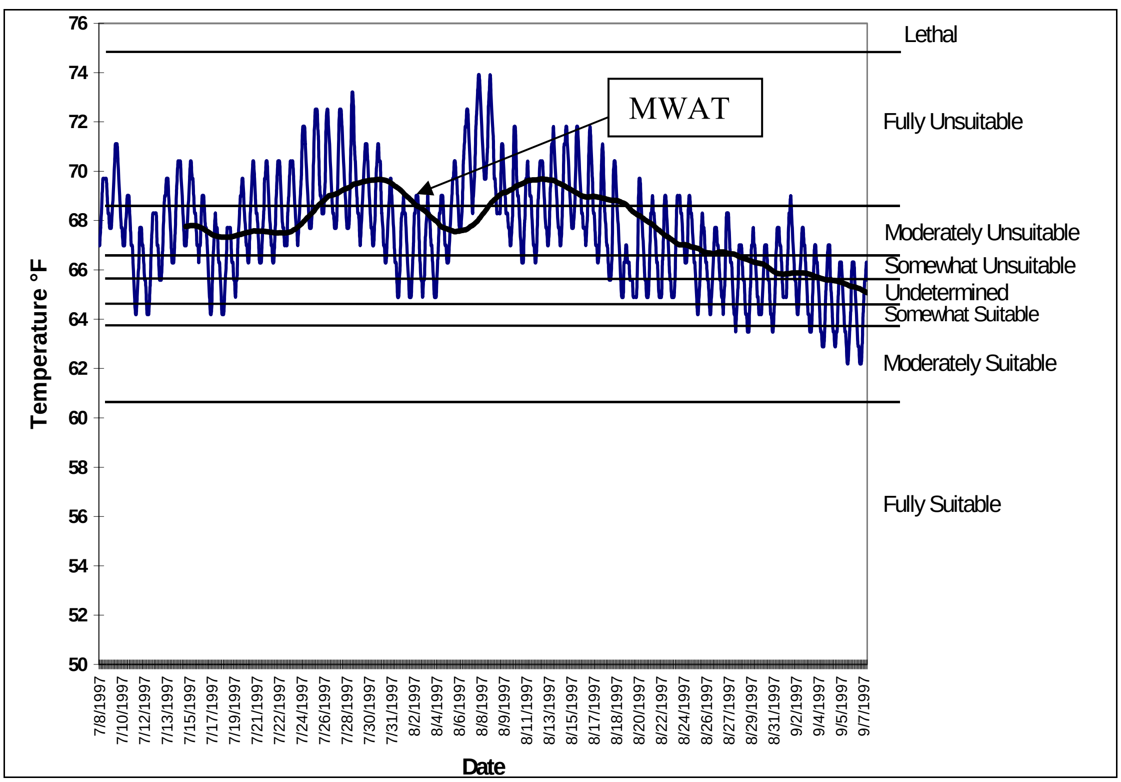


Figure 20. Raw data plot of continuous water temperatures with EMDS ratings

The cumulative distribution of the same raw data is depicted in Figure 21. This type of plot is used to determine the percentage of time that particular criteria or levels are met or exceeded. In this example, water temperatures are within the EMDS "suitable" ranges about 3 percent of the time, in the "undetermined" area about 7% of the time, in the "unsuitable" ranges about 90% of the time. The species is subjected to temperatures outside the "suitable" ranges about 97% of the time, but never exceeding the short-term maximum.

Other water quality parameters (including flow and diversion information) are subjected to similar analyses using raw data plots and cumulative distribution plots, as well as statistical methods (e.g., nested analysis of variance to analyze data from stations in different sub-watersheds).

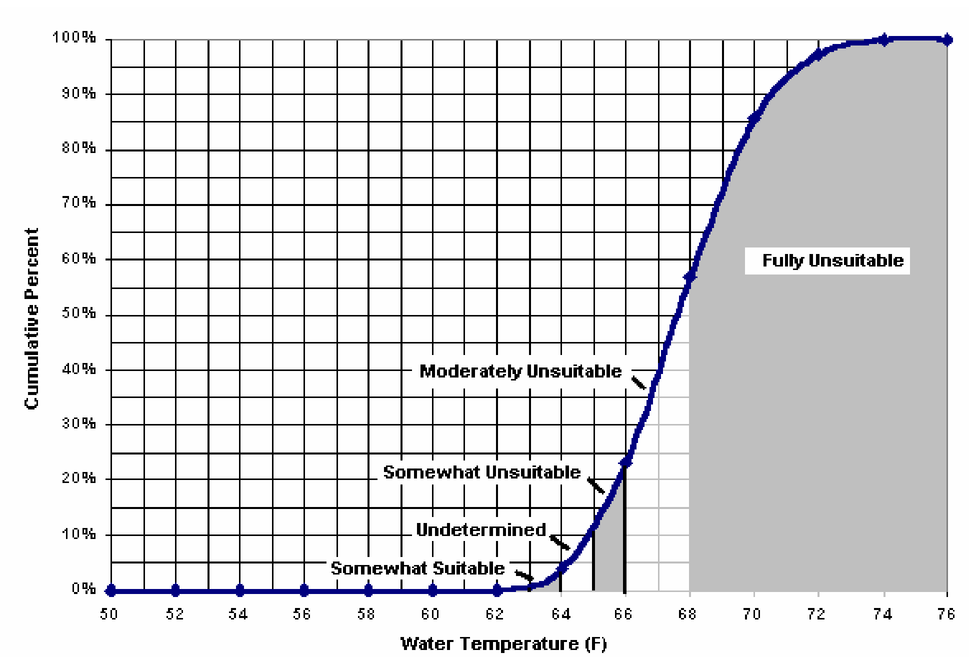


Figure 21. Cumulative distribution of water temperature data from a single site with example EMDS ranges

Limitations

The usefulness of these data is limited by the clarity of connections among watershed perturbations and the stream. Temporal considerations come into play in those links, with some current physical conditions the result of past disturbance in the watershed. Likewise, short-term disturbances not measurable today, may have translated to effects in the stream that are evident from distribution, diversity, and abundance of the biota.

Other factors that limit water quality assessments include the numbers and spatial density of measurements, the time frame for assessment (shorter equates to less detailed analysis), and limitations on access for data collection due to landowner concerns.

3.7 FISH HABITAT

The Department of Fish and Game is responsible for collecting and analyzing data related to anadromous salmonid habitat and production for the NCWAP assessments. Habitat requirements of anadromous salmonids vary by species, season, and life stage. All salmonids need spawning, incubation and rearing habitat to complete their complex life cycles. If habitat conditions needed during a particular life stage are impaired or absent, some level of reduced growth and/or mortality will occur in the population (Reeves et al. 1989).

This section addresses key habitat components that affect anadromous salmonid production and describes the approach used by the North Coast Watershed Assessment Program to help assess the status of stream and fish habitat. This information is essential for assessment of factors limiting production of salmonids. Further discussion of limiting factors analysis and its underlying premises are provided in the limiting factors analysis section of this manual (Chapter 4.2).

To understand present and potential fish production in stream systems, it is necessary to know the status of watershed processes and how their products work together to create or alter successful fish habitat relationships. Stream channel classification, sediment delivery and transport mechanisms, riparian conditions, water quality, and water quantity are ultimately expressed as instream habitat. The integration of all the above components produces fish habitat and helps determine success of fish in a stream system. A stream and fish habitat inventory provides information regarding the status of a basin, stream, or reach, and insight to help evaluate its ability to support salmonid populations.

Stream and fish habitat inventory methods have been developed by state and federal agencies and private consultants (Platts et al. 1983, Reeves et al. 1989, Schuett-Hames et al. 1994, Flosi et al. 1998, Berbach et al. 1998, O'Connor Environmental, Inc. 1999, Taylor 2000). These inventory methods involve different levels of effort for data collection at different scales. The multi-scale approach examines a variety of conditions in the stream, and the parameters that influence those conditions such as riparian, large woody debris recruitment, and sediment delivery. Inventories can include: classification of channels; habitat typing; development of instream shelter ratings; substrate characterization and gravel composition surveys; riparian canopy measurements; inventories of large woody debris; monitoring water quality; and identification of upstream or downstream barriers to fish movements.

Results from stream and fish habitat inventories can be compared to reference conditions considered essential to salmonids at different life stages. As described in the limiting factors analysis section of this manual, reference conditions for habitat target values are derived using an interdisciplinary approach. Many values are contained in Department of Fish and Game's *California Salmonid Stream Restoration Manual* (Flosi et al. 1998) in order to help guide restoration and management decisions.

Questions and Issues

The Department of Fish and Game has posed a series of questions to facilitate investigation of fish habitat relationships:

- What are the current salmonid habitat conditions in watersheds and how do these compare to target conditions favorable for fish?

- Do current habitat conditions reflect the numbers of salmon and steelhead returning to streams as adult spawners?

- Do habitat conditions provide the diverse habitats needed to support all life stages of salmon and steelhead?

- What role does large wood play within the watershed in relation to fish habitat, channel morphology, and sediment storage?

- How well will near stream vegetation provide wood for streams in the future?

- What is the frequency of pools compared to other habitats and how does this relationship vary within the watershed?

- What percentage of the reach length is composed of pools deep enough to be considered primary pools?

- Do barriers affect upstream or downstream fish movement at any life stage?

- Where do fish barriers exist and what are the classifications of these barriers (temporary, seasonal, permanent, natural, or unnatural)?

Approach

To address these questions about fish habitat relationships, the Department of Fish and Game and the assessment team investigate abiotic and biotic factors contributing to salmonid habitat. Abiotic factors include:

- Water quality
- Channel type
- Habitat type
- Habitat diversity
- Habitat complexity
- Large woody debris
- Substrate composition
- Shelter availability

Biotic Factors include:

- Aquatic/riparian condition

- Predators present
- Food availability
- Aquatic and terrestrial vegetation

Data Sources and Gaps

In order to investigate abiotic and biotic factors affecting salmonid habitat, the Department of Fish and Game compiles existing available data and anecdotal information pertaining to instream habitat and enters it into a database. DFG, other agencies, watershed groups, and landowners have conducted various stream and fish habitat inventories for many streams on the North Coast. Anecdotal and historic information is cross-referenced with other existing data whenever possible, and rated for quality. Both types of data are used when information is of good quality and applicable. Instream habitat information gaps are mapped and matched with corresponding land parcels. Where data gaps are identified, access is requested from landowners to conduct instream habitat evaluations. Landowner cooperation is necessary for acquiring existing privately held data and gaining access to lands for collecting new data.

Data Collection

Much of the data used for assessment of fish habitat relationships is collected during DFG stream habitat evaluation surveys. Generally, habitat evaluation surveys are conducted from the mouth of a stream to the upstream end of anadromy. This methodology allows DFG to draw conclusions about the status of salmonid habitat throughout the entire surveyed stream. However, when only certain streams within a basin have been surveyed, the assessment can only draw conclusions about those specific streams surveyed, and not the basin as a whole. Unfortunately, this is often the case since DFG is limited by personnel and time constraints and access issues.

Given the limited time frame to complete the assessment process, it is not always possible to inventory the entire portion of a basin supporting salmonids and supply the missing data. Therefore, DFG employs a fractional sampling strategy in some in basins that do not have continuous stream data.

This sampling strategy employs the current DFG habitat inventory protocol, but selects sample survey reaches within a basin based on a random stratified design and restricts the length of stream surveyed. Sample reaches are selected based on an equal probability random tessellation stratified (RTS) survey design with an over sample (Olsen 2000) to develop a set of spatially balanced sampling points in the area of interest. The length of the sampling reach is determined by multiplying the average bank full width by 20. The product is the number of feet surveyed in the reach. However, a minimum length of 500 feet and a maximum length of 1500 feet are also used for sites with extremely narrow or wide bank full widths. The sites are inventoried using DFG protocols, measuring 100% of the selected reach. These sites do not necessarily represent the entire reach of any stream. Unlike the typical DFG stream inventory protocols, these data only represent site-specific attributes because the sample size is too small for characterizing entire streams. However, due to the site selection process the results are useful to characterize the nature of the entire study area.

DFG follows protocols outlined in the *California Stream Habitat Restoration Manual* (Flosi et. al 1998) when conducting the following habitat evaluations:

Stream Channel Typing. A standardized habitat typing inventory form based on Bisson et al. (1982) has been developed by DFG for conducting stream surveys. The DFG habitat inventory employs the Rosgen (1994) delineation criteria for categorizing stream channel types. There are nine components to the standard habitat assessment process described on the form. All methods mentioned are fully described in Flosi et al. (1998).

Habitat Typing. The diversity of habitat necessary to support salmonid populations is formed by dynamic interactions between a stream ecosystem and its watershed. Climate, geology, stream flows, stream gradient, substrate, sediment routing, vegetation, inputs of woody debris, and land use activities all interact in channel and habitat forming processes. The cumulative interactions between these components are expressed as various channel classes and habitat types (i.e. pools, flatwaters, and riffles). These habitats become more complex considering the biotic and physical functions of large wood, riparian vegetation, and substrate. Channel and habitat typing are conducted according to methods presented in Flosi et al. (1998).

Instream Shelter Rating. The percentage of shelter provided by various structures (i.e. undercut banks, woody debris, root masses, terrestrial vegetation, aquatic vegetation, bubble curtains, boulders, or bedrock ledges) is described in DFG surveys. The dominant shelter type is elucidated and then the percentage of a stream reach in which the dominant shelter type is provided by organic debris is calculated. Pool shelter is also measured during DFG surveys. Pool shelter rating illustrates relative pool complexity.

Substrate Composition. Stream channel substrates provide important components of salmonid habitat and the aquatic ecosystem. In addition to sediment size, the amount of sediment in a stream and the filling of pools or silting of spawning gravels are all important habitat characteristics. Data on sediment sources and deposition in streams are collected by NCWAP according to methods presented above under *Water Quality* and *Sediment Production and Transport*. Additional information pertinent to fish habitat are collected according to methods presented in Flosi et al. (1998).

Riparian Canopy Density. Near-stream forest density and composition contribute to microclimate conditions that help regulate air temperature, which is an important factor in determining stream water temperature. Furthermore, canopy levels provide an indication of the potential present and future recruitment of large woody debris to the stream channel, as well as the insulating capacity of the stream and riparian areas during winter. In general, the percentage of stream canopy density increases as drainage area and therefore, channel width, decreases. Deviations from this trend in canopy may indicate streams with more suitable or unsuitable canopy relative to other streams of that subbasin. Canopy density, and relative canopy density by coniferous versus deciduous trees are measured at each habitat unit during DFG stream surveys.

Large Woody Debris Inventory. The importance of large woody debris (LWD) in the development of a stream's morphology and biological productivity has been well documented (see review in Lassettre and Harris 2001). Fish populations benefit from cover and habitat diversity created by LWD as well as the food source provided by benthic macroinvertebrates that use LWD as a substrate (Sedell et al. 1988). LWD inventories are conducted according to DFG methods presented in Flosi et al. (1998).

Water Quality. Stream flow, water temperature, dissolved oxygen, turbidity, nutrients, and chemical pollutants are important parameters of water quality that affect fish habitat. Besides flow, water temperature is one of the most important environmental factors affecting virtually every aspect of a fish's life (Armour 1991). Adverse temperatures may reduce growth rates and can affect fish behavior, disease resistance, and result in mortality (Sullivan et al. 2000). Water quality data collection is conducted by NCWAP according to methods previously presented in this manual (see Chapter 3.6, Water Quality).

Fish Passage Barriers. In the freshwater phase in salmonid life history, stream connectivity is essential for survival. Stream access describes the absence of barriers to the free instream movement of adult and juvenile salmonids. Free movement allows salmonids to find food, escape from high water temperatures, escape from predation, and migrate to and from their stream of origin as juveniles and adults. Dry or intermittent channels can impede free passage for salmonids; temporary or permanent dams, poorly constructed road crossings, landslides, debris jams, or other natural and/or man-caused channel disturbances can also disrupt stream connectivity. Data on dry channels is collected during DFG stream habitat inventories. NCWAP also uses Ross Taylor and Associates reports of fish passage at road-stream crossings in several Northern California counties. Inventories and fish passage evaluations of culverts within the Humboldt County and the coastal Mendocino County road systems were conducted between August 1998 and December 2000 by Ross Taylor and Associates, under contract with the Department of Fish and Game's Fishery Restoration Grants Program (Taylor, 2000b, 2001). In addition, other counties' assessments have now been completed.

Pool Tail Embeddedness. Cobble embeddedness is an indicator of the suitability of substrate for spawning, egg incubation, fry emergence and aquatic invertebrate production. At least five small cobbles (2.5 to 5.0 inches) are sampled at pool tail outs (where spawning is likely to occur) to visually estimate the average percent buried in fine substrate (the shiny lower portion of the cobbles). The value is assigned to a category. Category 1 = 0-25% embedded, Category 2 = 26-50% embedded, Category 3 = 51-75% embedded, Category 4 = 76-100%, and Category 5 = unsuitable for spawning due to factors other than embeddedness (e.g. log, rocks). High embeddedness may indicate elevated delivery of fine sediments to the aquatic system.

Data Analysis

Data analysis protocols are outlined in the *California Stream Habitat Restoration Manual* (Flosi et. al 1998). Table 12 shows how data is summarized in tabular form from a DFG survey.

Figure 22 through Figure 25 are graphical examples of how habitat inventory data are presented in NCWAP'S Mattole River Watershed Assessment report. These figures include discussions of how these factors are assessed using criteria developed for NCWAP within the EMDS tool (Chapter 4).

Table 12. Summary of current (1995, 1997, and 2001) conditions based upon habitat inventory surveys from the North Fork Subbasin, Gualala River , California

Habitat Element Stream Name	Surveyed Length (feet)	Canopy Cover	Embeddedness	Primary Pool Depth/ Frequency	Shelter Cover Ratings
North Fork Subbasin*					
Doty Creek	6,237	74%	25%	4%	36
Dry Creek	11,161	58%	70%	6%	32
Dry Creek Tributary #1	2,695	59%	51%	22%	30
Little North Fork	20,806	76%	83%	16%	54
Log Cabin Creek	1,698	83%	90%	1%	43
McGann Gulch	1,980	76%	0%	3%	5
North Fork	59,362	78%	82%	29%	28
Robinson Creek	7,819	66%	65%	3%	70

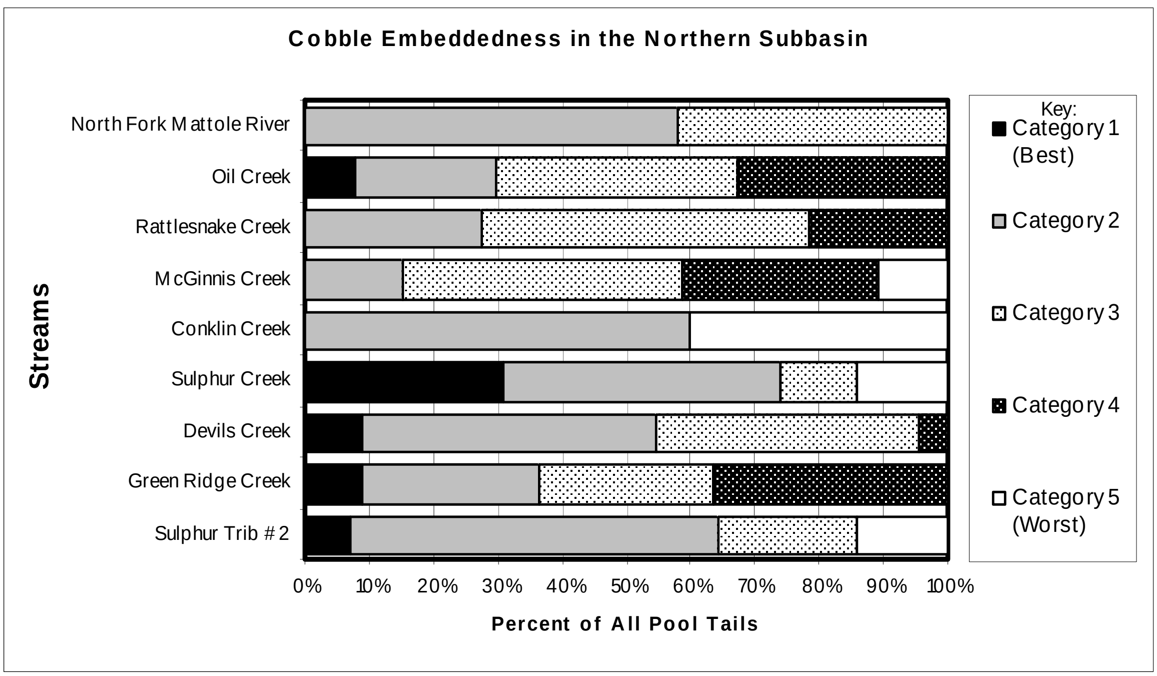


Figure 22. Cobble embeddedness categories as measured at pool tail crests in surveyed streams, Mattole River Northern Subbasin. Substrate embeddedness Categories 3, 4, and 5 are considered by EMDS to be somewhat unsuitable to fully unsuitable for the survival of salmonid eggs and embryos. Streams are listed in descending order by drainage area (largest at the top).

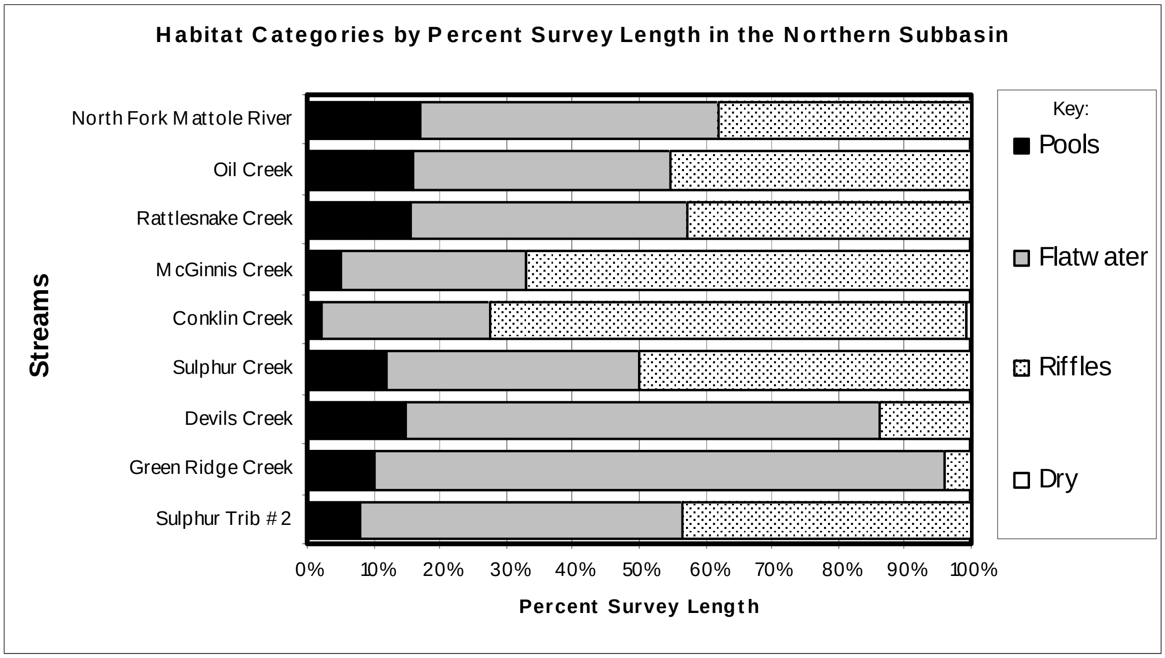


Figure 23. Percentage of pool habitat, flatwater habitat, riffle habitat, and dewatered channel by surveyed length, Mattole River Northern Subbasin. EMDS does not evaluate the ratio of these habitat types, but a balanced proportion is desirable. Streams are listed in descending order by drainage area (largest at the top).

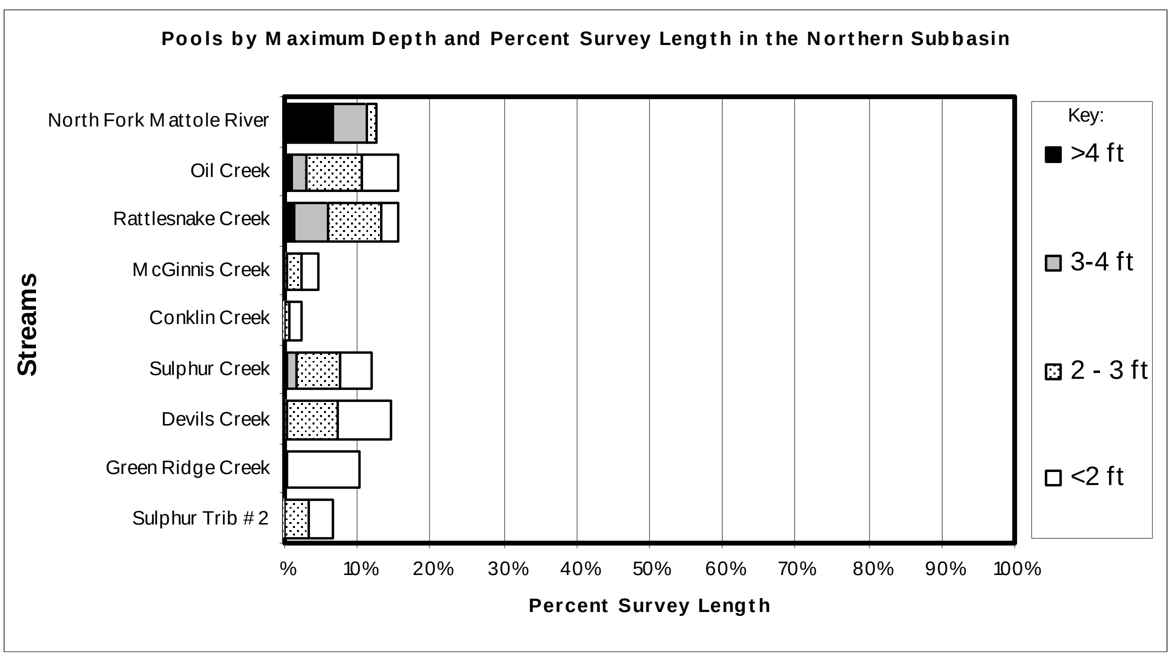


Figure 24. Percent length of a survey composed of deeper, high quality pools, Mattole Northern Subbasin Values sum to the length of percent pool habitat in Figure 23. As described in the EMDS response curves, a stream must have 30-55% of its length in primary pools to provide stream conditions that are fully suitable for salmonids. Streams with <20 % or >90% of their length in primary pools provide conditions that are fully unsuitable for salmonids. Streams are listed in descending order by drainage area (largest at the top).

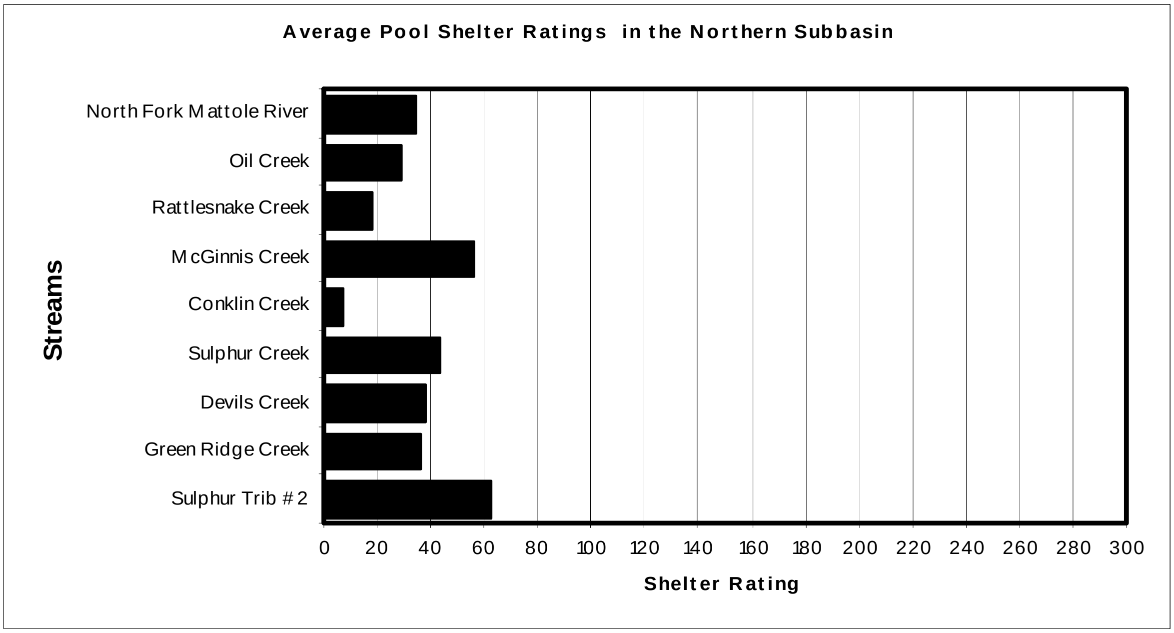


Figure 25. Average pool shelter ratings from CDFG stream surveys, Mattole River Northern Subbasin

As described in the EMDS response curves, average pool shelter ratings exceeding 80 are considered fully suitable and average pool shelter ratings less than 30% are fully unsuitable for contributing to shelter that supports salmonids. Streams are listed in descending order by drainage area (largest at the top).

In addition to standard tabulations and mapping typically provided with DFG stream habitat surveys, the primary use of fish habitat data is for limiting factors analysis and refugia habitat condition ratings. Information collected through the random sampling method is also used for these analyses, but less emphasis is placed on these results due to the limited representation of the overall stream network. In addition, both continuous and random sampling stream habitat surveys are used for formulating habitat improvement recommendations.

Limitations

Fish habitat relationship assessment is based on the assumption that fish are responding to the cumulative interactions among physical, chemical, and biological components of watersheds. The general assumption is that fish numbers are directly related to habitat quality. Fish population data are required to validate this assumption. Although some population data are available for the NCWAP assessment area, they are quite limited both spatially and temporally. Therefore, validation of the results of fish habitat studies and limiting factor analysis depends on future population monitoring.

It is not likely that the same amount of fish habitat data is available for all watershed assessments. Continuous sampling sites provide sufficient data to understand stream conditions and build stream improvement recommendations at the basin scale. Random stratified sampling provides data at the sub-basin scale for understanding stream conditions and developing recommendations. Therefore, high quality data are abundant in some watersheds while it is sparse or of questionable quality in others. As a result, the degree of confidence in results varies from basin to basin.

Finally, outside factors such as weather, flow conditions, ocean conditions, etc. All influence numbers of adults returning to reproduce. Thus, factors extraneous to freshwater habitat can mask how well fish are responding to habitat conditions.

3.8 FISH HISTORY AND STATUS

It is generally accepted that many of California's salmon runs have declined sharply over the span of the last century. Currently Chinook, coho, and steelhead are listed under the Endangered Species Act as federally threatened. These three species and coastal cutthroat are also listed as species of special concern by the California Fish and Game Commission. Moreover, coho are State listed as threatened north of San Francisco to the Oregon border. The importance of monitoring these species has increased with these listings and related efforts to restore salmonid habitat and improve fish populations.

Comprehensive research and monitoring to determine fish populations throughout a watershed area requires time and sufficient personnel. Such efforts go beyond the limited time frame and resources of NCWAP. Therefore, current Department of Fish and Game data is supplemented with reliable, available information developed by other agencies, private landowners, and non-profit organizations. The collective dataset is used to determine current salmonid status and distributions throughout the various assessment watersheds.

Approach

To assess the status of fish history and status, the Department of Fish and Game and the assessment team investigate historic and current salmonid population data. Department staff compiles existing available data and anecdotal information pertaining to salmonid populations and distribution. A limited amount of new biological data on salmon and steelhead is also collected through spawner surveys, snorkel surveys, electrofishing, and downstream migrant trapping.

Questions and Issues

Questions to be answered during the assessment include:

- What was the historic distribution of fish populations throughout the watershed?
- What was the historic distribution of each species of salmonids within the watershed?
- What is the current distribution of each species of salmonids within the watershed?
- What is the current status of fish populations throughout the watershed?
- Are native stocks currently supplemented or have they previously been supplemented with hatchery stocks?
- Has monitoring been conducted for a time period long enough to detect measurable changes in salmon populations?
- Have previous restoration projects improved salmonid populations?
- Have exotic species been introduced and have there been impacts to salmonids associated with exotics?

Data Sources and Gaps

The Department of Fish and Game, other agencies, non-profit organizations, and landowners have conducted biological sampling for numerous streams on the North Coast. Existing data are collected and evaluated for scientific credibility and utility for assessment. Next, data gaps are identified and new field investigations are designed and conducted to address these gaps if possible.

Sufficient biological and fish population data are not available for all NCWAP basins. Where fish population and distribution inventory data are lacking, NCWAP makes recommendations for future monitoring. Landowner cooperation is necessary for acquiring privately held existing data and gaining access to lands to collect new data.

Data Collection

Stream Inventories. Biological sampling during DFG and NCWAP stream inventories is used to determine existing fish species and their distribution in the stream. Biological sampling methods include: streambank observation, snorkel surveys, electrofishing, and carcass surveys. These surveys are conducted according to protocols presented in Flosi et al. (1998). Salmonid distribution is obtained using the Modified Ten Pool Protocol (Preston et al. 2001) with snorkeling and Smith Root Model 12 backpack electro-fishing units. The Ten Pool Protocol was designed to detect the presence of coho salmon and is not a valid method for calculating fish density or age class structure (personal communication, L. Preston).

Coho Assessment Project. In addition, the Coho Assessment Project adopted a systematic 10 Pool Survey Protocol to represent coho distribution in north coast streams as presented in Jong et al. (2000). Their findings are also used by NCWAP.

North Coast Watershed Assessment Program and Department of Fish and Game personnel perform quality control and assurance on all data collected during stream surveys. DFG crews review information collected on a daily basis. Biologists and other pertinent personnel also inspect data incorporation into assessment reports. As mentioned earlier, NCWAP relies on supplementing data collection with previous research and studies, anecdotal information, and verbal communication with local residents and resource professionals. In most cases, the means of verifying data accuracy is through careful examination of material and discussion of its legitimacy with the agency, individual or organization that provided the information.

Data Analysis

Biological data obtained from historic records and current biological studies are used to examine historic and current salmonid population status and distributions.

Historic. Although historic population numbers do not exist for most basins, historic accounts are used to obtain a general idea of salmonid abundance. Additionally, maps of estimated historic distributions are generated. The limits of the estimated range of steelhead trout, the most athletic of the north coast salmonids, are initially defined as a stream reach of 1000 feet or more with a gradient in excess of 10%. The limits of the coho and Chinook salmon range estimates are defined as reaches of 1000 feet or more with a gradient in excess of 5%. Initial species distribution estimates are thus generated with 10-meter digital elevation model (DEM) analyses. Preliminary range estimates are then reviewed by a team of DFG and other fishery biologists in collaboration with local biologists and residents. Historic accounts are also used to validate historic salmonid distribution maps.

Current. Available streambank observation, snorkel survey, electrofishing, and carcass survey data are used to describe current salmonid populations and distributions. Where possible, a list of salmonid species detected in basin tributaries, and tables and maps of the extent of anadromy are produced. Where more detailed population data exist, they are summarized to estimate populations and salmonid status. Available data concerning stocking and fish enhancement projects also are summarized. If possible, comparisons of fish populations before and after enhancement projects are made. Last, available data concerning sensitive species, salmonid predators, and exotic species is summarized.

Limitations

Although some population data are available for streams in the assessment area, data are quite limited both spatially and temporally. In some watersheds, existing data are abundant. In other watersheds, data may be sparse or of questionable quality. Therefore, it is not likely that the same level of fish population data is available for all assessments. As a result, the degree of confidence in results varies from basin to basin.

Constraints such as lack of funds, limited personnel, and variable stream conditions contribute to irregularity of fish population monitoring and research in many basins; thus, reliable data are generally scarce. Current methods utilized (i.e. DFG electro-fishing conducted for stream survey inventories and various carcass surveys) do not necessarily contribute to meaningful population estimates.

3.9 DATA QUALITY CONTROL AND ASSURANCE

The quality of data gathered from other sources or directly collected by North Coast Watershed Assessment Program staff determines its utility for watershed assessment. Basically, the quality of data decreases when variability in the methods used for collection increases (Montgomery 1996). Collection of new data by NCWAP agencies can be done in accordance with a stated level of quality. While NCWAP has no control over the quality of data acquired by others, categorizing those data provides a perspective on their relative utility. Categorizing data according to quality ensures that the data fit assessment needs. It also avoids misuse of data by assigning different weight to data of different quality (Brossman et al. 1985, Montgomery 1996, Taylor 1985).

Guidelines for assessing the quality of existing data, as well as for collecting new data are presented in the sections below. The following discussions are intended to provide an overview of the quality assurance and quality control (QA/QC) principles for reviewing data and collecting new data, and as such are not extensive. The reader is referred to the large body of literature available on QA/QC for more detail and specific methods.

Quality control and assurance on existing data

Most existing data from agency and scientific sources was collected subject to quality control and assurance standards. This is not necessarily true for data from local watershed groups, agencies, and landowners. Experience has shown that those data were collected in a variety of formats for various reasons using various techniques. Assimilating the information into the assessment requires that the data first be evaluated for utility in answering watershed assessment questions.

Metadata describe details about purpose and objectives, methodology, and other quality assurance and control factors. These factors can be evaluated to determine the relative quality of the information and thus its potential level of use in an assessment. Data collected with low precision may be more useful for assessment screening purposes. Likewise, data collected for one purpose may not be appropriate for another purpose due to the collection sampling design.

Some data are easier to evaluate than others. Traditional water quality data, including pH or dissolved oxygen, can be screened using a fairly clear decision process to judge its quality. Spatial data present special problems, and habitat data may be rather subjective. There is an element of subjectivity in any data quality determination, and subjectivity increases as strict regimented techniques give way to more loosely defined methodologies.

Data Screening Approach

Four categories of data quality have been identified for the North Coast Watershed Assessment Program:

1. Excellent (suitable for the most detailed and robust analysis)
2. Good (suitable for most watershed assessment needs, characterizes a process or condition providing evidence from which to draw specific conclusions)

3. Fair (characterizes a process or condition on a broad basis to provide a perspective)
4. Poor (only useful for screening or broadly qualified statements)

A number of criteria are considered in assigning existing data to a quality category. These pertain to the purpose for which the data were collected, the sampling design, methods used, data precision and other factors. Different screening procedures are used for spatial and non-spatial data. Some relevant questions include:

- *Are these data collected at a level of detail appropriate to the analysis for assessment?*

  For example, data collected at a sub-watershed scale may not be useful for making conclusions about conditions on a stream reach basis. Data collected on a reach basis may be analyzed to make statements on a sub-watershed scale, even providing statistical metrics to further define such statements. Data quality categorization reduces the likelihood that data will be used inappropriately.

- *Is there sufficient documentation accompanying these data to feel comfortable in drawing conclusions?*

  The data may be robust (highly dense or large numbers of observations), but lacking in sufficient documentation to define specific methodology, thereby creating uncertainty about use. The level of uncertainty affects the ultimate use of the data (and perhaps the way in which the data are analyzed) as well as the conclusions drawn from the data. Clearly identifying the characteristics of the data that result in its categorization will assist in quantifying the uncertainty associated with a decision arising from the data.

- *Are these data representative of conditions in a selected unit of scale (temporal and spatial)?*

  Site selection, sampling design, and level of resolution are important considerations when determining if a data set represents watershed conditions. For instance, water quality data collected in the summer low flow period in an estuary may adequately represent conditions at that site for that time of year, but are not useful in characterizing the site in the winter. Data quality categorization is necessary to determine how representative data are for answering assessment questions.

It is important to recognize that although qualification of all data is desirable - many sources do not include sufficient metadata or raw data to allow this (e.g., data includes the average, but not the numbers used to calculate the average, nor any statistic on dispersion). In those cases, judgment based on experience and the agreement of those data to data of known quality are used to make the categorization.

Quality control and assurance for GIS data

The North Coast Watershed Assessment Program has developed several geographic information system (GIS) data layers, as previously described in this manual, including current and historical land use, vegetation, in-stream habitat features data, road and stream networks, geology, landslides, and landslide potential. GIS data typically consist of point, linear, or extensive data that represent some phenomenon of concern within a spatial (geographical) context. The inherently spatial nature of these data greatly facilitates a land-based approach to watershed assessment.

Two main types of errors typically occur in GIS data layers. First, the polygon area perimeter, linear feature, or data point may be misplaced in the geo-referenced framework (i.e., an error in position). This "spatial error" can cause incorrect inferences to be drawn with regard to the watershed and cumulative effects, depending on the magnitude of the error (i.e., distance from its actual location). For example, a misplaced road might cross a perennial stream twice in one locality in the data layer, when in fact it does not cross at all. If uncorrected, this spatial error could lead to an inaccurate assessment of the level of disturbance on a given stream reach.

The second type of error occurs when a feature (point, line or polygon) is incorrectly labeled. These "thematic errors" are misidentifications of the conditions observed at a given (correct) spatial location. In some cases the error may have negligible effects, as when the feature is mislabeled with a label from a closely related category (e.g., dirt vs. paved road). When a grossly incorrect label is applied, the error may have larger consequences for the assessment.

The standard procedure for assessing GIS data accuracy is to compare thematic labels (spatial locations are not usually directly addressed) against some independent source of very similar information, often collected from field visits. The field and GIS-developed data are then compared, in the form of a confusion or error matrix, and a parameter is derived (Kappa statistic) indicating the level of agreement between them. Type I (omission) and type II (commission) errors are computed. Any differences are typically ascribed to errors in the GIS-developed data layers.

The QA/QC for current and historical land use and road network is conducted in the following ways:

1. As data layers near completion, staff not directly involved in their development reviews them for data inconsistencies and obvious spatial and thematic errors.
2. GIS data layers of existing phenomena (i.e., not of historical conditions), are validated against field information using standard methods. In those instances, a stratified random approach may be used to select field sites to visit, in some cases weighting them towards areas of greater concern or uncertainty. (About half of the field data points are used to assist in labeling the GIS data, while the remainder may be used for validation.)
3. GIS data layers for historical data are validated using consensus or majority opinion from the judgment of several parties experienced in the watershed, or in the interpretation of aerial photography. This is because events that occurred decades ago may no longer be visible on field visits.
4. Some data are pre-released to watershed groups, stakeholders and other parties with interest or experience in the watershed to review the data layers and offer feedback. Comments and suggestions received from this "beta test" are incorporated in the data layers.

5. Metadata are produced to explain the data layer development and important parameters and caveats. A protocol is employed similar to that developed by the Resources Agency's California Environmental Resources Environmental System (CERES).
6. A final review of the data product is done prior to its formal release.

The GIS layers produced should be viewed as "version 1" of the data they present, not as immutable output "written in stone." In this way they are analogous to software releases, which although very valuable and useful, contain errors that over time are addressed and "fixed" as the information improves with time and more thorough long-term review occurs. Watershed groups and personnel from state agencies using the data should provide feedback on GIS products, to assist in updates and maintenance.

Quality control and assurance on new field data

Just as categorizing data that others provide is important, defining the level of quality for new field data collection is essential (Mitchell et al. 1985, Taylor 1985). The first step in developing a program for quality control and assurance is defining the level of quality for data collection.

Quality assurance combines training and feedback with quality control checks for accuracy and precision. Data collectors must be trained and their work checked to assure collection of data is consistent with the data quality category selected for data collection.

Quality control involves checks on accuracy and precision with procedures to follow when a measurement does not fall within acceptable ranges. Quality control procedures are well developed for most routine water quality measurements, and can be adapted to other measurements such as channel geometry measurements and habitat typing.

Approach

Data quality goals for new collections must first be established (Mitchell et al. 1985, Montgomery 1996). For much of the fieldwork, the categories of data quality presented above are used to define the characteristics of new field data collected under the program. However the process is reversed to first determining the quality of data needed, then devising means to achieve that level of quality.

For instance, water quality data are collected at a minimum quality of *Good*, except for robustness (number of samples criterion), which is limited by access and budget. This level of quality implies the following characteristics:

- *Purpose/objectives:* These are specific and clearly stated.
- *Sampling design*: The density of sites is sensitive to the number of tributaries to the stream. Specific problems with seasonality are addressed and a statistical design is used for sampling.
- *Reliability:* Data precision is $\pm$10%. Measurements are more than twice the detection limit (this factor comes into play after analysis of a sample and generally cannot be

predicted). Data are collected using a good field meter, in the centroid of flow, without confounding factors, and data collection is well-documented and controlled.

- *Robustness:* 10-20 samples are collected within the evaluation period.

An effective quality control and assurance program collects meaningful data on a scale and in a way that is useful for answering assessment questions. Additionally, categorization of data quality allows commingling of data from various sources (Mitchell et al. 1985, Taylor 1985).

Once the quality of data to be collected is determined, appropriate levels of quality assurance and control are applied. These include specifying the data collection personnel and roles, providing training at the appropriate level, and checking on performance (Brossman et al. 1985, Stanley and Verner 1985). These elements must be satisfied before entering the field. In the field, data quality is enhanced by use of field manuals providing written protocols for reference. Field data sheets help maintain data quality by ensuring that data elements are not overlooked and by documenting meta-data needs.

Quality control checks are applied during data collection. This is relatively easy for water column measurements like pH, where equipment calibration is routinely checked for accuracy and duplicate samples are analyzed for instrument precision. Quality control charts with acceptable levels of accuracy and precision are developed for measurements of that type.

Field collection of habitat data and channel characteristics is modified from the example provided above. Those data are collected within levels of accuracy and precision specified for specific equipment (levels, tapes, rulers). Precision is tested by repeat measurements. When observations are somewhat subjective (e.g., some habitat elements), measurements are also repeated by different teams. After collection, instream data are entered into a computer application that summarizes certain parameters and generates graphs and other summaries. Data are then reviewed by manually checking each field for "out of range" values, actual data value entries, and other primary data errors typically associated with a data entry. After this quality check, data are converted to a spatial format. During conversion, length and measurements are checked against 1:24,000 scale USGS topographic maps and the associated "routed" hydrography.

CHAPTER 4: INTERDISCIPLINARY ANALYSIS AND SYNTHESIS

A major challenge in watershed assessment is integrating and synthesizing a large amount of information from multiple sources and disciplines in a fashion that allows the exploration and understanding of the interrelationships among watershed process, land use activities, and conditions. Reid (1996) discusses 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.

The North Coast Watershed Assessment Program met the challenge of interdisciplinary analysis and synthesis both through **process** methods and through **analytical** approaches.

The **process** methods used by NCWAP to conduct interdisciplinary analysis and synthesis center on the use of multidisciplinary teams that spend a significant amount of time together conferring, presenting, and discussing to ensure that the participants from each discipline fully understand each others' scientific underpinnings, methods, approaches, and findings. Team members work together to develop working hypotheses, findings, conclusions, and recommendations for the basin and subbasins. This "working hypothesis" approach is described toward the end of this chapter.

The **analytical** methods used by NCWAP to examine causal relationships among watershed processes, activities and conditions, and to describe trends and trajectories within the watershed include the use of the Ecosystem Management Decision Support Model, a fish habitat limiting factors analysis, and a fish refugia analysis. NCWAP also developed a number of tabular presentations of data intended to examine relationships among land use, landslides, relative landslide potential, and sediment sources contributing to streams referred to as "integrated analysis" tables.

4.1 ECOLOGICAL MANAGEMENT DECISION SUPPORT WATERSHED MODEL

The North Coast Watershed Assessment Program selected the Ecological Management Decision Support system (EMDS) (Reynolds 1999a, 1999b; http://www.fsl.orst.edu/emds/) software to help evaluate and synthesize information on watershed and stream conditions important to salmonids during the freshwater phases of their life history. It is a type of 'expert system' software that uses 'linguistic' models and a formal branch of mathematics termed 'fuzzy logic' to evaluate data against specified criteria. This approach helps to conceptualize and assess how well complex systems, such as watersheds, are functioning for fish.

EMDS is made of knowledge base models that describe and evaluate how watersheds function with regard to environmental factors (e.g. watershed geology, stream sediment loading, stream reach condition, land use activities, etc.) that shape anadromous salmonid habitat. EMDS employs a linked set of software that includes MS Excel, NetWeaver, the 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. These networks are then used in conjunction with environmental data stored in a Geographic Information System (GIS – ArcView™) to perform the assessments and facilitate rendering the results into maps. This combination of software is also currently being used for watershed and stream reach assessment within the federal lands included in the Northwest Forest Plan (NWFP).

NCWAP Models

NCWAP agency scientists developed an approach including models for anadromous stream reach, potential sediment production, water quality, and fish food conditions. These models are intended to evaluate the suitability of watersheds for salmonids, and to conduct limiting factors analysis and identification of anadromous salmonid refugia habitat. They use available data and new data developed by NCWAP. NCWAP makes limited use of EMDS' Potential Sediment Production model outputs in some of the initial watershed synthesis reports due to lack of sufficient scientific information to improve them according to suggested modifications from a scientific peer review panel. Although the program implemented several of the panel's recommendations, future assessment program efforts should continue to refine the model. Appendices G and H contain more details of EMDS and the development of NCWAP models.

The two key EMDS models in use by NCWAP, anadromous reach condition and potential sediment production, are presented in Figure 26 and Figure 27. Data and methods may not be available to populate all of the variables shown. Available data have varied across the watersheds assessed to date by NCWAP. "Grayed out" elements of the potential sediment production model were not implemented in the first five NCWAP assessments due to the lack of data or the unavailability of models, such as SEDMODL 2.0, at the time.

EMDS models are used to assess the degree of truth (or falsehood) of a proposition unique to that model. In the NCWAP EMDS, the core proposition is that watershed conditions are suitable for salmonids. Since it is hierarchical, any given node assesses the proposition that all the factors leading to it to provide suitable conditions at that level. For example, when working within the Potential Sediment Production model, the node below the label "Potential Stream Sediment from Natural Processes" would evaluate whether the combined streamside erosion conditions (which in turn includes bank and inner gorge erosion and landslides) and mass wasting conditions are suitable for salmonids. This principle operates from the most highly aggregated nodes on the left-hand side of the model to the individual parameters found on the right-hand side.

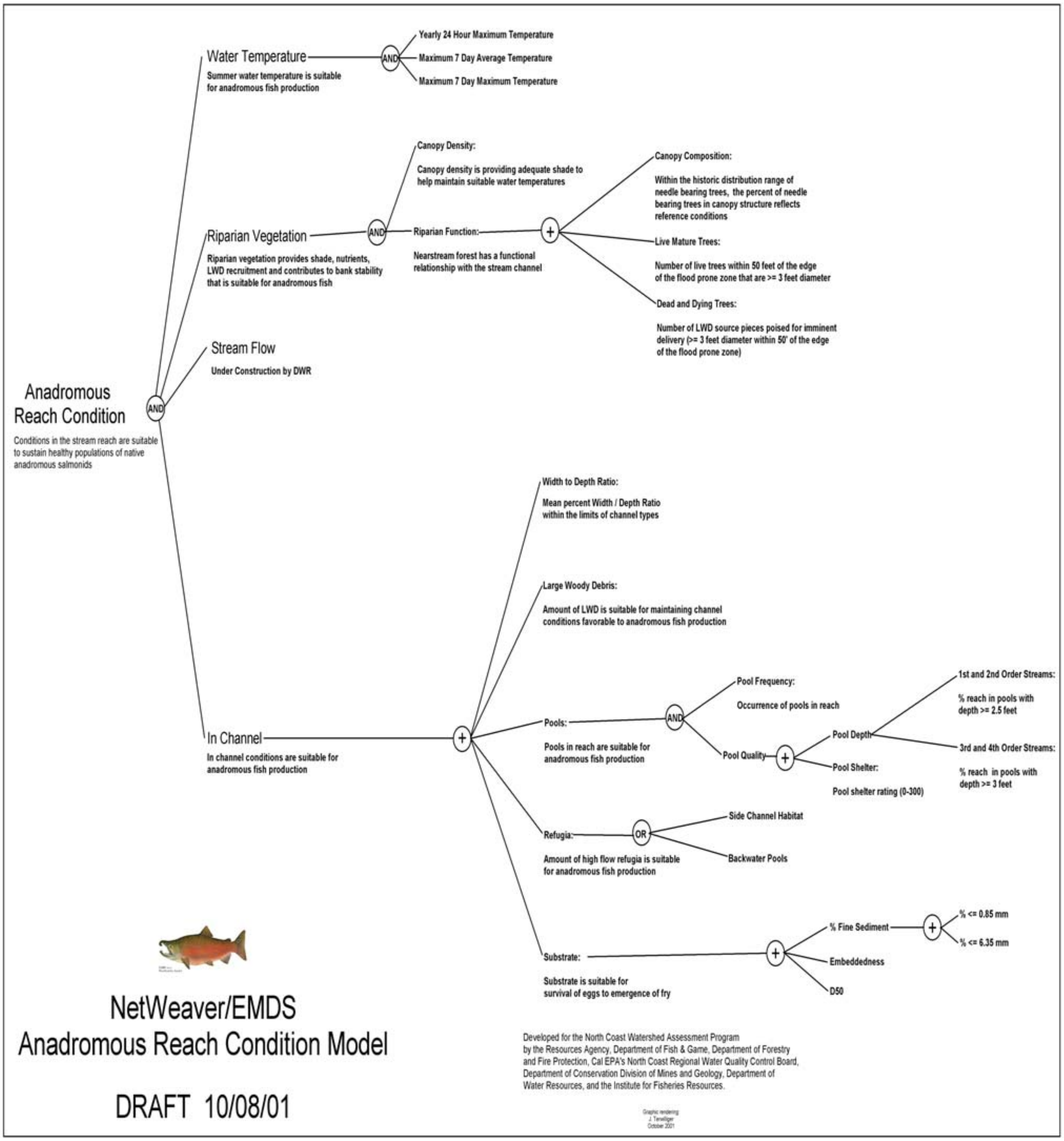


Figure 26. NCWAP EMDS anadromous stream reach condition model.

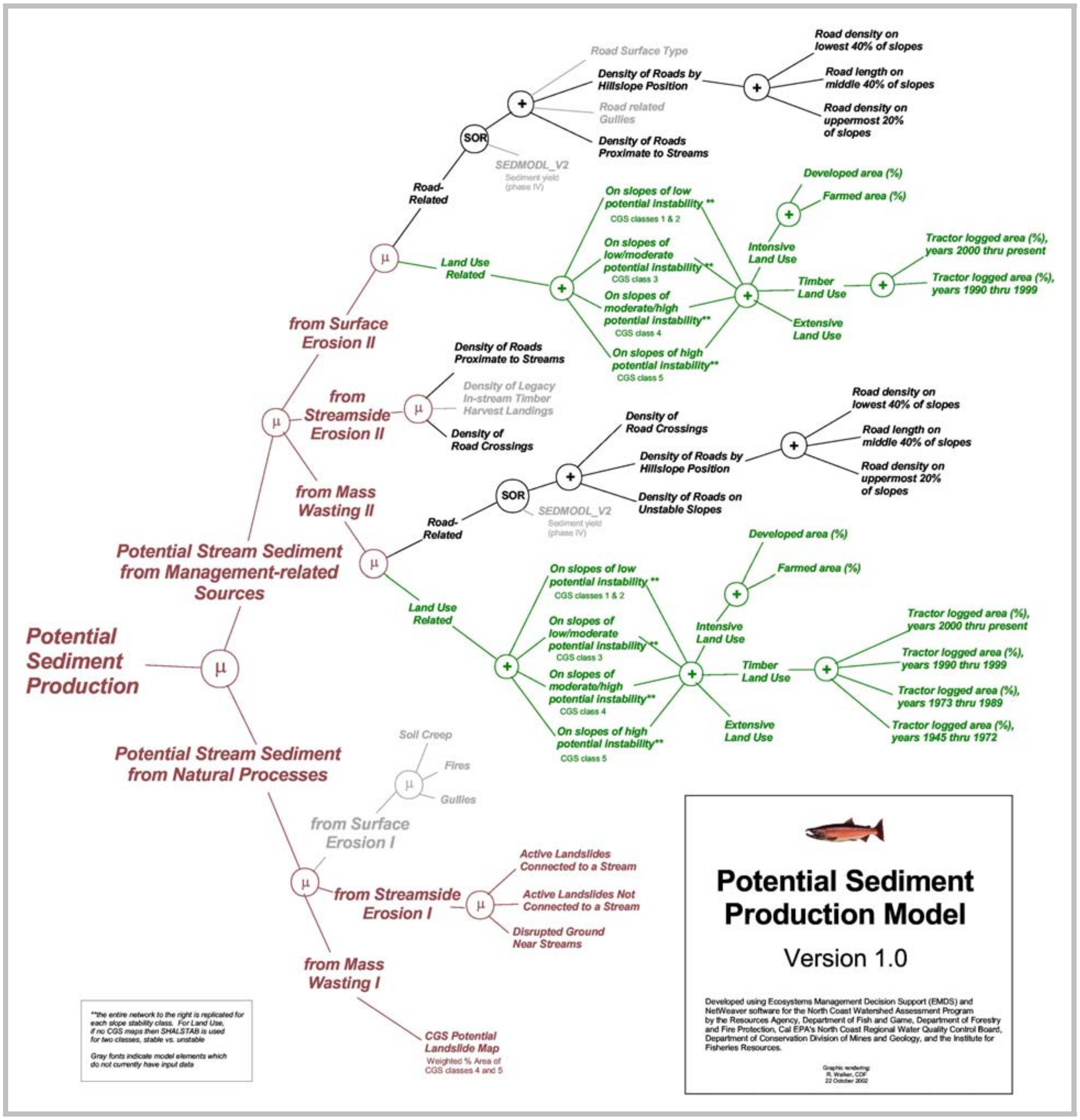


Figure 27. NCWAP EMDS potential sediment production model.

Building Reference Curves

At each node in the model, the individual and combined factors are evaluated in reference to simple graphs called reference curves that determine their degree of truth/falsehood (with respect to the proposition that conditions are suitable for salmonids), according to the data's implications for salmon. Figure 28 shows an example reference curve for the proposition, *the water 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.

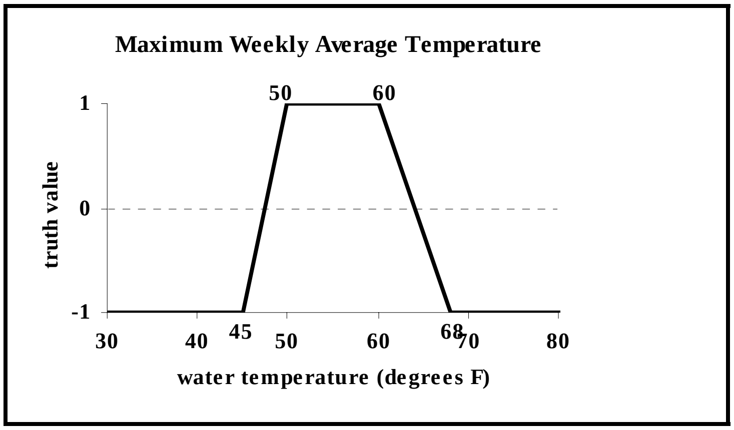


Figure 28. EMDS reference curve.

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.

Thus, for each evaluated proposition in the EMDS model network, the result is a value between –1 and +1. The value is proportional to the degree to which the data support or refute the proposition. In all cases a +1 means that the proposition is completely true, and –1 implies that it is completely false, while in-between values indicate degrees of truth (i.e., values approaching +1 being closer to true and those approaching –1 converging on completely untrue). A zero value means that the proposition cannot be evaluated based upon the data available. Breakpoints (where the slope of the reference curve changes) in the Figure 28 example occur at 45°, 50°, 60° and 68 °F. For the Stream Reach model, fisheries biologists determined these temperatures by a review of the scientific literature.

While fisheries biologists determined reference curves based on the scientific literature for the Stream Reach model, there were no appropriate scientific studies for many of the assessment parameters, particularly those relating to upland geology and management activities. Therefore NCWAP scientists used an empirically based approach for creating reference curve breakpoints for the potential sediment production model. Specifically, for each evaluated parameter in the potential sediment production model, the mean and standard deviation were computed for all planning watersheds in a basin. Breakpoints were then selected with which 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 10^{th} and 90^{th} percentiles serving as the low and high breakpoints (Figure 29).

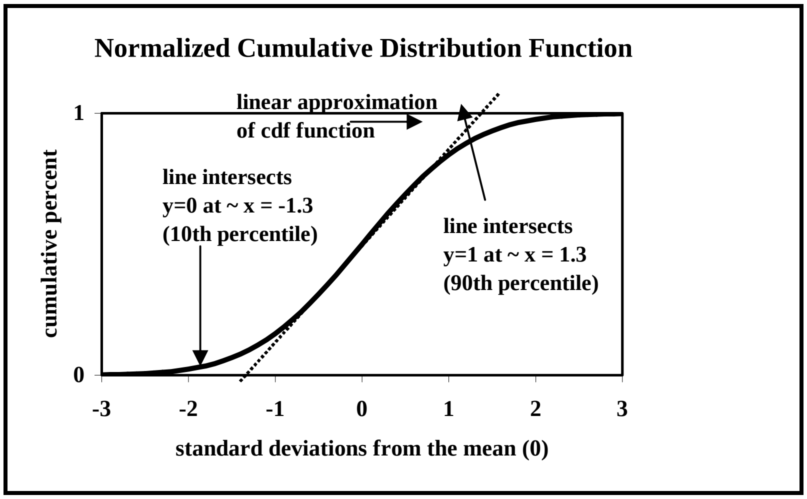


Figure 29. Normalized cumulative distribution function.

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. (Note: The science review panel recommended that this empirical method of determining breakpoints be changed. They advised the use of a set of reference watersheds from the region, computing the distributions of land use and other parameters from those watersheds to determine breakpoints. Unfortunately, reference watershed data were not available to this process. This issue must be addressed in future watershed assessments and the breakpoints adjusted as the information from reference watersheds becomes available.)

Map Products from EMDS

Map legends used a seven-class system for depicting the EMDS truth-values. Values were classed as follows:

+1.0	Fully suitable or highest suitability
0.99 to 0.50	Moderately suitable
0.49 to 0.01	Somewhat suitable
0.0	Uncertainty
-0.01 – 0.49	Somewhat unsuitable
-0.50 – 0.99	Moderately unsuitable
-1.0	Fully unsuitable or lowest suitability

In EMDS, the data fed into the knowledge base models come from GIS layers stored and displayed in ArcView. Thus, EMDS was able to readily incorporate many of the GIS data layers developed for the program into the watershed condition syntheses. Figure 30 portrays an example map of EMDS results.

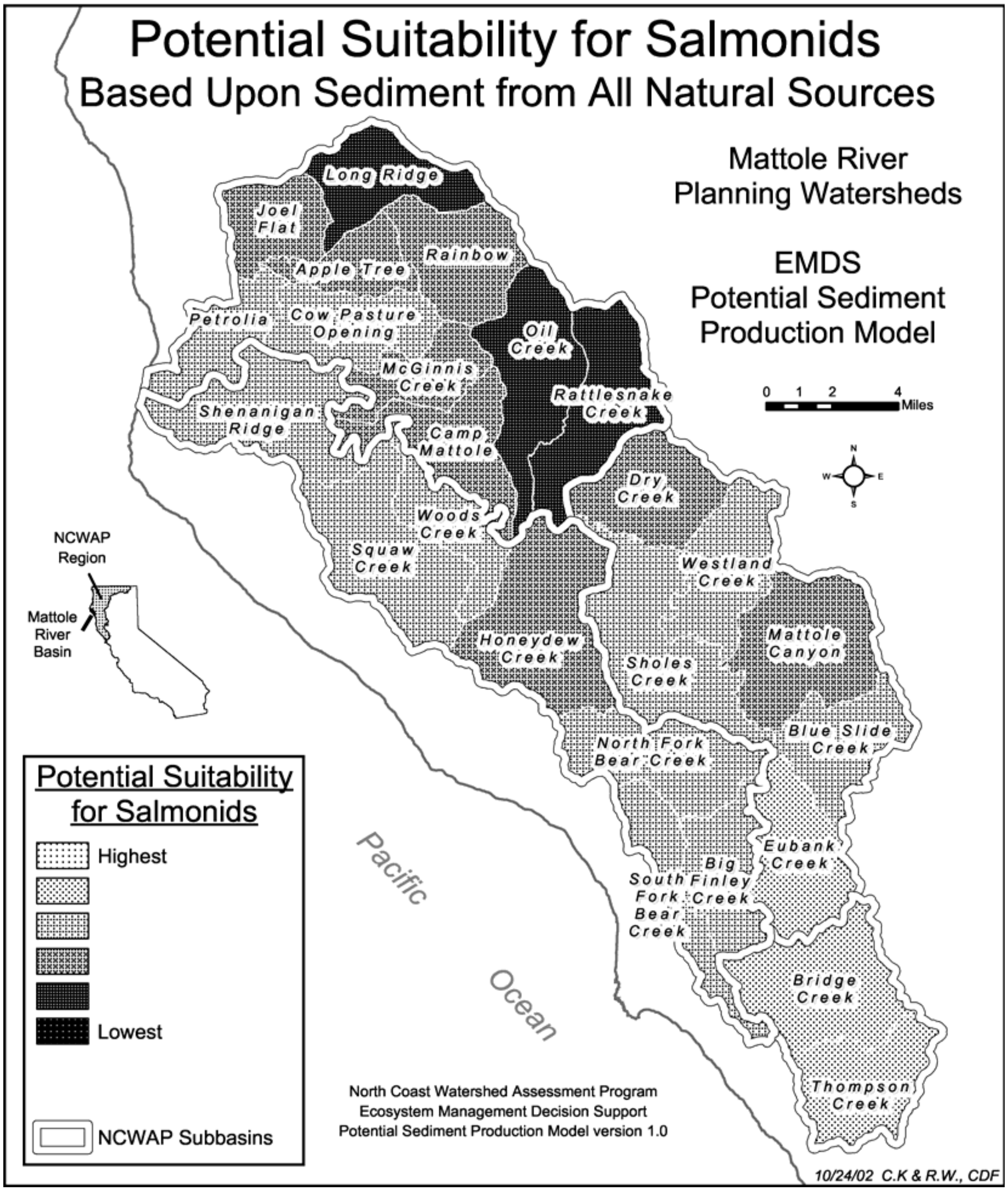


Figure 30. EMDS graphical output.

This example illustrates the graphical outputs of an EMDS run. This demonstration graphically portrays the relative amounts of potential sediment production in the Mattole Basin that comes from natural sources.

Table 13 provides an example of how EMDS results can be presented in a tabular format. The stream habitat components are assigned a general overall score with respect to suitability for anadromous salmonid production. The '+ + +' (+1.0) scores represents fully suitable conditions, + + (.99 to .5) demonstrates moderately suitable conditions, and + (.49 to.01) displays somewhat suitable conditions. A '- - - ' **(**-1.0**)** represents fully unsuitable conditions, a '- -' (-.99 to -.5) demonstrates moderately unsuitable conditions, and '-' (-.49 to -.01) displays somewhat unsuitable conditions. A '0' represents data that lies between suitable and unsuitable conditions, or there is a lack of any data to categorize. These overall scores provide a general overview of current stream conditions and may be used to focus on areas for habitat improvements.

Table 13. Summary from Redwood Creek Upper Subbasin EMDS stream reach evaluation

Stream	Reach Length (ft)	Reach number	Reach Condition	Canopy Density	Pool Quality	Pool Depth	Pool Shelter	Embeddedness
Fern Prairie Creek	852	1	-	+ + +	- - -	- - -	- - -	0
Upper Redwood Ck	13996	1	-	-	- -	- - -	- - -	-
Minon Creek	1101	1	-	+ +	- - -	- - -	- - -	+
Minon Creek	1784	2	-	+ + +	- - -	- - -	- - -	+ +
Minon Creek	3294	3	-	+ + +	- -	- - -	- -	0

Specific NCWAP Models

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

The Stream Reach Condition model. Parameter definition and breakpoints for this model (shown in Table 14) are based on reviews of the scientific literature The fundamental unit of DFG stream surveys is the stream reach, which is defined as a continuous length of stream characterized by a homogenous channel type (Rosgen 1994, Flosi et. al 1998). Thus a stream may be composed of one or more reaches depending on changes of channel gradient, entrenchment, dominant substrate particle size, width to depth ratio, or sinuosity (Rosgen 1994). For evaluation at the stream, subbasin, and basin scale, EMDS scores are weighted according to each stream reach length. Scores from long reaches carry more weight than those from short reaches. The equation for calculating stream reach weighted average for identifying stream, subbasin and basin scale limiting factors is:

$$\text{Weighted Average by Stream Reach} = \frac{\sum L_i S_i}{\sum L_i}$$

Where: L_i = reach length

S_i = EMDS score by reach

The Potential Sediment Production model. Parameter definitions and respective weights are shown in Table 15. Parameters not used in the model for lack of data are noted (grayed out) in the table. All breakpoints for this model were determined empirically (i.e., based upon percentiles of the data distributions for each of the three basins), due to time constraints and the use of parameters that have no equivalents or surrogates in the scientific literature.

The Water Quality model. This model was also under development. Water temperature was to be modeled with software such as Stillwater Sciences' BasinTemp. Methods for modeling stream flow parameters were not determined.

The Fish Food Availability model was never developed.

Table 14. Reference curve metrics for 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^o F fully unsuitable, 50^o -60^o F fully suitable, >68^o 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 greater and -0.8 evaluate to fully false
Percent fines in substrate <0.85mm (dry weight)	Percent of fine sized particles <0.85 mm collected from McNeil type samples. <10% fully suitable, > 15% fully unsuitable. There was not enough of percent fines data to use Percent fines in EMDS evaluations
Percent fines in substrate < 6.4 mm	Percent of fine sized particles <6.4 mm collected from McNeil type samples. <15% fully suitable, >30% fully unsuitable. There was not enough of percent fines data to use Percent fines in EMDS evaluations
Large Woody Debris (LWD)	The reference values for frequency and volume is derived from Bilby and Ward (1989) and is dependent on channel size. See EMDS Appendix (B)for details. Most watersheds do not have sufficient LWD surveys for use in EMDS.
Winter high flow habitat	Winter high flow habitat is composed of complex backwater pools, side channel habitats and complex deep pools (>3 feet deep). Not implemented at this time.
Pool to Riffle Ratio	Under development
Width to Depth Ratio	Under development

Table 15. Reference curve metrics for EMDS sediment production risk model, Version 1.0.

Sediment Production Factor	Definition*
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
Mass Wasting I	The mean truth value from natural mass wasting: Landslide Potential, Deep-seated Landslides, and Earth Flows
Landslide Potential	A selective OR (SOR) node takes the best available data to determine landslide mass wasting potential.
CGS Landslide Potential Map	(1st choice of SOR node) Percentage area of planning watershed in the landslide potential categories (4 and 5)
Landslide Potential Class 5	Percentage area of watershed in class 5 (CGS rating)
Landslide Potential Class 4	Percentage area of watershed in class 4 (CGS rating)
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
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
Surface Erosion I	The mean truth value from natural processes of surface erosion: Gullies, Soil Creep, and Fires
Gullies	Density of natural gullies in planning watershed (currently no data supplied to model here)
Soil Creep	Percentage area of planning watershed with soil creep (currently no data supplied to model here)
Fires	Percentage area of planning watershed with high fire potential (currently no data supplied to model here)
Streamside Erosion I	The mean truth value from natural processes of streamside erosion: Active Landslides Connected to Watercourses; Active Landslides Not Connected to Watercourses; Disrupted Ground Near Watercourses
Bank Erosion	Percentage of stream length in planning watershed with bank erosion
Inner Gorge Landslides	Percentage of stream length in planning watershed with inner gorge landslides
Non-inner Gorge Landslides	Percentage of stream length in planning watershed with non-inner gorge landslides
Management-related Processes	The mean truth value from Mass Wasting II, Surface Erosion II, and Streamside Erosion II knowledge base networks
Mass Wasting II	The mean truth value from management-related mass wasting: Road-related and Land Use-related
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
SEDMODL_V2	(when model is available – 1st choice of SOR node)
Density of Road/Stream Crossings	(2nd choice of SOR node, averaged with DRHP directly below) Number of road crossings/km of streams
Density of Roads / Hillslope Position	Weighted sum of road density by slope position (weights determine relative influence, and sum to 1.0)
Road length on lower slopes	Density of roads of all types on lower 40% of slopes
Road length on lower slopes	Density of roads of all types on mid-slope (41-80 % of slope distance)
Road length on upper slopes	Density of roads of all types on upper 20% of slopes
Density of Roads on Unstable Slopes	Density of roads on geologically unstable slopes
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
On slopes of *low* potential instability	Slope stability defined by CGS map classes 1 and 2 (or SHALSTAB if CGS maps unavailable)
On slopes of *low/moderate* potential	Slope stability defined by CGS map class 3 (or SHALSTAB if CGS maps

Sediment Production Factor	Definition*
instability	unavailable)
On slopes of *moderate/high* potential instability	Slope stability defined by CGS map class 4 (or SHALSTAB if CGS maps unavailable)
On slopes of *high* potential instability	Slope stability defined by CGS map class 5 (or SHALSTAB if CGS maps unavailable)
Land Use related mass wasting parameter details (evaluated separately for each category of potential slope instability)	
Intensive land use	
- - developed areas	Percentage of the planning watershed area in high density buildings and pavement
- - farmed areas	Percentage of planning watershed area in intensive crop cultivation
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
- - Era 1 (1990 – 1999)	Tractor logged area 1990-1999
- - Era 2 (1973 – 1989)	Tractor logged area 1973-1989
- - Era 3 (1945 – 1972)	Tractor logged area 1945-1972
Ranched area	Percentage of watershed area used for grazing livestock; estimated based on vegetation type and parcel type
Surface Erosion II	The mean truth value from management-related surface erosion: Road-related and Land Use-related
Road-Related	Fine sediment contribution to streams from roads from either SEDMODL_V2 (first choice) or the mean of Density of Roads 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)
Density of Roads Proximate Streams	(2nd choice of SOR node, averaged with 3 subsequent road-related measures directly below)
Density of Roads Hillslope Position	Weighted sum of road density by slope position
Road length on lower slopes	Density of roads of all types on lower 40% of slopes
Road length on lower slopes	Density of roads of all types on mid-slope (41-80 % of slope distance)
Road length on upper slopes	Density of roads of all types on upper 20% of slopes
Density of Road-related Gullies	Density of gullies related to roads
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)
Land Use related	Fine sediment contribution to streams from intensive, timber harvest, and ranched areas (*see below in table***)
On slopes of *high* potential instability	Slope stability defined by CGS map class 5
On slopes of *moderate/high* potential instability	Slope stability defined by CGS map class 4
On slopes of *low/moderate* potential instability	Slope stability defined by CGS map class 3 (or SHALSTAB if unavailable)
On slopes of *low* potential instability	Slope stability defined by CGS map classes 1 and 2 (or SHALSTAB if unavailable)
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
- - Farmed areas	Percentage of planning watershed area in intensive crop cultivation
Area of timber harvests	Percentage of planning watershed area tractor logged, by time period
- - Era 0 (2000 – present)	Tractor logged area 2000-present
- - Era 1 (1990 – 1999)	Tractor logged area 1990-1999
Ranched area	Percentage of planning watershed area used for grazing livestock; estimated based on vegetation type and parcel type
Streamside Erosion II	The mean truth value from management-related streamside erosion: Road-related and Land Use-related

Sediment Production Factor	Definition*
Density of Roads Proximate to Streams	Length of all roads within 200' of stream ÷ length of all streams
Density of Road/Stream Crossings	Number of road crossings/km of streams
Density of Instream Timber Harvest Landings	Number of legacy timber harvest landings instream per unit length of stream

*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

Advantages Offered By Netweaver/EMDS/Arcview™ Software

The Ecological Management Decision Support system offers a number of advantages for use in assessment. Instead of being a hidden black box, the models have an open and intuitively understandable structure. The explicit nature of the model networks facilitates 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 GIS software, EMDS maps the factors affecting fish habitat and shows how they, in combination, vary across a basin. This link to a GIS is vital to the production of maps and other graphics reporting the watershed assessments. EMDS models also provide an explicit, consistent and repeatable approach to evaluating watershed conditions for fish. In addition, the maps from supporting levels of the model show the specific factors that, taken together, determine overall watershed conditions. This latter feature helps to identify phenomena or activities most limiting to salmonids in a watershed (see section on Limiting Factor Analysis), and thus can assist in prioritizing restoration projects or modifying land use practices. Other applications of EMDS are described in the Appendix.

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-base network and breakpoints. This feature allows "what-if" scenarios to be run by changing the shapes of reference curves, or by changing the way the data are combined and synthesized in the network.

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

Limitations of the EMDS Model and Data Inputs

EMDS results require interpretation. 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. Outputs needed to be considered and interpreted in the light of other information sources, the inherent limitations of the model, and data inputs. Where possible, validation of the model using fish population data, expert opinion, 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. Any future work using EMDS will need to address this issue.

In the first five basin reports, the North Coast Watershed Assessment Program uses the Ecological Management Decision Support system to indicate the quality of watershed or instream conditions based on available data and the model structure. It is not intended to provide highly definitive answers, such as from a statistically based process model, but rather provides a reasonable first approximation of conditions through a robust information synthesis approach.

During the course of this program, we were not able to implement all of the recommendations made by our peer reviewers. Hence, the model outputs should be used with caution. It also should be clearly noted that our EMDS models do not assess the marine phase of the salmonid lifecycle, nor do they consider commercial or recreational fishing pressures.

4.2 LIMITING FACTORS ANALYSIS OF SALMONID POPULATIONS

Although several factors have contributed to the decline of anadromous salmonid populations, habitat loss and modification are considered to be major determinants of their current depressed status (FEMAT 1993; Meehan 1991). High quality freshwater environmental conditions are required at both the beginning and end of their life cycles. These conditions include adequate flow, good water quality, free access to natal streams, clean gravel for successful spawning, adequate food supply for juvenile rearing and protective cover to escape predators and from which to ambush prey. If any of these environmental factors is missing or in poor condition at the time required, the fishery's population and individuals within it will likely be impacted.

When identifying anadromous salmonid limiting factors, the process takes into account that anadromous salmon have several non-substitutable habitat needs during their life cycle. A minimal list (NMFS 2001) includes:

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

The identification of limiting factors in freshwater habitat conditions is an important step towards setting priorities for habitat improvement projects and management strategies aimed at the recovery of declining fish stocks and for protection of viable fish populations. Limiting factors analysis results can be used to support regional, basin, sub-basin, and tributary level planning efforts.

At the regional level, the State anticipates the limiting factors analysis (LFA) to be incorporated into Chinook and coho salmon, and steelhead recovery plans. These analyses will provide a finer level of analysis than factors identified at the Evolutionary Significant Unit (ESU) or domain level. They will enable recovery planning to focus on defined problems and potential corrective actions by landowners and others. At the basin and watershed scales, LFA can help guide protection and restoration planning by watershed groups and others by identifying both good habitat and habitat "bottlenecks" to salmonid production and health. At the project planning level, LFA will help landowners, watershed groups and others select the restoration measures and locales (i.e., planning watersheds or larger) that can best contribute to salmonid recovery. State agencies will also use LFA to guide restoration investments, consider grant proposals, and support cumulative effects analyses of projects.

The NCWAP Approach to Limiting Factors Analysis

The NCWAP limiting factors analysis is based on evaluating physical aquatic habitat conditions. These analyses compare habitat components to a range of reference conditions determined from empirical studies and/or peer reviewed literature. If a component's condition does not fit within the suitable range of reference values, it may be viewed as a limiting factor. Table 16 describes environmental factors that may limit anadromous fish production.

Table 16. Fish habitat components and parameters applicable for limiting factors analysis

Habitat Component	Limiting Factor Parameters	Habitat Concerns
Water Quality	Flow Temperature Chemistry Turbidity Nutrients	Steam flow, water temperature, nutrients, and turbidity are important parameters of water quality that affect fish habitat. Adverse water quality may reduce growth rates, affect fish behavior, reduce disease resistance, and result in mortality.
Sediments	Pool tail embeddedness Gravel composition	Excessive sediment delivery may result in a loss of available cover as it fills interstitial spaces between substrates and decreases channel depth by filling in pools and channels to become more shallow and wide which can increase the wetted area exposed to direct sunlight. Excessive quantities of fine sediment may adversely impact production of aquatic invertebrates needed as food for fish and impede the flow of water and oxygen to developing salmonid eggs and embryos.
Riparian zone	Shade canopy Species diversity Large wood recruitment Sediment filtration Bank stability Source of nutrients Overhead and instream cover	Riparian forests provide shade over streams and help regulate water and air temperature. Large wood needed for channel forming process and stream habitat complexity is largely recruited from the riparian forest. Riparian vegetation acts to trap fine sediments mobilized from upslope areas. The root systems of riparian vegetation increase bank stability, protect land from erosion, and regulate sediments entering streams. Leaf litter and woody debris are sources of nutrients for insect production and primary productivity. Overhanging and instream vegetation provide cover for fish and slow water velocity. Removal or disturbance to riparian vegetation may have far reaching adverse cumulative impacts to stream ecosystems and fish production by eliminating or reducing the function of the critical elements listed above.
Large Wood	Abundance Size/Volume Distribution	Large wood strongly influences stream habitat and biota. It is a structural element involved in pool formation or is often associated with pools. Large wood affects sediment routing. Fish benefit from the cover and habitat diversity created by large wood. Large wood provides substrate for benthic invertebrates. The removal of large trees and woody debris from riparian zones and streams results in loss of pool habitat, reduces structural complexity within stream channels, and may interfere with sediment routing processes.
Pool and Riffle Habitat Characteristics	Pool depth Pool and riffle frequency Pool and riffle length Pool shelter complexity	Cumulative effects of land use activities have substantially altered pool, riffle, and off-channel habitats needed by salmonids for spawning, summer rearing, and winter refuge. These impaired habitats are factors limiting the recovery of salmonid populations to desired levels.
Fish Barriers	Stream gradient Stream crossings Debris jams Intermittent flows Water Temperature	Barriers or impediments to spawning migrations and upstream and downstream movements affect the distribution and survival of anadromous salmonids. Culverts and other structures used for stream crossings are often barriers or impediments to fish migrations or movements. Excessive gravel deposition in channels can cause stream flows to go prematurely intermittent and prevent fish from moving to suitable spawning and rearing areas. Unsuitable water temperature can delay spawning migrations and influence smolt downstream migrations.

This approach to LFA integrates two data-based methods: the DFG expert habitat inventory analysis described in Chapter 3.7 and the Ecosystem Management Decision Support model, described in the previous section of this chapter.

Table 17 shows how DFG inventory data contribute to this analysis. It indicates that cobble embeddedness falls short of DFG targets in Doty and McGann tributaries of the Gualala's North Fork subbasin, and that pool depth and shelter fail to meet targets in all sampled tributaries.

Table 17. Example Of DFG habitat inventory data and analysis

Habitat Element Stream Name	**Surveyed Length (feet)**	**Canopy Cover**	**Cobble Embeddedness** (< 50% cobble buried in fine substrate)	**Primary Pool Frequency** (2 feet deep in 1st and 2nd order, >3 feet in 3rd and 4th order streams)	**Shelter Cover Ratings**
Target Values		> 80%	50% or more of stream length	> 40% of stream length	> 80
North Fork Subbasin					
Doty Creek	6,237	74%	25%	4%	36
Dry Creek	11,161	58%	70%	6%	32
Dry Creek Tributary #1	2,695	59%	51%	22%	30
Little North Fork	20,806	76%	83%	16%	54
Log Cabin Creek	1,698	83%	90%	1%	43
McGann Gulch	1,980	76%	0%	3%	5
North Fork	59,362	78%	82%	29%	28
Robinson Creek	7,819	66%	65%	3%	70

NCWAP then focuses on EMDS outputs, which use DFG data as input. For the first five assessments, scores for the following EMDS parameters are considered as potentially limiting factors to salmonid health:

Pool Tail Embeddedness: Percent cobble embeddedness is an indicator of the suitability of substrate for spawning, egg incubation, fry emergence, and aquatic invertebrate production. High embeddedness may indicate elevated delivery of fine sediments to the aquatic system.

Percent Canopy: Percent canopy is a measurement of tree canopy providing shade to the wetted stream area. Canopy cover reduces direct sunlight from warming water. It also provides nutrients like leaf litter to the stream.

Reach in Primary Pools: Primary pools are those with maximum depths $\geq$ 2.5 feet in first and second order streams, and $\geq$3 feet for third and fourth order streams. Evaluating the amount of deep pool habitat in a stream reach identifies an important channel characteristic for fish. Lack of deep pools may indicate a disturbance to channel forming processes.

Pool Shelter Rating: A measure of pool habitat complexity, pool shelter rating evaluates the abundance and complexity of LWD, root wads, boulders, undercut banks, bubble curtain, and submersed vegetation. These cover elements provide juveniles with both shelter from predators and ambush sites for feeding.

EMDS parameters that receive low rating scores in comparison to reference values are considered to indicate unsuitable conditions for salmonids and thus limiting factors. Outputs ranging from one minus to three minuses indicate relative unsuitability, and thus relative importance as potential limiting factors (see Table 18).

Table 18. EMDS reach model scores for the North Fork Subbasin, Gualala Watershed

Subbasin Stream Name	Canopy Cover Score	Cobble Embeddedness Score	Pool Depth Score	Pool Shelter Score	Pool Quality Score	2001 MWAT Water Temperature Score
North Fork Subbasin						
Doty Creek	+++	-	- - -	- -	-	
Dry Creek	-	++	- - -	- - -	- - -	+++
Dry Creek Tributary #1	-	+	- - -	- -	- -	
Little North Fork	+++	++	- - -	- -	- -	+++
Little North Fork Tributary #1	+++	+	- -	- -	- -	
Log Cabin Creek	+++	+	- - -	- -	- -	
McGann Gulch	++	- - -	- - -	- - -	- - -	
North Fork	++	++	+++	- - -	U	U
Robinson Creek	-	-	- - -	+	-	+++

+++	=	Fully Suitable	-	=	Somewhat Unsuitable
++	=	Moderately Suitable	- -	=	Moderately Unsuitable
+	=	Somewhat Suitable	---	=	Fully Unsuitable
U	=	Undetermined			

Other parameters derived from watershed and stream assessments like flow, water quality, fish passage, etc. are also used if they are available for a particular stream or group of streams. Unfortunately, these parameters often lack the sampling base and necessary data sets to run in the EMDS system. They are used in conjunction with the DFG analyses, DFG tributary recommendations, and EMDS outputs during interdisciplinary analysis and synthesis. This integration results in a final Limiting Factors Analysis.

Table 19 provides an example of how the results can be presented.

Table 19. Example of limiting factors determination.

Subbasin Stream Name	Canopy cover related to shade over the stream	Cobble embeddedness related to spawning suitability	Pool depth related to summer flow conditions	Pool shelter related to juvenile salmonid ambush and escape cover
North Fork Subbasin Score				
Doty Creek		3	1	2
Dry Creek	3		1	2
Little North Fork			1	2
Little North Fork Tributary #1			1	2
Log Cabin Creek			1	2
McGann Gulch		3	2	1
North Fork				1
Robinson Creek	2		1	

4.3 METHOD FOR IDENTIFYING AND RATING REFUGIA AREAS

The North Coast Watershed Assessment Program generally considers salmonid refugia as those areas containing high quality fish habitat conditions in watersheds with undisturbed or slightly disturbed processes, and healthy fish meta-populations capable of populating nearby areas via natural straying. Refugia habitat elements include the following:

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

Establishment and maintenance of salmonid refugia areas are vital to the conservation and long-term survival of Pacific anadromous salmonid resources (Moyle and Yoshiyama 1992; Li et al. 1995; Reeves et al. 1995; Sedell et al. 1990; Frissell 1993, 2000). Li et al. (1995) suggested three prioritized steps to use the refugia concept to conserve salmonid resources.

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

Potential refugia may exist in areas where the surrounding landscape is marginally suitable for salmonid production or altered to a point that stocks have shown dramatic population declines in traditional salmonid streams. If altered streams or watersheds recover their historic natural productivity, either through restoration efforts or natural processes, the abundant source populations from nearby refugia can potentially re-colonize these areas or help sustain existing salmonid populations in marginal habitat. Refugia also include areas where critical life stage functions such as migrations and spawning occur.

Habitat provides refuge at many scales from a single fish to groups of them, and finally to breeding populations. For example, refugia habitat may range from a piece of wood that provides instream shelter for a single fish, or individual pools that provide cool water for several rearing juveniles during hot summer months, to watersheds where conditions support sustaining populations of salmonid species. Although fragmented areas of suitable habitat are important, their connectivity is necessary to sustain the fisheries. Today, watershed scale refugia are needed to recover and sustain aquatic species (Moyle and Sato 1991). NCWAP evaluates refugia at the scale of fish bearing tributaries and sub-basins because these scales of refugia are generally more resilient than the smaller, habitat unit scale to the deleterious effects of landscape and riverine disturbances such as large floods, persistent droughts, and human activities (Sedell et al. 1990).

Refugia and Meta-population Concept

Spatially structured population models are important to consider when identifying refugia because in dynamic habitats, the location of suitable habitat changes (McElhany et al. 2000) over the long term from natural disturbance regimes (Reeves et al. 1995) and over the short term because of human activities. There are several meta-population models that potentially apply to salmonids.

The classic meta-population model proposed by Levins (1969) assumes that discrete patches of suitable habitat and relatively isolated, segregated breeding populations are connected to some degree by migration between them, and by a dynamic relationship between extinction and re-colonization of habitat patches. The core and satellite (Li et al. 1995) or island-mainland population (McElhany et al. 2000) model depicts a core or mainland population from which dispersal to satellites or islands results in smaller surrounding populations. The source-sink population model is similar to the core-satellite or mainland-island models, but straying is one directional, only from the highly productive source towards the sink subpopulations.

NCWAP Approach to Identifying Refugia

Since there is no established methodology to designate refugia habitat for California's anadromous salmonids due to a lack of sufficient data describing fish populations, meta-populations, and habitat conditions and productivity across large areas, NCWAP developed a classification system based on criteria from a number of classification and rating systems (Moyle and Yoshiyama 1992; FEMAT 1993; Li et al. 1995; Frissell et al. 2000; Kitsup County 2000).

These studies recognize that: 1) ecologically intact areas serve as dispersal centers for stock maintenance and potential recovery of depressed sub-populations, 2) refugia are not limited to areas of pristine habitat and lower quality habitat areas also play important roles in long-term salmonid meta-population maintenance, 3) over time within the landscape mosaic of habitat patches, good habitat areas will suffer impacts and become less productive while other areas recover; and that therefore 4) it is important that a balance be maintained in the alternating, patchwork dynamic to ensure that adequate good quality habitat is available for viable anadromous salmonid populations (Reeves et al. 1995.)

NCWAP Salmonid Refugia Categories and Criteria

High Quality Habitat, High Quality Refugia

- Maintains a high level of watershed ecological integrity (Frissell 2000);
- Contains the range and variability of environmental conditions necessary to maintain community and species diversity and supports natural salmonid production (Moyle and Yoshiyama 1992; Frissell 2000);
- Relatively undisturbed and intact riparian corridor;
- All age classes of historically native salmonids present in good numbers, and a viable population of an ESA listed salmonid species is supported (Li et al. 1995);
- Provides population seed sources for dispersion, gene flow and re-colonization of nearby habitats from straying local salmonids;
- Contains a high degree of protection from degradation of its native components.

High Potential Refugia

- Watershed ecological integrity is diminished but remains good (Frissell 2000);
- Instream habitat quality remains suitable for salmonid production and is in the early stages of recovery from past disturbance;
- Riparian corridor is disturbed, but remains in fair to good condition;
- All age classes of historically native salmonids are present including ESA listed species, although in diminished numbers;
- Salmonid populations are reduced from historic levels, but still are likely to provide straying individuals to neighboring streams;
- Currently is managed to protect natural resources and has resilience to degradation, which demonstrates a strong potential to become high quality refugia (Moyle and Yoshiyama 1992; Frissell 2000).

Medium Potential Refugia

- Watershed ecological integrity is degraded or fragmented (Frissell, 2000);
- Components of instream habitat are degraded, but support some salmonid production;
- Riparian corridor components are somewhat disturbed and in degraded condition;
- Native anadromous salmonids are present, but in low densities; some life stages or year classes are missing or only occasionally represented;
- Relative low numbers of salmonids make significant straying unlikely;
- Current management or recent natural events have caused impacts, but if positive change in either or both occurs, responsive habitat improvements should occur.

Low Quality Habitat, Low Potential Refugia

- Watershed ecological integrity is impaired (Frissell, 2000);
- Most components of instream habitat are highly impaired;
- Riparian corridor components are degraded;
- Salmonids are poorly represented at all life stages and year classes, but especially in older year classes;
- Low numbers of salmonids make significant straying very unlikely;
- Current management and / or natural events have significantly altered the naturally functioning ecosystem and major changes in either of both are needed to improve conditions.

Other Related Refugia Component Categories

In addition to the foregoing four refugia categories there are areas important to fisheries because they contribute to flow, water quality, and fish passage. They also may potentially become refugia in the future if management priorities change. These can be areas where habitat quality remains high but does not currently support anadromous salmonid populations. An example would be a stream reach with high habitat quality but no anadromous fish passage because of man made obstructions such as dams or poorly designed culverts at stream crossings. These categories are:

Potential Future Refugia (Non-Anadromous)

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

Critical Contributing Areas

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

Data Limited

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

Steps to Identifying Refugia

The NCWAP interdisciplinary team identifies and characterizes refugia habitat by using expert professional judgment and criteria developed for North Coast watersheds. The criteria include the status of extant fishery populations and stream and watershed conditions affecting them. The team also considers the status and trends in processes delivering watershed products including the transport and routing of water, sediment, wood, nutrients, and heat through the system. Thus, the level of natural and land use disturbances – past, present, and future – are considered as well. This process provides insights concerning current watershed conditions, processes, and trends. It also projects likely outcomes for refugia status in the future.

Step One: A refugia rating team is established. The team includes the interdisciplinary assessment team plus local landowners or other experts.

Step Two: The team meets in an expert "Delphi" session to consider:

- Ecological Management Decision Support system outputs and LFA conclusions based on stream reach scale. EMDS parameters include pool shelter rating, pool depth, embeddedness, and canopy cover. LFA parameters include these and others like flow, water quality, fish passage, etc.
- EMDS Planning Watershed scale parameters road density, number of stream crossings, road proximity to streams, riparian cover, and LWD loading potential. These parameters are used to estimate watershed process disturbance levels and risk to streams.
- The Basin Assessment Report's Integrated Analysis process for each subbasin in the assessment area. These analyses consider the status and linkages between geology, vegetation history, land use, water quality, fluvial geo-morphology, stream habitat, and fishery status at the sub-basin scale.
- Systematic, stratified, random samples of streams within the sub-basin units. These samples have only been used in one sub-basin to date, but they provide the information to estimate the conditions on several stream parameters (Gallo, 2001).
- Local information provided by landowners and others well acquainted with the subject area.

Step Three: The Team constructs a Refugia Worksheet

The assessment team creates a worksheet for rating refugia at the tributary scale using the foregoing information to evaluate several fish, stream, and watershed components on the worksheet. Initially, team members complete the sections of the worksheet in the area of their expertise independently. Then the team collectively reviews the independent ratings to validate the overall collective rating.

- Twenty-one condition factors are rated on a sliding scale from high to low quality (Table 20). Those factors are grouped into five categories: 1) stream condition; 2) riparian condition; 3) native salmonid status; 4) present salmonid abundance; and 5) management impacts (disturbance impacts to terrain, vegetation, and the biologic community).
- The tributary ratings are determined by combining the results of aerial photo analyses, EMDS, and data in the CDFG tributary reports by a multi-disciplinary, team of expert analysts. Ratings of various factors are combined to determine an overall refugia rating on a scale from high to low quality.
- The tributary ratings are subsequently aggregated at the sub-basin scale and expressed as a general estimate of sub-basin refugia conditions. Factors with limited or missing data are noted. In most cases there are data limitations on one to three factors. These are identified for further investigation and analysis. The comments section can be used to explain items like missing data, or special situations like diversions or dams, etc.

Table 20. Refugia Rating Worksheet

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

Step Four: The team summarizes the data for reports.

After the sheets are completed, the ratings in each section are averaged as are the five sections' mean ratings to produce an overall summary rating for the sub-watershed (stream) (Table 21).

These stream ratings are then normalized by stream distance and/or sub-watershed area and once more combined to produce a mean refugia rating useful for comparison between sub-basins.

Table 21. Refugia Table

Northern Subbasin	**Stream**	**Refugia Categories:**				**Other Categories:**		
		High Quality	**High Potential**	**Medium Potential**	**Low Quality**	**Non-Anadromous**	**Critical Contributing Area/ Function**	**Data Limited**
	North Fork Mattole River			X			X	X
	Sulphur Creek			X				X
	Sulphur Creek Tributary #1			X				X
	Sulphur Creek Tributary #2			X				X
	Conklin Creek			X				X
	McGinnis Creek			X				X
	Oil Creek			X				X
	Green Ridge Creek				X			X
	Devils Creek			X				X
	Rattlesnake Creek			X				
Subbasin Rating				X				

Table 22 provides an alternative example of how refugia ratings can be summarized at the subbasin level. The summary is done by indicating how many streams on a subbasin fall into each refugia rating category.

Table 22. Refugia Summary Table

Subbasin and Number of Streams	Refugia Categories				Other Categories		
	High Quality	High Potential	Potential	Low Quality	Passage Barrier Limited	Critical Contributing Area/Function	Data Limited
Estuary refugia (4 streams)			2	2		4	3
Prairie Creek (9 streams)	5	3			2		1
Lower Redwood Creek (15 streams)		7	1	1		5	3
Middle Redwood Creek (21 streams)		2	10	2	3	2	5
Upper Redwood Creek (17 streams)		1	3	1			11

The table indicates the number of streams in each category found in the subbasin. Some streams may be represented in more than one column (e.g., a given stream may be both potential and passage barrier limited).

Limitations of Method

Although the range of variance within these layers is somewhat blurred through this lumping procedure, particulars and detail can be regained by focusing back down through the layers from sub-basin to sub-watershed, stream, and finally to the individual parameters. In this manner guidance can be given to an analyst investigating opportunities for watershed improvements through restoration or management activities.

4.4 INTEGRATED ANALYSES OF GEOLOGY AND LAND USE DATA

In order to consider potential interactions among land use, watershed processes and stream conditions for salmonids, NCWAP assessment teams constructed a series of tables, referred to as the Integrated Analysis (IA) tables. This approach follows the down-slope movement of watershed products delivered to streams and allows us to appraise the status of watershed health and to predict trends for the future. Thus, it can increase our understanding of the implications for activities carried out on the landscape and for fluvial systems and aquatic habitat affected by delivery of sediment.

Fundamental to watershed processes and products are the underlying geology and geomorphology of the watershed. Geologic conditions determine, in large part, the landslide and sediment production potential of the terrain. Geologic processes are influenced in varying degrees by the vegetative community, which is often linked to human activities across the landscape. Current watershed conditions combine with natural events like fire, flood, and earthquakes to affect the fluvial geomorphology and water quality in the stream reaches of a watershed. Finally, the effects of these combined processes are expressed in the stream habitats encountered by the organisms of the aquatic riparian community, including salmon and steelhead.

NCWAP's approach provides the context within which to better plan improvement activities and help make better land use decisions. The integrated analysis is conducted at the basin, subbasin, planning watershed, and tributary scales. The following approaches that differ slightly were used for the first three watershed assessments.

Example from the Mattole River Northern Subbasin Watershed Assessment

In the Mattole River Watershed Assessment, Integrated Analysis tables are organized in a logical, causal series intended to mimic the down-slope processes and products in the watershed. They intend to provide a dynamic, spatial picture of watershed conditions that ultimately form the stream conditions encountered during the freshwater life stages of salmon and steelhead. All the IA tables are organized with three general field columns:

- Feature (e.g., Terrain Types, Vegetation Types, etc.)
- Significance (i e., Terrains represent groupings of similar geologic map units)
- Comments (i e., Discussion of findings on the feature in the study area)

The fields are organized to first show the distribution of the various watershed factors and their conditions. The second field discusses the importance of function in the overall watershed dynamic. Finally, a comment is presented on the impact made by the distribution and condition of the factor on the watershed, stream, and / or fishery. Especially at the finer tributary and subbasin scales, the dynamic, spatial nature of these processes provides a synthesis of the watershed conditions and indicates the quantity and quality of the freshwater habitat for salmon and steelhead.

In the Mattole, the stratification of the various parameters in the Geology and Vegetation / Land Use tables was based on the percentage and/or distribution of four terrain types: hard, moderate, soft, and quaternary. The Mattole Assessment integrated analysis of geology and land use starts with tables, using the format described above, showing associations between geomorphic terrain and other features. They include:

- Geomorphic terrain types by percentage
- Hillside gradient by terrain types
- Small historically-active landslides by terrain types
- All historically-active landslides by terrain types
- Distribution of dormant landslides by terrain types
- Gullies and inner gorges by terrain types
- Landslide potential by terrain.

Next it looks at associations between different geologic parameters and vegetation or land use, producing the following tables:

- Vegetation types associated with terrain types (example provided in Table 23)
- Riparian vegetation types associated with terrain types (within 150' of streams)
- Land use (public, private agriculture or timberland, other) associated with terrain types
- Road mileage and density associated with terrain types
- Data summary table for various land uses (nine categories of timber harvest, grazing, agriculture, development, and timberland harvested before 1990)
- Land use and vegetation types associated with historically active landslides
- Land use (timberland harvested from 1990-2000, timberland without recent harvest) and vegetation types (woodland or grassland) associated with relative landslide potential (Table 24).

Table 23. Vegetation types associated with terrain types in the Northern Subbasin.

Vegetative Condition in the Northern Subbasin								
Feature/Function							**Significance**	**Comments**
Terrain Type	Vegetation Type						Differences between slope, soils, and stability of geologic terrain results in different mosaics of vegetation. The combination of the geologic and	Conifer and mixed hardwood/conifer occupy 40% of the soft terrain while grassland occupies 43%. Timber harvesting impacts in soft terrain may
	Conifer	Mixed	Hard-wood	Grass-land	Other	Total		
Hard	9%	62%	18%	10%	1%	100%		
Moderate	12%	59%	13%	15%	1%	100%		
Soft	7%	33%	14%	43%	3%	100%		

Vegetative Condition in the Northern Subbasin								
Feature/Function							**Significance**	**Comments**
Quarter-nary	2%	14%	15%	43%	26%	100%	vegetative conditions between terrains results in some differences in land use and sensitivity to impacts from land use.	be higher than the THP required estimated surface soil erosion hazard rating (EHR) worksheet may indicate.

Table 24. Land use and vegetation type associated with relative landslide potential.

Relative Landslide Potential[1]	Northern Subbasin	Woodland or Grassland[2]	THPs 1990 - 2000[5]	Timberland, No Recent Harvest[3]	Roads[4]	
	% of Area	% of Area	% of Area	% of Area	Length (miles)	% of Total Length
Very Low	5.8%	3.2%	0.1%	0.7%	34.0	9.9%
Low	6.2%	2.8%	0.4%	2.8%	29.5	8.6%
Moderate	27.2%	8.2%	1.2%	17.2%	91.9	26.9%
High	29.0%	12.2%	1.6%	14.7%	98.7	28.9%
Very High	31.9%	10.3%	1.4%	19.3%	87.5	25.6%
TOTAL	**100%**	**35%**	**5%**	**55%**	**342**	**100%**

Recent THPs in 1991-2000 covered 5%of the subbasin. Sixty percent of those acres (3.0% out of 5.0%) were in the two highest relative landslide potential classes. This percent is consistent with the percent of total northern subbasin acreage in high and very high relative landslide potential classes. The subbasin has about 342 miles of roads. The proportion of road length in relative landslide potential categories is also similar to the percentage of total acres in each class, although there is a slight shift towards lower relative landslide potential classes.

The Mattole Assessment also uses this tabular format to summarize fluvial geomorphology information about negative channel characteristics, and water quality information about temperature, sediment, and water chemistry. It uses a similar approach, in conjunction with figures, for summarizing instream information about primary pools, cobble embeddedness, canopy density, fish passage barriers, and large woody debris. Since the Fluvial Geomorphology, Water Quality and Instream Habitat components of the analysis are in large part responses to the products from above, the tabular association with terrain type was dropped in their tables.

Each of the groups of tables is introduced with an explanation of how and where the analysis was conducted, terms defined, and why the particular parameter was measured and how it relates to the other components of the IA series. At the end of each group, a short discussion of the results and watershed trends affected by the processes is given.

Examples from the Redwood Creek River Watershed Assessment

The first example of the approach used in the Redwood Creek assessment is provided by Table 25. It looks at how historically active features underlie woodland/grassland areas and timberland. Historically active landslide features are defined as rockslides, earthflows, debris slides and debris flows that show evidence of movement within the last 150 years when European settlers first came to the North Coast. The land use or land type categories are divided into the following categories:

- *Woodland and grassland.* This category often implies a given kind of land use. On private lands in the Redwood Creek watershed, woodlands or grasslands are typically used for grazing.
- *Areas of recent, active timber management* represented by areas with timber harvesting plans (THPs) filed between 1991 and 2000.
- *Areas where recent timber harvest has not occurred* are represented by timberland with no THPs filed between 1991 and 2000 (although these areas could include less substantial forms of timber management such as pre-commercial thinning), including parklands with timberland characteristics,
- *Roads*.

Road lengths are recorded in miles while other categories are recorded on an area basis in acres. Note that the percentages reported in the tables refer to the specific watershed scale. In other words, in the section dealing with the entire Redwood Creek watershed, the percentages pertain to that entire watershed area. When the scale is the subbasin, percentages are based on the total area of the specific subbasin.

Table 25. Historically active landslide features associated with land type or use.

Unit of Analysis	**Historically Active Landslide**	**Entire Unit of Analysis**		**Woodland / Grassland**[1]		**THPs 1991 – 2000**[2]		**Timberland, No Recent Harvest**		**Roads**	
		Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Length (miles)	% Total Length
Redwood Creek Watershed (180,688 acres) (1,479 road miles)	Earthflow	7,602	4.2%	3,405	1.9%	955	0.5%	3,373	2%	53.8	3.6%
	Rock Slide	1,710	0.9%	380	0.2%	1	0.0%	1,327	1%	11.8	0.8%
	Debris Slide	591	0.3%	33	0.0%	37	0.0%	511	0%	5.3	0.4%
	Debris Flow	170	0.1%	13	0.0%	6	0.0%	149	0%	1.0	0.1%
	All Features	10,073	5.6%	3,831	2.1%	999	0.6%	5,361	3.0%	72.0	4.9%
Estuary Subbasin	All Features	2	0.1%	0	0.0%	0	0.0%	1	0.0%	0	0.0%
Prairie Creek Subbasin	All Features	348	1.4%	0	0.0%	0	0.0%	346	1.4%	1	1.1%
Lower Redwood Creek Subbasin	All Features	2,662	6.0%	274	0.6%	0	0.0%	2,377	5.3%	7.0	5.0%
Middle Redwood Creek Subbasin	All Features	4,166	6.5%	1,802	2.8%	852	1.3%	1,717	2.7%	42.3	5.9%
Upper Redwood Creek Subbasin	All Features	2,892	6.7%	1,756	4.1%	147	0.3%	919	2.1%	22	4.3%

[1] Woodland and grassland category includes areas mapped in 1998 as grassland and non-productive hardwood.
[2] THPs completed or active between the 1991 and 2000 timeframe.

Land use activities can exacerbate slope instability if the appropriate precautions are not followed. Activities such as removing lateral and end support from landslides, loading the head of a landslide or increasing the pore pressure of the landslide mass by improper drainage or diverting water to the landslide mass can contribute to initiating slope failures or reactivating landslides.

The juxtaposition of land use and landslides shown in Table 25 does not imply or establish a causal relationship between the two. Land uses such as timber harvest, roads, or construction can be contributing factors or causes of landslides. However, determining the actual cause of a landslide requires a site-specific investigation conducted by professionals. This is not within the scope of the NCWAP assessment. Additionally, examination of aerial photos with very limited field reconnaissance is most accurate in more open areas such as grasslands or recently harvested forestland. Landslides and mass wasting under the forest canopy are more difficult to see, leading to an inherent bias in identification. In many cases, the evidence of recent movement such as fresh landslide scarps are not visible due to scale and resolution of the aerial photographs and elapsed time of the photograph since movement of the landslide.

Table 26 is similar to Table 25, except that it looks at land use in the context of relative slope stability rather than active landslide features. The two categories of relative landslide potential that pose the greatest concern are "high" and "very high." Here is a brief description of these categories, with generalized implications and land management recommendations for each:

> *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.
>
> *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 greater than 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.

Since timber harvesting can cause disturbances that may contribute to slope instability, harvesting and associated road construction and maintenance must be conducted with care on slopes with higher levels of relative landslide potential. THP preparation and reviews include steps to examine and address mass wasting potentials. This includes use of geologists by land managers preparing THPs, and participation of the California Geological Survey on THP review teams and during pre-harvest inspections. See the Redwood Creek assessment report for examples of how to interpret and discuss the relationships illustrated in Table 26.

Table 27 provides a higher level of detail on the interrelationship between relative landslide potential and recent timber harvesting activities for Redwood Creek. This table shows the area and percent of total area by silvicultural and yarding systems. This classification is provided for the entire Redwood Creek watershed and for the middle and upper subbasins. The estuary, Prairie Creek, and lower Redwood Creek subbasins are not included since there was no timber harvest in these areas during the subject period. See the Redwood Creek assessment report for examples of how to interpret and discuss the relationships illustrated in Table 27.

Table 28 presents a summary of a wide range of information at the watershed and subbasin levels for Redwood Creek. It provides an opportunity to compare a large number of factors across the watershed and subbasins and, for some of the subbasins, to look at potential interactions between potential disturbance factors and instream fish habitat.

Table 26. Relative landslide potential and land use/type classes, Redwood Creek

Unit of Analysis	**Relative Landslide Potential**	**Entire Unit of Analysis**		**Woodland or Grassland[1]**		**THPs 1991-2000[2]**		**Timberland, No Recent Harvest**		**Roads**	
		Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Length (miles)	% Total Length
Redwood Creek Watershed 180,688 acres 1,479 road miles	Very Low	13,606	7.5%	2,001	1.1%	855	0.5%	9,315	5.2%	156	10.5%
	Low	14,298	7.9%	1,090	0.6%	1,243	0.7%	11,720	6.5%	155	10.4%
	Moderate	22,285	12.3%	765	0.4%	1,451	0.8%	19,816	11.0%	193	13.0%
	High	60,841	33.7%	6,223	3.4%	3,957	2.2%	50,219	27.8%	472	31.7%
	Very High	69,361	38.4%	10,483	5.8%	7,094	3.9%	51,101	28.3%	503	33.8%
	High + Very High	*130,202*	*72.1%*	*16,706*	*9.2%*	*11,052*	*6.1%*	*101,320*	*56.1%*	*975*	*65.5%*
	TOTAL	**180,391**	**100%**	**20,579**	**11%**	**14,602**	**8%**	**156,327**	**87%**	**1,479**	**100%**
Estuary 3,433 acres 16 road miles	Very Low	1,457	42.4%	641	18.7%			223	6.5%	8.1	50.9%
	Low	67	2.0%	7	0.2%			57	1.7%	1.0	6.3%
	Moderate	216	6.3%	55	1.6%			136	4.0%	1.7	10.7%
	High	1,200	35.0%	76	2.2%			1,095	31.9%	4.0	25.2%
	Very High	486	14.2%	21	0.6%			451	13.1%	1.1	6.9%
	High + Very High	*1,686*	*49.1%*	*97*	*2.8%*			*1,546*	*45.0%*	*5*	*32.1%*
	TOTAL	**3,426**	**100%**	**800**	**23%**	**0**	**0%**	**1,963**	**57%**	**16**	**100%**
Prairie Creek Subbasin 25,305 acres 110 road miles	Very Low	3,492	13.8%	360	1.4%			3,068	12.1%	28.6	26.6%
	Low	3,017	11.9%	3	0.0%			2,989	11.8%	14.5	13.5%
	Moderate	4,565	18.0%	8	0.0%			4,526	17.9%	19.2	17.8%
	High	9,480	37.5%	13	0.1%			9,424	37.2%	30.9	28.7%
	Very High	4,750	18.8%	4	0.0%			4,731	18.7%	14.4	13.4%
	High + Very High	*14,230*	*56.2%*	*17*	*0.1%*			*14,155*	*55.9%*	*45.3*	*42.1%*
	TOTAL	**25,304**	**100%**	**405**	**2%**	**0**	**0%**	**24,738**	**98%**	**107.6**	**100%**

Unit of Analysis	Relative Landslide Potential	Entire Unit of Analysis		Woodland or Grassland[1]		THPs 1991-2000[2]		Timberland, No Recent Harvest		Roads	
		Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Length (miles)	% Total Length
Lower Redwood Creek Subbasin 44,479 acres 138 road miles	Very Low	2,666	6.0%	92	0.2%			2,172	4.9%	17.7	12.8%
	Low	3,028	6.8%	96	0.2%			2,905	6.5%	14.0	10.2%
	Moderate	7,259	16.3%	96	0.2%			7,144	16.1%	30.6	22.2%
	High	17,431	39.2%	676	1.5%			16,734	37.6%	49.7	36.0%
	Very High	14,033	31.5%	25	0.1%			13,468	30.3%	26.0	18.9%
	High + Very High	*31,464*	*70.7%*	*701*	*1.6%*			*30,202*	*67.9%*	*75.7*	*54.9%*
	TOTAL	**44,417**	**100%**	**985**	**2%**	**0**	**0%**	**42,423**	**95%**	**138.0**	**100%**
Middle Redwood Creek Subbasin 64,082 acres 717 road miles	Very Low	2,689	4.2%	375	0.6%	334	0.5%	1,840	2.9%	44.5	6.2%
	Low	3,868	6.0%	454	0.7%	571	0.9%	2,803	4.4%	57.4	8.0%
	Moderate	6,002	9.4%	209	0.3%	849	1.3%	4,851	7.6%	81.4	11.4%
	High	20,402	31.8%	3,040	4.7%	2,836	4.4%	14,409	22.5%	241.3	33.7%
	Very High	31,023	48.4%	5,133	8.0%	5,859	9.1%	20,192	31.5%	291.6	40.7%
	High + Very High	*51,425*	*80.2%*	*8,173*	*12.8%*	*8,695*	*13.6%*	*34,601*	*54.0%*	*532.9*	*74.4%*
	TOTAL	**63,984**	**100%**	**9,211**	**14%**	**10,448**	**16%**	**44,095**	**69%**	**716.2**	**100%**
Upper Redwood Creek Subbasin 43,343 acres 502 road miles	Very Low	3,302	7.6%	533	1.2%	521	1.2%	2,012	4.6%	57.3	11.4%
	Low	4,318	10.0%	530	1.2%	672	1.6%	2,966	6.8%	67.8	13.5%
	Moderate	4,243	9.8%	397	0.9%	603	1.4%	3,159	7.3%	60.0	12.0%
	High	12,328	28.4%	2,418	5.6%	1,121	2.6%	8,557	19.7%	145.9	29.1%
	Very High	19,069	44.0%	5,300	12.2%	1,235	2.9%	12,259	28.3%	170.2	34.0%
	High + Very High	*31,397*	*72.4%*	*7,718*	*17.8%*	*2,357*	*5.4%*	*20,816*	*48.0%*	*316.1*	*63.1%*
	TOTAL	**43,260**	**100%**	**9,178**	**21%**	**4,153**	**10%**	**28,953**	**67%**	**501.2**	**100%**

[1] Woodland and grassland category includes areas mapped in 1998 as grassland and non-productive hardwood.
[2] THPs are complete or active between the 1991 and 2000 timeframe.
Empty cells denote zero

Table 27. Relative landslide potential by silvicultural system and yarding method

		Silvicultural System and Yarding Methods for THPs 1991 – 2000[2]																								Total THPs 1991-2000	
		Category 1 Silviculture[1]								Category 2 Silviculture								Category 3 Silviculture									
	Relative Landslide Potential	Tractor		Cable		Copter		Total		Tractor		Cable		Copter		Total		Tractor		Cable		Copter		Total			
		Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area
Redwood Creek Watershed 180,688 acres	Very Low	488	0.3%	9	0.0%	4	0.0%	501	0.3%	88	0.0%	0	0.0%	5	0.0%	93	0.1%	225	0.1%	9	0.0%	25	0.0%	259	0.1%	853	0.5%
	Low	714	0.4%	9	0.0%	11	0.0%	734	0.4%	117	0.1%	0	0.0%	2	0.0%	119	0.1%	384	0.2%	9	0.0%	1	0.0%	394	0.2%	1,247	0.7%
	Moderate	772	0.4%	37	0.0%	25	0.0%	834	0.5%	44	0.0%	0	0.0%	1	0.0%	45	0.0%	512	0.3%	44	0.0%	14	0.0%	570	0.3%	1,449	0.8%
	High	1,498	0.8%	259	0.1%	89	0.0%	1,846	1.0%	585	0.3%	9	0.0%	74	0.0%	668	0.4%	1,217	0.7%	110	0.1%	112	0.1%	1,439	0.8%	3,953	2.2%
	Very High	1,629	0.9%	656	0.4%	361	0.2%	2,646	1.5%	1,489	0.8%	44	0.0%	173	0.1%	1,706	0.9%	1,730	1.0%	425	0.2%	583	0.3%	2,738	1.5%	7,090	3.9%
	High+Very High	*2,621*	*1.5%*	*790*	*0.4%*	*450*	*0.2%*	*4,492*	*2.5%*	*2,074*	*1.1%*	*53*	*0.0%*	*247*	*0.1%*	*2,374*	*1.3%*	*2,379*	*1.3%*	*535*	*0.3%*	*695*	*0.4%*	*4,177*	*2.3%*	*11,043*	*6.1%*
	TOTAL	**5,194**	**2.9%**	**970**	**0.5%**	**490**	**0.3%**	**6,561**	**3.6%**	**2,323**	**1.3%**	**53**	**0.0%**	**255**	**0.1%**	**2,631**	**1.5%**	**4,068**	**2.3%**	**597**	**0.3%**	**735**	**0.4%**	**5,400**	**3.0%**	**14,592**	**8.1%**
Middle Redwood Creek Subbasin 64,082 acres	Very Low	139	0.2%	8	0.0%	2	0.0%	149	0.2%	33	0.1%	0	0.0%	5	0.0%	38	0.1%	121	0.2%	6	0.0%	18	0.0%	145	0.2%	332	0.5%
	Low	268	0.4%	9	0.0%	0	0.0%	277	0.4%	75	0.1%	0	0.0%	2	0.0%	77	0.1%	212	0.3%	8	0.0%	0	0.0%	220	0.3%	574	0.9%
	Moderate	392	0.6%	30	0.0%	6	0.0%	428	0.7%	37	0.1%	0	0.0%	1	0.0%	38	0.1%	330	0.5%	40	0.1%	12	0.0%	382	0.6%	848	1.3%
	High	945	1.5%	198	0.3%	5	0.0%	1,148	1.8%	449	0.7%	9	0.0%	69	0.1%	527	0.8%	945	1.5%	107	0.2%	107	0.2%	1,159	1.8%	2,834	4.4%
	Very High	1,388	2.2%	523	0.8%	98	0.2%	2,009	3.1%	1,162	1.8%	44	0.1%	153	0.2%	1,359	2.1%	1,517	2.4%	420	0.7%	551	0.9%	2,488	3.9%	5,856	9.1%
	High+Very High	*2,333*	*3.6%*	*596*	*0.9%*	*103*	*0.2%*	*3,157*	*4.9%*	*1,611*	*2.5%*	*53*	*0.1%*	*222*	*0.3%*	*1,886*	*2.9%*	*1,894*	*3.0%*	*527*	*0.8%*	*658*	*1.0%*	*3,647*	*5.7%*	*8,690*	*13.6%*
	TOTAL	**3,132**	**4.9%**	**768**	**1.2%**	**111**	**0.2%**	**4,011**	**6.3%**	**1,756**	**2.7%**	**53**	**0.1%**	**230**	**0.4%**	**2,039**	**3.2%**	**3,125**	**4.9%**	**581**	**0.9%**	**688**	**1.1%**	**4,394**	**6.9%**	**10,444**	**16.3%**
Upper Redwood Creek Subbasin 43,343 acres	Very Low	349	0.8%	1	0.0%	2	0.0%	352	0.8%	55	0.1%	0	0.0%	0	0.0%	55	0.1%	104	0.2%	3	0.0%	7	0.0%	114	0.3%	521	1.2%
	Low	446	1.0%	0	0.0%	11	0.0%	457	1.1%	42	0.1%	0	0.0%	0	0.0%	42	0.1%	172	0.4%	1	0.0%	1	0.0%	174	0.4%	673	1.6%
	Moderate	380	0.9%	7	0.0%	19	0.0%	406	0.9%	7	0.0%	0	0.0%	0	0.0%	7	0.0%	182	0.4%	4	0.0%	2	0.0%	188	0.4%	601	1.4%
	High	553	1.3%	61	0.1%	84	0.2%	698	1.6%	136	0.3%	0	0.0%	5	0.0%	141	0.3%	272	0.6%	3	0.0%	5	0.0%	280	0.6%	1,119	2.6%
	Very High	241	0.6%	133	0.3%	263	0.6%	637	1.5%	327	0.8%	0	0.0%	20	0.0%	347	0.8%	213	0.5%	5	0.0%	32	0.1%	250	0.6%	1,234	2.8%
	High+Very High	*288*	*0.7%*	*194*	*0.4%*	*347*	*0.8%*	*1,335*	*3.1%*	*463*	*1.1%*	*0*	*0.0%*	*25*	*0.1%*	*488*	*1.1%*	*485*	*1.1%*	*8*	*0.0%*	*37*	*0.1%*	*530*	*1.2%*	*2,353*	*5.4%*
	TOTAL	**2,062**	**4.8%**	**202**	**0.5%**	**379**	**0.9%**	**2,550**	**5.9%**	**567**	**1.3%**	**0**	**0.0%**	**25**	**0.1%**	**592**	**1.4%**	**943**	**2.2%**	**16**	**0.0%**	**47**	**0.1%**	**1,006**	**2.3%**	**4,148**	**9.6%**

[1]Category 1 silviculture includes clearcut, rehab, seed tree step, and shelterwood seed step prescriptions; Category 2 silviculture includes shelterwood prep step, shelterwood removal step, and alternative prescriptions; Category 3 silviculture includes selection, commercial thin, sanitation salvage, transition, and seed tree removal step prescriptions.
[2]THPs are complete or active between the 1991 and 2000 timeframe.
Column for % of area refers to the respective unit of analysis, watershed or subbasin.

Table 28. Integrated information for the Redwood Creek Watershed and subbasins.

Factor	Redwood Creek Watershed		Estuary Subbasin		Prairie Creek Subbasin		Lower RC Subbasin		Middle RC Subbasin		Upper RC Subbasin	
Relative Landslide Potential	**acres**	**% area**	**acres**	**% area**	**acres**	**% area**	**acres**	**% area**	**acres**	**% area**	**acres**	**% area**
Very Low	13,606	7.5%	1,457	42.4%	3,492	13.8%	2,666	6%	2,689	4.2%	3,302	7.6%
Low	14,298	7.9%	67	2.0%	3,017	11.9%	3,028	7%	3,868	6.0%	4,318	10.0%
Moderate	22,285	12.4%	216	6.3%	4,565	18.0%	7,259	16.3%	6,002	9.4%	4,243	9.8%
High	60,841	33.7%	1,200	35.0%	9,480	37.5%	17,431	39.2%	20,402	31.9%	12,328	28.5%
Very High	69,361	38.5%	486	14.2%	4,750	18.8%	14,033	31.6%	31,023	48.5%	19,069	44.1%
High/Very High Subtotal	*130,202*	*72%*	*1,686*	*49%*	*14,230*	*56%*	*31,464*	*71%*	*51,425*	*80.4%*	*31,397*	*72.6%*
GRAND TOTAL	**180,391**	**100%**	**3,426**	**100%**	**25,304**	**100%**	**44,417**	**100%**	**63,984**	**100%**	**43,260**	**100%**
Landslide and Selected Geomorphic Features	**acres**	**% area**	**acres**	**% area**	**acres**	**% area**	**acres**	**% area**	**acres**	**% area**	**acres**	**% area**
Historically Active Landslide Total	10,070	5.6%	2		348	1.4%	2,662	6.0%	4,166	6.5%	2,892	6.7%
Earthflow	169	0.1%	1	0%	13	0.1%	78	0.2%	68	0.1%	9	0.0%
Rock Slide	591	0.3%	0	0%	25	0.1%	82	0.2%	257	0.4%	227	0.5%
Debris Slide	7,602	4.2%	0	0%	161	0.6%	1,762	4.0%	3,187	5.0%	2,492	5.8%
Debris Flow	1,708	0.9%	1	0%	148	0.6%	740	1.7%	654	1.0%	165	0.4%
Dormant Landslide Features Total	38,837	21.5%	700	20%	2,022	8%	5,263	11.8%	15,150	23.7%	15,702	36.3%
Selected Geomorphic Features Total	31,215	17.3%	617	18%	2,493	10%	5,540	12.5%	13,495	21.1%	9,070	21.0%
Disrupted Ground	18,782	10.4%	277	8%	355	1%	2,831	6.4%	10,099	15.8%	5,219	12.1%
Debris Slide Slope	10,599	5.9%	337	10%	2,067	8%	2,472	5.6%	2,943	4.6%	2,780	6.4%
Inner Gorge (area)[1]	1,834	1.0%	3	0%	71	0%	236	0.5%	453	0.7%	1,071	2.5%
Total of All Above Features	**80,122**	**44.4%**	**1320**	**39%**	**4,863**	**19%**	**13,465**	**30.3%**	**32,811**	**51.3%**	**27,664**	**63.9%**
Timber Harvest 1990 – 2000[2]	**acres**	**% area**	**acres**	**% area**	**acres**	**% area**	**acres**	**% area**	**acres**	**% area**	**acres**	**% area**
Silviculture Category 1												
Tractor	5,381	3.0%	0	0%	0	0%	0	0%	3,375	5.3%	2,006	4.6%
Cable	1,123	0.6%	0	0%	0	0%	0	0%	896	1.4%	227	0.5%
Helicopter	492	0.3%	0	0%	0	0%	0	0%	112	0.2%	380	0.9%
TOTAL	6,996	3.9%	0	0%	0	0%	0	0%	4,383	6.9%	2,613	6.0%
Silviculture Category 2									0			
Tractor	2,342	1.3%	0	0%	0	0%	0	0%	1,761	2.8%	582	1.3%
Helicopter	79	0.0%	0	0%	0	0%	0	0%	79	0.1%	0	0%
Cable	228	0.1%	0	0%	0	0%	0	0%	203	0.3%	24	0.1%
TOTAL	2,649	1.5%	0	0%	0	0%	0	0%	2,043	3.2%	606	1.4%
Silviculture Category 3									0			
Tractor	4,078	2.3%	0	0%	0	0%	0	0%	3,129	4.9%	949	2.2%
Helicopter	598	0.3%	0	0%	0	0%	0	0%	582	0.9%	17	0%
Cable	736	0.4%	0	0%	0	0%	0	0%	689	1.1%	47	0.1%
TOTAL	5,413	3.0%	0	0%	0	0%	0	0%	4,400	6.9%	1,013	2.3%
TOTAL	**15,058**	**8.3%**	**0**	**0.0%**	**0**	**0%**	**0**	**0%**	**10,826**	**16.9%**	**4,232**	**9.8%**

Factor	Redwood Creek Watershed		Estuary Subbasin		Prairie Creek Subbasin		Lower RC Subbasin		Middle RC Subbasin		Upper RC Subbasin	
Other Land Uses	**acres**	**% area**	**acres**	**% area**	**acres**	**% area**	**acres**	**% area**	**acres**	**% area**	**acres**	**% area**
Grazing	2,659	1.5%	113	3.3%	230	0.9%	29	0.1%	1,301	2.0%	986	2.3%
Agriculture	1,418	0.8%	1	0%	1,393	5.5%	0	0%	24	0.0%	0	0%
Development	1,436	0.8%	0	0%	1,421	5.6%	4	0%	11	0.0%	0	0%
Timberland, No Recent Harvest	136,388	75.6%	1,963	57.3%	23,345	92.3%	38,032	85.6%	44,095	68.9%	28,953	66.9%
TOTAL	**139,114**	**77.1%**	**2,077**	**60.6%**	**23,603**	**93%**	**38,065**	**85.7%**	**45,430**	**71.0%**	**29,939**	**69.2%**
Roads												
Road Density (miles/sq. mile)	5.3		3.0		2.7		2.0		7.2		7.4	
Density of Road Crossings (#/stream mile)	0.3		0.2		0.6		0.1		1.1		1.2	
Roads within 200' of Stream (miles/stream mile)	0.2		0.1		0.2		0.1		0.2		0.3	
Streams	**% stream length**		**% stream length**		**% stream length**		**% stream length**		**% stream length**		**% stream length**	
% Stream by Gradient												
< 1% (Response Reach)	13.7%		77.4%		14.7%		17.8%		11.6%		7.0%	
1-4% (Response Reach)	11.6%		6.8%		25.5%		10.4%		5.1%		9.8%	
rt Reach)	35.7%		11.6%		43.8%		31.7%		31.1%		43.7%	
>20% (Source Reach)	38.9%		4.3%		16.0%		40.1%		52.3%		39.5%	
Historically Active and Dormant Landslide and Selected Geomorphic Features[3]	**% area**	**% stream length**	**% area**	**% stream length**	**% area**	**% stream length**	**% area**	**% stream length**	**% area**	**% stream length**	**% area**	**% stream length**
Within 180' of Blue Line Stream	5.3 %	29.3%	1.2%	2.5%	2. 6%	8.0%	4.2%	16.1%	6.4%	20.5%	6.8 %	70.2%
Instream Fish Habitat – EMDS[4]	*Main-stem*	*Tribs*	*Main-stem*	*Tribs*	*Main-stem*	*Tribs*	*Ma in-stem*	Tribs	*Main-stem*	*Tribs*	*Main-stem*	*Tribs*
Reach Condition	na	na	na	na	na						na	na
Canopy Density	na	na	na	na	na	+ +	- -	+ +	- -	+ +	na	na
Pool Quality	na	na	na	na	na	- -	- -	- -	- -	- -	na	na
Pool Depth	na	na	na	na	na	- -	- - -	- -	-	- -	na	na
Pool Shelter	na	na	na	na	na	-	- -	-	- - -	- -	na	na
Embeddedness	na	na	na	na	na	-	-	- -	-	-	na	na

[1]Area based on inner gorges captured as polygons plus inner gorges captured as linear features, which are treated as having an average width of 100 feet.

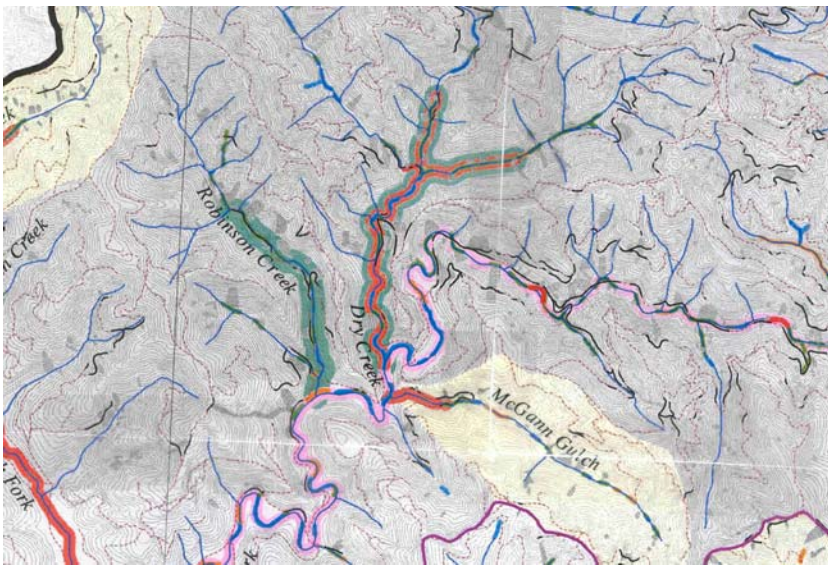
[2] Category 1 includes clearcut, rehab, seed tree step, and shelterwood seed step prescriptions; Category 2 includes shelterwood prep step, shelterwood removal step, and alternative prescriptions; Category 3 includes selection, commercial thin, sanitation salvage, transition, and seed tree removal step prescriptions.

[3] Landslide features and selected geomorphic features include earth flow, rockslide, debris slide, debris flow, debris slide slopes, disrupted ground, eroding banks, inner gorges.

[4] EMDS rankings for fish habitat suitability   +++ Fully suitable   ++ Moderately suitable   + Somewhat suitable
- Somewhat unsuitable   - - Moderately unsuitable   - - - Fully unsuitable   U Undetermined   na Information not available

4.5 MAPPING POTENTIAL RESTORATION SITES

Interdisciplinary synthesis of spatial data can be used to identify site-specific opportunities for restoration or management guidelines. In the Gualala River watershed assessment, the team developed a map of sediment sites (i.e., sources and deposits) that may contribute to habitat degradation (primarily pool filling and cobble embeddedness). The intended use of the map is to provide information in a summary fashion for remediation and restoration planning purposes. 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. A section of the Gualala River Watershed Assessment Report Plate 3, *Potential Restoration Sites and Limiting Factors for the Gualala River Watershed* (Klamt et al. 2002), is provided as an example in Figure 31.



Limiting Factors are indicated by broad ribbons:
Green=canopy
Pink=pool shelter
Red=both pool depth and shelter

Narrow colored strings indicate **sediment accumulations** possibly associated with:
Roads=yellow, red, black
Landslides only=green, brown and those that lack any of the above associations.

Figure 31. Potential restoration sites and limiting factors for the Gualala Watershed.

The map was produced using multiple database queries of GIS data developed by NCWAP:

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; and

e. University of California Information Center for the Environment (ICE) roads map of the current roads in the watershed.

Sediment sites were categorized as follows:

- Historically active landslides;
- Historical instream roads possibly related to fluvial sediment;

- Roads possibly related to landslides and/or eroding banks;
- Fluvial sediment conditions possibly related to landslides; and
- Potentially unrelated fluvial sediment conditions.

In order to provide guidance for future analysis, mitigations, and restoration, the sediment sites are analyzed for their potential as restoration sites, especially those upslope of reaches limited by sediment conditions. General recommendations are made for each category of sediment site and limiting factor. Areas identified as potential restoration targets that have not been inventoried are prioritized for habitat surveys to understand their significance as habitat.

The map contains the following information:

a. Road segments that cross or are within 60 meters of a historically active landslide;
b. Road segments that are both within 60 meters of historically active landslides and within 60 meters of eroding stream banks;
c. Road segments that are within 60 meters of dormant landslides;
d. Historical instream or near stream road segments 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; and
g. CDFG stream habitat inventory surveys completed by 2001.

The map also identifies potential road related sediment sources in each subbasin that are 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 potential 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. Areas identified as potential restoration targets that have not been inventoried are prioritized for habitat surveys to understand their significance as habitat.

4.6 USE OF 'WORKING HYPOTHESES' AND WEIGHT OF EVIDENCE

The culmination of an assessment conducted by the North Coast Watershed Assessment Program is development and prioritization of recommendations for conserving, protecting and restoring watersheds. In order to recommend specific actions, the assessment team focuses on responses to the assessment questions posed on habitat factors limiting salmonid production. Answers are developed using information from each discipline or agency along with the results of interdisciplinary analyses. The relationship between watershed processes and human activities is hypothesized in order to develop recommendations for actions to improve habitat conditions.

The team uses a weight-of-evidence approach to consider the consistency and quality of the information for answering these questions. In the final report, conclusions are treated as "working hypotheses" followed by a list of the key findings that support or contradict the hypothesis as well as gaps or limitations to the existing data. The following examples are provided from the Gualala River and Mattole River Watershed Assessment Reports.

A Working Hypothesis from the North Fork Subbasin of the Gualala River assessment report

A lack of in stream large woody debris contributes to a simplified habitat structure (e.g., lack of large, deep pools).

Supporting Findings:

- Shelter/cover did not meet Flosi, et al (1998) target values on any of the streams surveyed.
- Pool shelter EMDS scores were somewhat to fully unsuitable for the streams surveyed.
- Pool depth and pool shelter are ranked 1 and 2 as limiting factors throughout the subbasin.
- LWD is low due to streamside road construction, timber harvesting, and salmonid migration barrier removal.
- Roads, landings, and skid trails built in or adjacent to streams between 1952 and 1968 buried, removed, and dispersed large woody debris. The reduction of LWD likely reduces pool formation and sediment storage in the tributaries.
- Timber harvest up to the mid-1990s in the lower and middle reaches frequently selectively cut large conifer vegetation down to the stream bank, reducing the available recruitment supply of large woody debris.
- Stream clearance projects in the 1970s and 1980s to clear log jam barriers to salmonid migration removed large amounts of woody debris throughout the North Fork subbasin, except on the North Fork.
- Stream buffers are regenerating since the mid-1990s under current land management practices and Forest Practice Rules, and large trees are present in the riparian zone in the alluvial flats. However, the dense stands of riparian zone conifers have not reestablished to levels seen before mid-20th-century.
- The Watershed Cooperative Monitoring Program identified deficient large woody debris on the North Fork, Little North Fork, Robinson Creek, and Dry Creek.

- Pool depth and pool shelter are ranked 1 and 2 as limiting factors throughout the subbasin.
- Enhancement of instream structure is a restoration priority.

Contrary Findings:

- Shelter was somewhat suitable on Robinson Creek.
- In the lower watershed woody debris large enough to function in the channels is abundant adjacent to Little North Fork, lower Doty Creek and lower Robinson Creek.

Limitations:

- Only 81 percent of the subbasin was habitat inventory surveyed.

Conclusion: The hypothesis is supported.

A Working Hypothesis from Mattole River Western Subbasin

Aggradation from fine sediment in some stream channels of this subbasin has reduced channel diversity needed to provide suitable conditions for anadromous salmonid populations and has compromised salmonid health.

Supporting Evidence:

- Based on limited sampling, instream conditions indicate moderate sediment levels. The limited data available suggests that there is a degradation of habitat due to instream sediment accumulation in the lower gradient reaches of the larger tributaries (CGS).
- Air photos and field observations show that the Mattole River bordering the Western Subbasin downstream of Honeydew Creek is highly aggraded with sediment (CGS).
- Air photos after the 1955 and 1964 floods indicate significant changes in the stream channel in the Western Subbasin (CGS).

Contrary Evidence:

- V* of 0.26 for Mill Creek, 0.24 for Squaw Creek and 0.22 for Honeydew Creek in 2000 indicating low to moderate residual pool filling (NCRWQCB Appendix E).

Conclusion: Based upon current supportive and contrary findings, the hypothesis is supported.

4.7 IDENTIFICATION OF RECOMMENDATIONS FOR WATERSHED IMPROVEMENT ACTIONS

Once limiting factors and integrated analyses have been conducted, the assessment team recommends actions to protect or improve conditions of basins and watersheds that address those analyses. The team considers stewardship approaches and options such as conservation easements to protect and conserve high quality watershed areas, as well as restoration actions to improve poorer conditions.

In order to prioritize actions, the team identifies areas critical to recovery of the whole watershed unit (e.g. refugia within the subbasin, or the estuary for the basin). Restoration recommendations address the most important factors (i.e. the high quality habitat, the most limiting factors, and the most common limiting factors) and the pertinent scale of action needed (i.e. from stream reach activities, where known, to basin-wide actions or approaches).

Appropriateness and feasibility of potential recommendations are considered. The interdisciplinary analyses are used to consider potential causes or contributing factors and their likely response to specific activities. The assessment team considers practices and recommendations from standard guidance or handbooks, published technical notes, regulations, agency plans, etc. The team considers the effectiveness of known activities and practices, the expected time frame for improvements in response to those activities, and the appropriate sequences of actions where more than one factor is limiting in order to develop cost-effective recommendations.

NCWAP incorporates or builds on previous restoration or protection activities when making management recommendations. The team reviews existing site-specific recommendations, such as restoration suggestions from Department of Fish and Game tributary surveys, Timber Harvest Plan permit mitigations, County grading ordinances, 1600 agreements, as well as existing work in the watersheds. These are considered in conjunction with new data on channel and upslope conditions and processes produced during the assessment.

Finally, the team integrates all information using an estimate of the relative weight of different limiting factors in order to prioritize recommendations for the entire sub-basin or basin. The following examples show NCWAP recommendations provided at a subbasin scale.

Excerpt from Gualala River Watershed Assessment Report recommendations for addressing riparian canopy limiting factors in the North Fork Subbasin

Maintain and enhance riparian zones to achieve target canopy density and diversity including large conifers for LWD recruitment.

a. Ensure that adequate streamside protection zones are used to reduce solar radiation and moderate air temperatures in order to reduce heat inputs to the North Fork and its tributaries.

b. Maintain or enhance existing riparian cover. Where current canopy density and diversity are inadequate and site conditions are appropriate, initiate tree planting, thinning, and other vegetation management to hasten the development of a denser, more extensive and diverse riparian canopy. Dry Creek, Robinson Creek, the central and higher reaches of the mainstem, and the lower reaches of Bear and Stewart Creeks are high priority areas for riparian improvements. Areas with persistent bank exposure include: (1) the central and higher reaches of the mainstem, (2) the lower reaches of Bear and Stewart Creeks, and (3) the upper reaches of Dry Creek.

c. Land managers in this subbasin should be encouraged to add more large organic debris and shelter structures in order to meter sediment inputs, improve channel structure, channel function, habitat complexity, and habitat diversity for salmonids. Pool shelter has the lowest suitability for salmonids in the whole subbasin. The natural large woody debris recruitment process should be enhanced by developing large riparian conifers with tree protection, planting, thinning from below, and other vegetation management techniques. Instream enhancement is the top tributary recommendation.

Excerpt from Mattole River Watershed Assessment Report providing recommendations for addressing all limiting factors in the Western Subbasin

What habitat improvement activities would most likely lead toward more desirable conditions in a timely, cost effective manner?

- Based upon the latest science on placement of large woody debris in stream channels, managers in the Western Subbasin should work to improve channel structure and function for salmonids. Pool shelter has the lowest suitability for salmonids in Mill Creek Tributary #1 and South Fork Big Finley Creek;
- Establish monitoring stations and train local personnel to track in-channel sediment and aggraded reaches throughout the subbasin and especially in the lower reaches of major tributaries and Squaw, Honeydew, Finley, Big Finley, Woods and Bear creeks;
- Continue efforts such as road improvements and decommissioning throughout the basin to reduce sediment delivery to the Mattole River and its tributaries. Road inventories have been completed for much of this planning basin, and it is recommended that this effort be continued until a complete inventory is compiled. CDFG stream surveys indicated Mill Creek and Bear Trap Creek have road sediment inventory and control as a top tier tributary improvement recommendation;
- Monitor summer water and air temperatures to detect trends using continuous 24 hour monitoring thermographs. Continue temperature monitoring efforts in Stansberry, Mill, Clear, Squaw, Woods, Honeydew, Bear, North Fork Bear, South Fork Bear, Little Finley, Big Finley, and Nooning creeks, and expand efforts into other subbasin tributaries;
- Ensure that near stream forest projects retain and recruit high canopy densities in riparian areas to reduce solar radiation and moderate air temperatures;
- Where current canopy is inadequate and site conditions, including geology, are appropriate, use tree planting and other vegetation management techniques to hasten the development of denser and more extensive riparian canopy. Canopy density has the lowest suitability for salmonids in Squaw Creek. Use cost share programs and conservation easements as appropriate;

- The three cooperative salmon rearing facilities in this subbasin should be continued as needed to supplement wild populations while the improvements from long-term watershed and stream restoration efforts develop;
- Initiate a systematic program to monitor the effectiveness of these fish rescue and rearing activities, and determine the need for the continuance of cooperative, supplemental fish rearing efforts on an ongoing, adaptive basis using the best available science;
- The nature and extent of naturally occurring unstable geologic terrain, landslides and landslide potential must be considered when planning potential projects in the subbasin;
- Encourage the use of appropriate Best Management Practices for all land use and development to minimize erosion and sediment delivery to streams;
- In order to protect privacy on private lands in this subbasin while developing data, the possibility of training local landowners to survey streams and conduct salmonid population status surveys is advisable;
- Ensure that high quality habitat within this subbasin is protected from degradation. The highest stream reach condition as evaluated by the stream reach EMDS and refugia analysis were found in Bear, Mill, North Fork Bear, South Fork Bear, Big Finley, and South Fork Big Finley creeks and the tributary to North Fork Bear Creek.

APPENDICES

APPENDIX A: DEFINITION OF TERMS.. 130

APPENDIX B: MANUAL FOR REGIONAL OR WATERSHED SCALE MAPPING OF LANDSLIDE AND FLUVIAL GEOMORPHIC CONDITIONS 138

APPENDIX C: LAND USE HISTORY DATA COLLECTION AND METHODS PROCEDURES 139

APPENDIX D: ORIGIN AND DESCRIPTION OF CALWATER 2.2.. 145

APPENDIX E: REGIONAL WATER QUALITY CONTROL BOARD METHODS MANUAL.. 146

APPENDIX F. CALIFORNIA SALMONID STREAM HABITAT RESTORATION MANUAL.. 147

APPENDIX G: STREAM REACH CONDITION EMDS MODEL 148

APPENDIX H: POTENTIAL SEDIMENT PRODUCTION EMDS MODEL 159

REFERENCES.. 175

APPENDIX A: DEFINITION OF TERMS

ADAPTIVE MANAGEMENT: Monitoring or assessing progress toward meeting management objectives and incorporating what is learned into future management plans.

AGGRADATION: The geologic process by which stream channels and floodplains are raised by deposition of material eroded from elsewhere. The opposite of degradation.

ALEVIN: The life stage of salmonids that occurs after eggs have hatched but before young emerge from the gravel nests where they have incubated. Alevin still have yolk sacs attached to provide them with nutrition within the nest.

ANADROMOUS: Fish that leave freshwater and migrate to the ocean to mature then return to freshwater to spawn. Salmon, steelhead and shad are examples.

ANTHROPOGENIC: Having a human source or cause.

BED LOAD: The portion of the total sediment load carried by a stream which consists of large-sized material that rolls or slides along the stream bottom.

BENEFICIAL USES: In the context of water quality control in California, the priority uses of stream water for humans and non-humans, including drinking water, irrigation water, hydro-power generation, recreation, fisheries, and aquatic habitat.

BEST MANAGEMENT PRACTICES (BMPs): Methods, measures, or practices to prevent or reduce water pollution, including structural and nonstructural controls, and operation and maintenance procedures. Some BMPs are also certified by the USEPA under the Clean Water Act, Section 208.

BENTHIC: Bottom dwelling or substrate oriented; at or in the bottom of a stream or lake, e.g., benthic aquatic insects.

BIOTA: The flora and fauna of a region.

CARRYING CAPACITY: The maximum number of organisms of a given species and quality that can survive in a given ecosystem without causing deterioration of the habitat within an interval of time.

CANOPY: The cover of branches and foliage formed collectively by the crowns of adjacent trees and other woody growth.

CANOPY COVER: The percent of an area covered by a canopy layer, typically the crowns of trees.

CENTROID: The center of water mass of a flowing stream at any location. This location usually correlates well with the thalweg, or deepest portion of the stream. Sampling in the centroid is intended to provide a representative sample of the stream.

CHANNEL CLASSIFICATION: Categorization of stream channels into discrete types based on physical criteria including channel slope, geometry, entrenchment, confinement or location within a watershed. Classification allows for comparison of channel condition and habitat of similar stream reaches.

CHANNEL CONFINEMENT: The ratio of the width of the valley floor to the width of the stream channel. This describes how restrictive the valley's walls are in limiting the channel's lateral movement (meandering).

CHANNEL ENTRENCHMENT: The degree of vertical containment of a river channel in the floodplain, i.e., downcutting or incising.

CHANNEL GEOMETRY: The physical size, shape, and characteristics of a channel caused by hydraulic factors of velocity, roughness, slope and flow frequency.

COBBLE EMBEDDEDNESS: The degree to which cobbles (small rocks 3-12 inches in diameter on the bottom of the stream) are surrounded or covered by fine sediment (sand or silt). Usually expressed as a percentage.

COLD WATER FISH HABITAT: Stream and lake waters that support fishes which require cold temperatures. Cold water fish include salmon, trout, and smelt. Salmon require water temperature below 56 degrees Fahrenheit as eggs, and below 65 degrees as smolts and adults.

CONDUCTANCE: The readiness by which a material transmits an electrical current. In the context of water quality, it is an indirect measure of dissolved solids.

CUMULATIVE WATERSHED EFFECTS: Cumulative effects are those effects on the environment that result from the incremental effect of an action when added to past, present and reasonably foreseeable future actions. Cumulative effects can result from individually minor but collectively significant actions taking place over a period of time.

DEGRADATION: The lowering of a stream channel by erosion of bed materials.

DISCHARGE RATE: In a stream, the volume of water passing through a channel in a given time. Also, stream flow.

DISSOLVED OXYGEN: The amount of oxygen dissolved in stream water which determines the ability of organisms to survive there.

DRAINAGE BASIN: The area from which a stream and its tributaries receives its water.

ECOTONE: A transition area between two distinct habitats that contains species from each area, as well as organisms unique to it.

ELECTROFISHING: Stunning fish with electricity to facilitate counting fish populations in a stream.

EPHEMERAL: A stream or portion of a stream that flows only in direct response to precipitation. The stream channel is poorly defined, with little riparian vegetation, and is above the water table at all times.

ESTUARY: A body of water where freshwater from a river or stream mixes with sea water.

FLATWATERS: In relation to a stream, low velocity pool habitat.

FLOODPLAIN: The area bordering a stream over which water spreads when the stream overflows its banks at flood stages.

FLUVIAL: Relating to or produced by a river or the action of a river. Situated in or near a river or stream.

FRESHET: A sudden rise or overflowing of a small stream as a result of heavy rains or rapidly melting snow.

FRY: The life stage of salmonids in which young fish leave gravel nests after their yolk sac is absorbed. Salmon fry live and grow in freshwater for one or two years.

GEOGRAPHIC INFORMATION SYSTEM (GIS): A computerized information processing technology used to input, store, manipulate, analyze, and display spatial resource data to support the decision-making processes of an organization about the land base and its resources.

GEOMORPHOLOGY: The study of surface forms on the earth and the processes by which these develop.

GIS: See geographic information system.

GRADIENT: The slope of a streambed or hillside. For streams, gradient is quantified as the vertical distance of descent over the horizontal distance the stream travels.

GROUND TRUTHING: Conducting limited field studies to confirm interpretations of data collected by remote means such as aerial photography.

INTERMITTENT STREAM**:** A stream that flows only during wet seasons of the year.

LARGE WOODY DEBRIS (LWD): Logs, stumps, and branches that enter and are transported by streams. LWD is an important influence on channel morphology and aquatic ecology by obstructing streamflow, storing and distributing sediment, and creating channel features, such as pools, riffles, and waterfalls.

LIFE STAGE: Critical stages in the life cycle of salmonids including alevin, fry, parr, smolt, and spawner. Each stage requires specific types of instream habitat including incubation, rearing, and spawning habitat.

LIMITING FACTOR: Any environmental or biological factor that prevents an organism or population from reaching its full potential of population, distribution, or activity.

LIMITING FACTORS ANALYSIS FOR SALMONIDS: Analysis of the conditions limiting production of native anadromous salmonids including current physical and biological constraints that limit migration, spawning and offspring survival.

MACROINVERTEBRATE: Invertebrates large enough to be seen with the naked eye (e.g., most aquatic insects, snails and amphipods).

MASS WASTING: The mass movement downslope of material under the influence of gravity. Often used synonymously with landslide and debris flows.

MEANDER: The bends in a stream channel that serve to slow down stream flow by forcing the water to cover more distance to reach a point than if it were traveling in a straight line.

METADATA: A description of the purpose, objectives, methodology, quality assurance, and quality control used to collect a specific data set. These factors are used to evaluate the relative quality and usefulness of the information for a particular purpose.

MICROCLIMATE: Climatic conditions found on a particular site or location. Microclimatic conditions vary significantly within larger climatic zones.

NONPOINT SOURCE POLLUTION: Polluted runoff from sources that cannot be defined as discrete points, such as areas of timber harvesting, surface mining, agriculture, and urban land use.

NUTRIENT CYCLING: The path taken by essential nutrients including nitrogen, carbon, phosphorous, and potassium within an ecosystem.

ORTHOPHOTOQUADS: A combined aerial photo and planimetric quad map (with no indication of contour) without image displacements and distortions.

PARR: Young trout or salmon actively feeding in freshwater; usually refers to young anadromous salmonids before they migrate to sea (See smolt).

PERENNIAL: A stream that flows continuously throughout the year in a well-defined channel.

PLATE TECTONICS: A theory in which the earth's crust is divided into mobile plates which are in constant motion causing earthquake faults, volcanic eruptions, and uplift of mountain ranges.

POINT BAR: Accumulations of sand and gravel deposited in slack water on the inside bend of a winding or meandering river.

POLYGON: An area of land mapped in a Geographic Information System based on its uniformity in a particular criterion such as vegetation type, age, geology or other environmental characteristic.

POOL: An area of stream that has reduced water velocity and where water depth is deeper than the surrounding areas. Pools are formed by features of the stream that cause local deepening of the channel.

QUALITY ASSURANCE: Procedures combining training of personnel and quality control checks to assure the accuracy and precision of data being collected.

QUALITY CONTROL: Checks made on the accuracy and precision of data collection and the procedures to be followed when a measurement does not fall within acceptable ranges.

REDDS: Nests made in gravel (particularly by salmonids) containing eggs consisting of a depression that is created and then covered.

REGION: One of the 18 major geographic regions categorized by the U.S. Geological Survey within the continental United States. California is Region 18.

RIFFLE: A shallow area extending across a streambed, over which water rushes quickly and is broken into waves by obstructions under the water.

RILL: An erosion channel that typically forms where rainfall and surface runoff is concentrated on slopes. If the channel is larger than one square foot in size, it is called a gully.

RIPARIAN: A type of wetland transition zone between aquatic habitats and upland areas. Typically, moisture-loving vegetation grows in this area along stream channels.

RIVER BASIN: A hydrologic unit composed of a river system, a reach of a stream and its tributaries, a closed basin, or a group of streams composing a coastal drainage area (e.g., Northern California Coastal). The U.S. Geological Survey codes each river basin with a six-digit code.

RUNOFF: Rainfall or snowmelt that flows overland across the surface of hillslopes and into a stream or body of standing water.

SALMONID: Fish of the family Salmonidae, including salmon, trout, chars, whitefish, ciscoes, and graylings.

SCOPING: Solicitation of involvement by stakeholders to identify important issues for consideration in natural resource management decision-making.

SEDIMENT LOAD: The total amount of sediment transported by a stream, composed of suspended and bed material.

SENSITIVITY ANALYSIS: A determination of the consequences of varying the level of one or several factors while holding other factors constant.

SERAL STAGE: The stage or recognizable condition of a plant community that occurs during its development from bare ground to climax community. Common stages in forest development include grass, forb, shrub seedling, pole-sapling, immature, mature, and old growth.

SHEET FLOW: The downslope movement of surface runoff over relatively smooth land surfaces in the form of a thin, continuous film that is not concentrated in channels. Sheet erosion is the detachment of soil particles by sheet flow.

SILVICULTURE: The management process whereby forests are manipulated through plantings, thinnings, and harvesting to control their growth, composition, health, and productivity

SINUOUSITY: The degree to which a stream channel curves or meanders across the land surface. Quantified as the ratio of channel length (measured as a curved line) to valley length (measured as a straight line).

SMOLT: A lifestage of salmonids occurring when a juvenile salmon migrates to the sea, or a young anadromous trout, salmon, or char is undergoing physiological changes to move from fresh water to the sea. The smolt stage follows the parr stage.

SPAWNER: A lifestage of salmonids occurring when adult fish return from the sea to their natal streams to reproduce.

STADIA RODS: Graduated rods observed through a telescopic instrument while surveying to determine distances and elevation.

STAKEHOLDER: A person or group that has a stake in the outcome of a natural resource management decision.

STOCK: A group of fish that is genetically self-sustaining and isolated geographically or temporally during reproduction. For anadromous salmonids, a stock originates from specific watersheds and returns to these birth streams to spawn as adults.

STREAM CLASS: The relative value of a stream based on its need for protection of its beneficial uses. Class I streams typically are very important for water supply, fisheries, or recreation values. Other stream classes denote streams of lesser value or streams that are intermittent or ephemeral.

STREAM FLOW: The amount of water flowing in a stream. This is often measured in units of cubic feet of water flowing past a cross section of stream per second. (See also discharge).

STREAM ORDER: A classification system for streams based on the number of tributaries to the stream.

STREAM REACH: A section of a stream between two points. Stream reaches may be delineated by confinement, gradient, or other physical factors.

SUB-BASIN: One of the smaller basins that makes up a river basin. The U.S. Geological Survey classifies subbasins using eight digit codes composed of four two-digit fields. In the context of NCWAP, a subbasin is a set of sub-watersheds within an assessment basin, e.g. Rockpile subbasin in the Gualala River watershed..

SUBSIDENCE: The sinking of the earth's surface due to overlying geologic materials, or the removal of groundwater.

SUBSTRATE: The material (silt, sand, gravel, cobble, etc.) that forms a stream or lake bed.

SUB-WATERSHED: One of the smaller watersheds that combine to form a larger watershed.

SUSPENDED LOAD: The amount of small-sized material (organic and inorganic) a stream carries in the water current.

SUSTAINED YIELD: The yield of commodities that a forest can theoretically produce continuously without impairment of the productivity of the land if managed intensively.

THALWAG: The portion of the stream with the deepest water and greatest flow. Also the line running longitudinally down the deepest portions of the stream channel.

TOTAL MAXIMUM DAILY LOAD: An estimate of the total quantity of a pollutant from all sources, including point, nonpoint, and natural, that may be allowed into waters without exceeding applicable water quality criteria.

TURBIDITY: A measurement of the optical property of water that scatters light. Turbidity increases with suspended organic or inorganic particulate matter.

WATERSHED: The total area above a given point of a water body that contributes flow to that point.

WATERSHED ANALYSIS: An interdisciplinary process of information collection and analysis that provides detailed information for specific management objectives and site-specific prescriptions.

WATERSHED ASSESSMENT: An interdisciplinary process of information collection and analysis that characterizes current watershed conditions at a coarse scale.

WATERSHED CONDITION: The state of a watershed based on physical characteristics and processes (e.g., hydrologic, geomorphic, landscape, topographic, vegetative cover, and aquatic habitat), water flow characteristics and processes (e.g., volume and timing), and water quality characteristics and processes (e.g., chemical, physical, and biological), as it affects water quality and water resources.

WATERSHED GOVERNANCE: The coming together of entities including companies, agencies, organizations in watershed groups to address natural resource issues on a watershed basis.

WATERSHED MANAGEMENT AREA: A grouping of smaller watersheds with similar management objectives used to identify and address water quality problems, e.g., the Humboldt WMA includes all watersheds draining to the ocean or bays north of the Eel River to and including Redwood Creek.

WEIR: A device across a stream to divert fish into a trap or to raise the water level or divert its flow.

APPENDIX B: MANUAL FOR REGIONAL OR WATERSHED SCALE MAPPING OF LANDSLIDE AND FLUVIAL GEOMORPHIC CONDITIONS

Click to download: http://www.consrv.ca.gov/cgs/ncwap/index.htm

APPENDIX C: LAND USE HISTORY DATA COLLECTION AND METHODS PROCEDURES

Land use and management practices have a significant influence on the condition of a watershed, both upland and aquatic ecosystems, including:

- water use (dewatering streams)
- sediment load
- shape of unit hydrograph (flood frequency, height and timing of peak flows)
- stream structure
- stream temperature
- habitat connectivity for fish

Land use changes often alter the rates of natural processes. For example, erosion from water has been an important part of the North Coast watershed landscape for all of geologic time. However, over the past 150 years rates of erosion by water have accelerated, due largely to the construction of roads and industrial timber harvest practices. Much larger quantities of sediment are being delivered to streams than under previous conditions, and this has caused major changes in stream morphology and fish habitat.

European-Americans have also introduced processes that were absent prior to their arrival. Industrial timber harvest practices have made intensive impacts in California's temperate rainforests at temporal and spatial scales that are distinct them from natural processes. Nitrogen fertilization of streams from agricultural wastes can create chemical and biological conditions that never occurred in these watersheds prior to intensive agricultural land use.

Knowledge of historic and current land use helps frame a better understanding of current watershed condition, the types and magnitudes of impacts experienced over history, and the legacy of past uses still observable in the system. Acquiring this knowledge is an important part of examining the relationships between land use and conditions of aquatic ecosystems (i.e. the net effect of human activities in the watershed).

Establishing definitive causal links is not possible in most cases, due to the complexity and variation of interactions between natural processes, disturbances and land use practices. Time lags of varying length occur between land use activities and their downstream effects, depending in part on other influences such as floods and precipitation. A single localized activity in a drainage can affect downstream conditions long after visible evidence of that activity has disappeared. In addition, historical conditions are difficult to reconstruct because of the paucity of available data and the difficulty of linking land use with watershed impacts.

Conceptual Framework of Land Use History

Creating watershed-specific land use histories presents CDF with a unique set of challenges. We developed the following set of questions to frame the land use history effort:

1. To what degree (level of confidence) can the vegetation and land use characteristics of the watershed at the time of European exploration/ settlement be inferred from present knowledge and available spatial (and other) data?
2. Where are the locations of historic and current disturbance of floodplains, riparian areas, and uplands? What was/is the type and extent of disturbance?
3. Are there general relationships that can be inferred between land use history and the current state of health among north coast watersheds?
4. What are the relative magnitudes of disturbance—sediment generation, habitat alteration, etc.—resulting from these land uses and activities? What types of land use activities appear to have had the most influence on the current state of the watershed?
5. What are the historical and current trends and locations of land use and land-disturbing activities in the watershed, both transient and permanent? What continuing longer-term effects might they have on the watersheds?
6. Which watersheds have experienced the largest degree of high-impact human alterations? Where (if they exist) are less-impacted watersheds that can be used for paired watershed analyses and to assist in determining natural background environmental parameters? Which watersheds offer the best potential for short-term restoration efforts?

Reports and data products

Our land use history work yields a mixture of qualitative and quantitative data. Qualitative, mostly non-spatial data collected includes a timeline of major landscape-altering events in the watershed, milestones in technology, major changes in resource protection laws, significant demographic changes, interpretation of historical photographs and maps, and analysis of written and oral historical records and accounts. Quantitative data, which is mainly in spatial digital format, includes the area of watershed within a particular land use, the amount of land converted from original vegetation to agriculture, rates of timber harvesting (and their changes over time), and the locations and occurrence of roads.

For each watershed, we created an information matrix incorporating a timeline of important events, natural and human-related (quasi-spatial, qualitative) and several coverages (spatially-explicit, quantitative data). Period dates used in each watershed were based on available information, aerial photography, and time constraints. Land use activities are dated to within 10 years of occurrence, according to decade (for more recent data). Where possible we note the actual date of the activity. Table 29 shows the variety of information sources we use in compiling the land use histories, including the period for which each is used. These vary according to the availability of data.

Table 29. Information Sources For CDF's Land Use History Development

Information Source	Pre-1940	1940-1970	1971-2000	Current Land Use
Written accounts	X	X	X	
Ground photos	X	X	X	
Maps from period	X	X	X	X

Information Source	Pre-1940	1940-1970	1971-2000	Current Land Use
Oral accounts	X	X	X	X
Public land survey	X			
Tax records	X	X		
THP GIS			X	X
Aerial photos		X	X	X
Satellite images			X	X
Digital ortho-photos			X	X
Land ownership GIS			X	X
USFS vegetation GIS			X	
Field observations				X
USGS 1:24K topo quads				X
US EPA Land Use GIS				X

Assembling and Interpreting Land Use History Data

Data collection for land use historical analysis is a difficult, time consuming and expensive process. Our methods encompass both researching and capturing existing land use related data. We used catalogs from historical society museums, university and government libraries, newspaper and timber company archives, county tax records, and the Internet to identify data for each watershed. Depending on the type of data, we obtained photocopies, scanned images, photographic reproductions or electronic copies. If a reference to data was found, but not the data, we tracked down its location and collected it if it was deemed to be of high potential value for reconstruction of land use history.

Use of data also varies according to source. Our researchers sifted through and interpreted information from written and oral accounts, public land survey data, and tax records. When possible we corroborated information across various accounts. We synthesized information from written records, historical maps and old ground level photographs into a history of the watershed since the arrival of European-Americans in the 19th century through about 1940.

For the post WWII era, aerial photographs were interpreted for significant noteworthy changes depending on the timing and location of the photography (Avery and Berlin 1992). Digital data most useful for land use history research includes remote sensing information mainly from satellite images [Landsat Thematic Mapper (TM), Landsat Multispectral Scanner (MSS), SPOT, etc.] and digital ortho-photography. Through image processing techniques, spectral changes between two satellite images taken on different dates can be enhanced to infer changes on the ground. This method is especially effective for showing changes due to large fires, timber harvesting, and vegetation regeneration. CDF has an ongoing program working with the U.S. Forest Service's Region 5 to detect land cover changes since 1994 using Landsat Thematic Mapper to detect (Levien, et al. 1999). NCWAP augmented this information with MSS data extending back to the early 1970s. Digital ortho-photo quads (DOQs) from recent aerial photography (1990s) are now available for the entire NCWAP region. These serve as a geo-referenced data layers used in conjunction with similar unrectified aerial photographs. These photos facilitate digitizing of land use activities.

Our land use history personnel were equipped with the following technical equipment:

- Laptop Personal Computers with ArcView™ software
- Handheld GPS devices
- Mirror Stereoscope (one per office)
- Hardcopy USGS 1:24K topographic quadrangles of area

We borrowed aerial photos from a number of different sources including CDF and CGS's Forest Practice program, the Bureau of Land Management, County Agricultural Extension offices, public libraries, and private landowners and non-profit groups. GIS coverages were created using ArcView tools (i.e., shape files). They were then imported to ARC/INFO coverages.

Attributes of GIS Historical Land Use Coverages

Land use history attributes of each polygon are digitized for incorporation in GIS. Attributes include:

- Approximate date of activity (if episodic)
- Aerial extent (i.e., how many hectares were in this land use? Implicit in GIS polygon)
- Type of activity (cropland, grazing, timber cut, building development, new road)
- Degree of impact (i.e., how impacting is this practice?)
- How permanent is the conversion (e.g., temporary timber harvest vs. permanent conversion to rangeland?)
- Any observable proximate impacts that may be ascribed to particular area of given land use
- Source of data
- Level of observer confidence in determining process at work

Land use digitizing procedure (for historical aerial photos):

1. In ArcView: DOQ of local area, overlain with contour vectors on screen.
2. Create or open a shape file to edit with new entries.
3. Have 1:24 K USGS quad sheet of locale nearby on desk to aid navigation through DOQ
4. Assemble set of aerial photos of given date(s).
5. Set up on table or desktop for stereo viewing.
6. Look for patterns in air photos giving the appearance of a land use practice or disturbance.
7. Delineate land use activities on clear Mylar sleeves overlaid on top of aerial photographs.
8. Input information on Mylar as polygon features into Arcview GIS system by onscreen or "heads-up" digitizing using 1993 black and white orthographic quadrangles as the background.

9. Correct distortion by using watercourses, ridges, and roads as reference indicators. Compare scale distortion apparent in the aerial photographs to the ortho-quads during heads-up digitizing. Manually correct by changing the scale of the ortho-quad to match the area near the polygon to provide the best fit.
10. Cross-correlate with satellite change detection images of area, if available.
11. Digitize the area of disturbance as carefully as possible.
12. Add labels and fill in a predetermined set of attributes about the observation.
13. Label the age of roads observed in the given aerial photos.

Validation and Accuracy Assessment

Little of the information available for the period prior to WWII is quantitative, and thus it cannot be assessed for validity except through comparison with other sources from the same era (Huntsinger 2001). It cannot therefore be evaluated for accuracy and consistency with more quantitative data. Historical narratives developed for NCWAP were assessed for accuracy by review within the agency and by the public and the scientific community. References were provided for primary materials used to develop the narratives to allow reviewers to access these primary sources and come to their own conclusions about historical trends and events.

Historical analysis using more quantitative data (mainly in digital spatial format) also poses challenges to validation. Much of the information developed concerns conditions that existed in the watershed prior to the present. Evidence of past events and land use clearly visible in historical photographs may be difficult to find in the landscape today.

CDF foresters assigned to the watershed made reconnaissance field visits before the analysis, compilation field visits during the process, and post hoc field visits after the assessment to assess accuracy GIS-based products they produced. Fieldwork on private lands was coordinated with other NCWAP agency personnel also needing the same access.

Table 30. Data Types, Status And Usage

Data Source/Type	Status	Usage
Historical photographs	Some digitized for Gualala, others unknown	Compare with other similar photos of later periods, today
Historical accounts	KRIS staff compiled for some watersheds	Compare verbal accounts with later and current status
Tax Records	Unknown; '12.75 rule' records still exist in some counties	Area, amount and timing of timber harvesting
Historical maps	Unknown	Interpret/digitize areas of observable land use
Public land survey notes	Unknown	Interpret accounts of surveyors
Aerial photographs	Few historical in-house photographs. Partial sets owned by many parties. Some sets are available for loan, others for on-site viewing only.	Interpret land use, digitize using DOQ comparison
Satellite data	MSS data 1973-1992; SPOT 1993 & 1999(?); TM of various dates	Change detection sets context for areas to look in more detail; SPOT helps reference analog aerial photos

Data Source/Type	Status	Usage
Digital ortho-photo quads	Available	Current land use and geo-reference for historical aerial photo interpretation
US Forest Service vegetation	Complete for north coast	Help to interpret vegetation types viewed in aerial photos
USGS 1:24K Topo Quads	Available for all watersheds; DRGs might be preferable	Navigate aerial photos interpretation through watersheds; use with contour DLGs
Digitized THPs	Complete for several watersheds	Assist current land use coverage creation
DLGs of hydrography, land ownership, roads, etc.	Varying degrees of completion, (watershed)	Assist in interpreting land use features

Roads Digitizing Procedure

Roads are specialized linear land uses that play a major part in watershed assessments. They are incorporated into GIS using methods paralleled to the polygon-based land use history data. Roads data is digitized using the following procedure:

1. Assemble 1:24K USGS DLGs of roads for a watershed. Use those with enhancements by CDF or the best available digital roads layer.
2. Overlay the roads GIS coverage and check it against recent DOQs of the same area.
3. Update the roads GIS coverage when roads or other human-made linear features are apparent in the recent DOQ but lacking in the coverage. Attribute new additions as carefully as possible.
4. Conduct field verification visits to validate digitized roads data.

For private industrial timberlands, we sought to obtain any existing road GIS coverages from the timber companies. We also identified opportunities for collection of additional road data through coordination with TMDL studies, local road assessment studies, etc. When successful, we assessed new coverage accuracy and quality and merged new roads vectors with ours when quality was deemed acceptable. This required strict attention to matching any differences in GIS attribute tables.

Where possible we digitized skid trails and landings, as well as old abandoned railroad beds. GIS attributes for the roads coverages include the following:

- Feature type (skid trail, haul roads, dirt, two-lane, county road, state highway, etc.);
- Road width
- Date or era of construction (if known)
- Apparent road condition (state of repair/disrepair from aerial photos)
- Apparent stream crossings (type, if discernible)

APPENDIX D: ORIGIN AND DESCRIPTION OF CALWATER 2.2

The North Coast Watershed Assessment Program uses the California Watershed Map (CalWater Version 2.2a) to delineate planning watershed units. CalWater is a geographic information system (GIS) developed to establish a common set of watershed definitions. CalWater uses the State Water Resources Control Board watershed delineation system. This hierarchy of watershed designations consists of six levels of increasing specificity: Hydrologic Region, Hydrologic Unit, Hydrologic Area, Hydrologic Sub-Area, Super Planning Watershed, and Planning Watershed (PW). CalWater version 2.2a is the third version of CalWater (after versions 1.2 and 2.0) and is a descendent of the 1:500,000-scale State Water Resources Control Board Basin Plan Maps drawn in the late 1970s.

NCWAP uses the Planning Watershed (PW) level of specificity in many analyses. PWs generally range from 3,000-10,000 acres in size and consist of a specific watershed polygon, which is assigned a single unique code. NCWAP used PWs for mapping, reporting, EMDS, and statistical analysis of geology, vegetation, land use, and fluvial geomorphology.

An important aspect of CalWater 2.2a is that individual PWs often do not represent true watersheds. In other words, PWs often are arrayed across streams and ridgelines and do not necessarily cover the true catchment of a stream or stream system. Large stream systems can drain and flow through multiple PWs. For example, the North Fork Mattole watershed contains five planning watersheds. Conversely, a stream may serve as a border between two CalWater 2.2a PWs, and thus receive runoff from two or more planning watersheds. For example, Rattlesnake Creek serves as the border between the Oil Creek PW and the Rattlesnake Creek PW. These occasional disconnects with natural hydrologic stream drainage systems is an artifact of the creation of CalWater 2.2a as a tool for managing forest lands in fairly consistent sized units.

APPENDIX E: REGIONAL WATER QUALITY CONTROL BOARD METHODS MANUAL

http://www.swrcb.ca.gov/rwqcb1/down/092203WQ-NCWAP-Manual.pdf

APPENDIX F: CALIFORNIA SALMONID STREAM HABITAT RESTORATION MANUAL

Click to download http://www.dfg.ca.gov/fishing/manual3.pdf

APPENDIX G: STREAM REACH CONDITION EMDS MODEL

A broad overview of the use of the Ecological Management Decision Support system within the North Coast Watershed Assessment Program is given in Chapter 4 above. The reader may want to refer to it, in particular for the graphics showing the structure of the models (Figure 26) and the tables showing in brief the various parameters used. This appendix expands on Chapter 4, providing detailed explanations of the Stream Reach Condition model developed for NCWAP.

The stream condition knowledge base uses data collected during DFG stream surveys to test the proposition: Stream conditions are suitable to support populations of anadromous salmonids. The stream reach knowledge base is composed of four logic networks relating to environmental factors that affect anadromous salmonid habitat conditions: 1) water temperature; 2) riparian function; 3) stream flow; and 4) in channel conditions. Within each network, individual habitat factors are evaluated. The overall stream reach condition is determined by combining the four evaluations through the "AND" logic node. This evaluates to "true" (+1) when all the network evaluations are "true", "false" (-1) if any of the four network evaluations is "false", or a numerical value between +1 and –1, showing the degree to which the above proposition is "true". The habitat factors NCWAP evaluated in the Stream Reach Condition EMDS are shown in black in Figure 32.

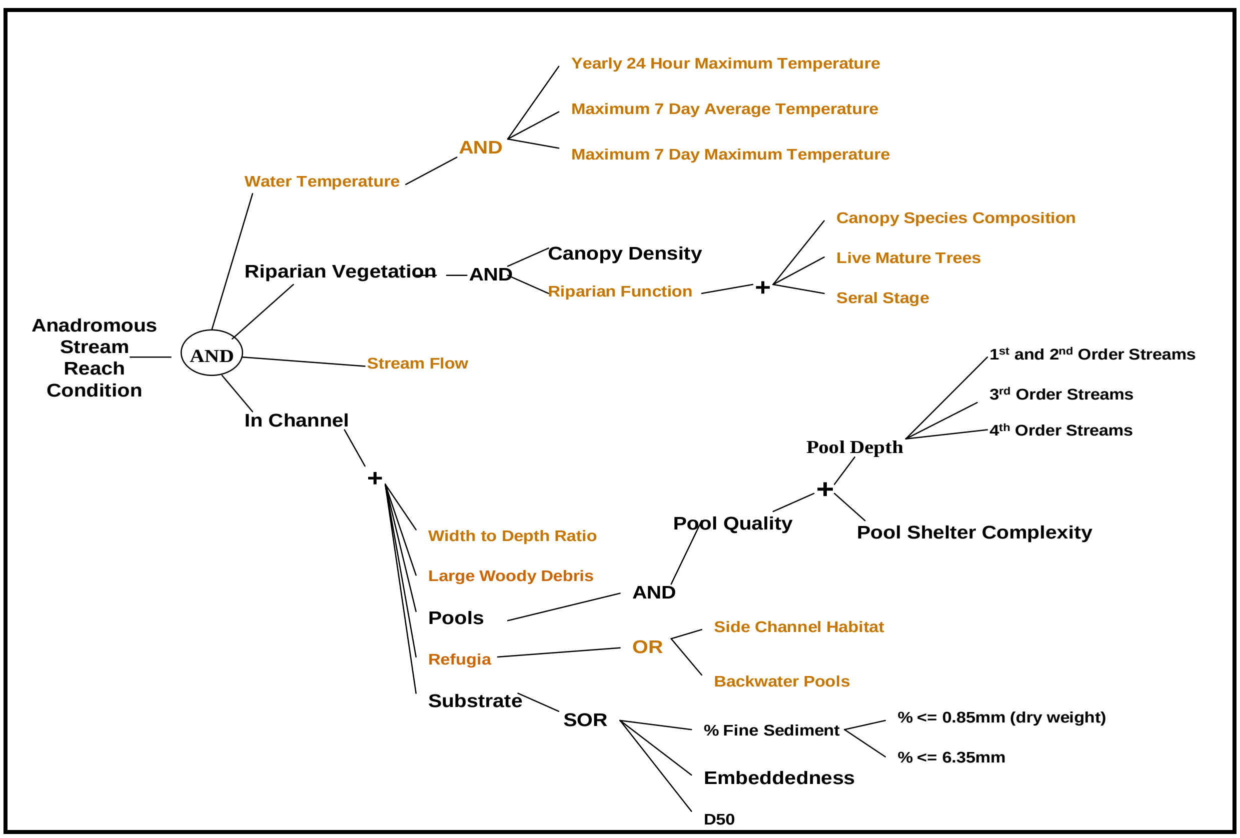


Figure 32. The Stream Reach Condition Model with Populated Habitat Factors Shown In Black. Some Other Factors Identified As Important To Evaluate Stream Habitat Conditions Are Shown in Grey.

A summary of the stream reach condition knowledge base used in the model is presented below. For each parameter in the model, its proposition, definition and explanation are presented. It is important to note that reference curve values used for this stream reach assessment are not intended to provide threshold values for single salmonid species management, but are designed to reflect agreement among experts on the point at which environmental conditions generally support or limit anadromous salmonid production. Reference curve values specific to a single species or life stage (e.g., juvenile coho) can be used according to research needs.

Water Temperature

Proposition: Summer water temperature is suitable to support healthy populations of anadromous salmonids.

Definition: Water temperature at the reach level is evaluated by comparing the 7-Day Maximum Average Temperature (7DMAT) collected from instream monitoring sites to the experimental and empirical based Maximum Weekly Average Temperature (MWAT) for summer rearing juvenile anadromous salmonids. Additional metrics will provide a broader based evaluation including: 1) Maximum Weekly Maximum Temperature, and 2) Yearly 24-hour maximum temperature. Maximum Weekly Average Temperature (MWAT) is a calculated value based on experimental and empirical data, that is the upper temperature recommended for a species life stage or a threshold that should not be exceeded (Armour, 1991). The MWAT is essentially the upper temperature that fish can withstand over long durations and still maintain healthy populations (Klamt et al 2000). The experimental calculation for the MWAT is:

$$MWAT = OT + \frac{UUILT - OT}{3}$$

- OT = Optimal Temperature reported for a particular species and life stage. In the NCWAP analysis, summer juvenile rearing is used.
- UUILT = Upper Ultimate Incipient Lethal Temperature is the highest temperature at which tolerance does not increase with increasing acclimation temperatures.
- UILT = Upper Incipient Lethal Temperature is the upper temperature that 50% mortality is observed for a given acclimation temperature. The UILT increases with acclimation temperatures to a point that higher acclimation temperatures have no effect.

Explanation: The 7DMAT measured from continuous temperature recorders located in streams are compared to reference values derived from experimentally and empirically determined MWAT's for anadromous salmonids. The assessment team decided to use one MWAT value across all streams rather than attempt a site- or species-specific approach. The reference values for the MWAT were selected from a synthesis of relevant studies (see Figure 33).

Stillwater Sciences (1997) has found that high water temperatures that are below those considered to be lethal may also result in negative impacts to rearing coho. Stein et al. (1972) reported that growth rates in juvenile coho salmon slow considerably at 18 ^{o} C (64.4 ^{o} F), and Bell (1973) reported that growth of juvenile coho ceases at 20.3 ^{o} C (68.5 ^{o} F). Decreases in swimming speed may occur at temperatures over 20 ^{o} C (68 ^{o} F) (Griffiths and Alderdice 1972).

Empirical studies by Hines and Ambrose (2000) found that the number of days a site exceeded an MWAT of 17.6 ^{o} C (63.7^{o} F) was one of the most influential variables predicting coho presence and absence. Welsh et al. (2001) suggest that an MWAT greater than 16.7 ^{o} C (62.0 ^{o} F) may preclude the presence of coho salmon in the Mattole River.

Reference Values: The proposition for summer water temperature (7DMAT) is fully true if field observations range from ≥50 and ≤60 ^{o} F and fully false if field observations are below ≤ 45 or above ≥ 68 ^{o} F.

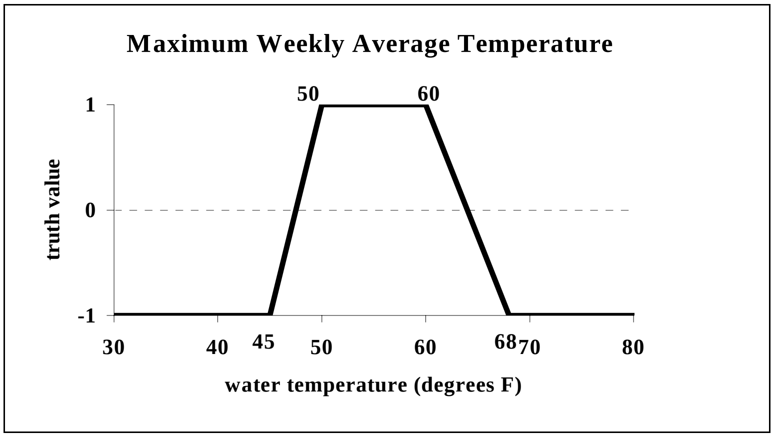


Figure 33. Breakpoints for 7DMAT Truth Values

Riparian Function

Proposition: Current riparian vegetation provides sufficient shade, nutrients, large woody debris recruitment, and contributes to bank stability to maintain healthy populations of anadromous salmonids.

Definition: The riparian function assessment consists of an evaluation of canopy density, which shades the stream channel, and an evaluation of the near-stream forest's ability to provide LWD and nutrients to the stream channel. The riparian vegetation function network is composed of an evaluation of: 1) canopy density, and the mean value of the evaluation of: 2) canopy species composition, 3) live mature trees, and 4) imminent sources of large woody debris.

Canopy Density

Proposition: Canopy density is provides adequate shade to help maintain suitable water temperature and nutrient input to maintain healthy anadromous salmonid populations.

Definition: Canopy density is the percent of stream influenced by tree canopy measured with a spherical densiometer from the center of wetted stream channel.

Explanation: Shade from streamside canopy helps to reduce stream water temperatures, especially during summer months. This parameter measures the adequacy of the vegetation in performing this important role. The California Department of Fish and Game's Salmonid Stream Habitat Restoration Manual recommends, in general, that revegetation projects should be considered when canopy density is less than 80% (Flosi et al. 1998). Naiman et al. (1992) report that in west side forests, the amount of solar radiation reaching the stream channel is approximately 1 - 3% of the total incoming radiation for small streams and 10 -25% for mid-order (3rd to 4rth order) streams.

Data Sources: Measurements from field observations collected during DFG stream surveys

Reference Values: The proposition for canopy density is fully true if field observations are 85 percent or above and fully false if field observations are below 50 percent (see Figure 34).

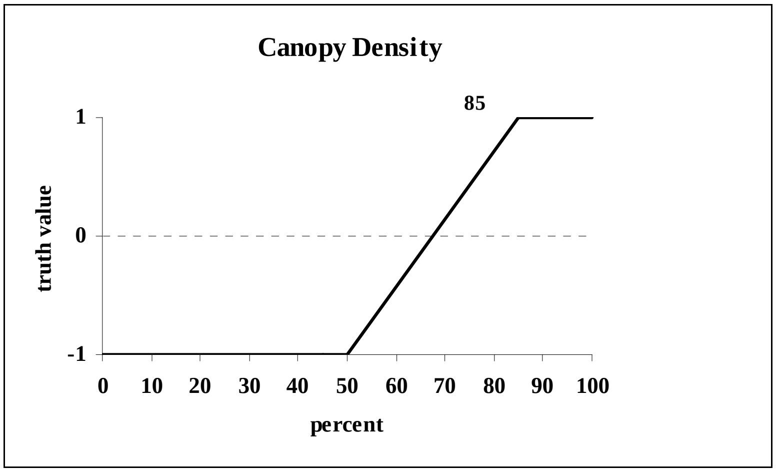


Figure 34. Breakpoints for Canopy Density

Canopy Species Composition (not yet implemented)

Proposition: The canopy species composition is within the range of historic species distribution and is suitable to maintain healthy anadromous salmonid populations. (Not yet implemented in the model).

Definition: The similarity of species and life forms between the current vegetation and that existing prior to Euro-American colonization.

Explanation: The species composition of the riparian vegetation can indicate recent historical events that have occurred in and near the stream reach. Some areas currently dominated by broad-leafed trees were dominated in the past by conifers. This can indicate that disturbances have occurred in the watershed, which resulted in this change in species composition. Also, conifers tend to provide more cooling in their shade than broad-leaf trees.

Data Sources: Measurements are made from field observations.

Reference Values: The proposition is fully true if the observed canopy species composition has a high degree of similarity to the pre-Euro-American range of species composition and fully false if it has a low similarity.

Live Mature Trees (not yet implemented)

Proposition: The number of live trees three feet or greater in diameter at breast height within a riparian buffer zone is sufficient to maintain conditions needed to support healthy anadromous salmonid populations. (The reference value curves and other aspects have not yet been developed for live mature trees.)

Imminent Source of Large Woody Debris (LWD) (not yet implemented)

Proposition: The mean age of riparian vegetation is suitable to provide shade, LWD, bank stability, and maintain channel conditions that benefit anadromous salmonid populations. (The reference value curves and other aspects have not yet been developed for this parameter.)

Stream Flow (not yet implemented)

Proposition: The stream flow regime is suitable to sustain healthy populations of anadromous salmonids. (This sub-network of the stream reach model is under construction by the Department of Water Resources. It is not yet ready for inclusion in the stream reach condition model.)

In-Channel Conditions

Proposition: In-channel conditions are suitable to support healthy anadromous salmonid populations

Definition: In-channel conditions are determined by the mean truth-value returned by the evaluation of 5 networks: 1) large woody debris, 2) width to depth ratio, 3) pool habitat, 4) winter habitat, 5) substrate composition.

Large Woody Debris (not yet implemented)

Proposition: The amount of in channel large woody debris is suitable for maintaining channel conditions to support healthy populations of anadromous salmonids.

Definition: The target reference values for LWD frequency and volume is derived from Bilby and Ward's (1989) channel-width dependent regression for unmanaged streams in western Washington. The relationships between channel width and number of pieces (Bilby and Ward 1989) is also presented in Spence et al. (1996) and "key" pieces of LWD in the Pacific Lumber company Habitat Conservation Plan, Aquatic Properly Functioning Condition Matrix (Pacific Lumber Company 1997).

Explanation: Large woody debris is important to stream ecosystems because it exerts considerable control over channel morphology, particularly in the development of pools (Keller et al. 1995). Petersen and Quinn (1992), noted that "in forested streams, LWD is associated with the majority of pools and the amount of LWD has a direct affect on pool volume, pool depth and percentage of pool area in a stream." Stillwater Sciences' Preliminary Draft Report suggests, "One of the working hypotheses concerning coho salmon ecology and management in Mendocino county streams is that large woody debris (LWD), and the rearing habitat that it provides, may currently be the most important factor limiting coho populations." The North Coast Water Quality Control Board in cooperation with the California Department of Forestry (1993) stated that, "woody debris benefits all life stages of salmonids by creating pools which are used as holding areas during migration." Large woody debris also serves to retain spawning gravels, creates slack water areas which provide opportunities for juveniles to feed on drift, and by providing essential cover from predators and freshets (Murphy and Meehan 1991). Woody debris in stream also increases the frequency and diversity of pool types (Bilby and Ward, 1991).

Deep (>45 cm), slow (<15cm/s areas in or near (<1m) instream cover or roots, logs, and flooded brush appear to constitute preferred habitat (Hartman 1965, Bustard and Narver 1975), especially during freshets (Tschaplinski and Hartman 1983; Swales et al. 1986, McMahon and Hartman, 1989). Underwater observations by Shirvell (1990) found that 99% of all coho salmon fry observed were occupying positions downstream of natural or artificial rootwads, during artificially created drought, normal, and flood stream flows.

Data Sources: Measurements from LWD field surveys.

Width-to-Depth Ratio (not yet implemented)

Proposition: The width-to-depth ratio of the stream reach is suitable for sustaining healthy populations of anadromous salmonids. (The reference values curves have not yet been developed for this parameter.)

Pool Habitat

Proposition: The pool frequency, pool depth, and pool complexity observed in the stream reach is suitable to support healthy populations of anadromous salmonids.

Definition: The pool habitat sub-network evaluation is composed from evaluations of: 1) pool frequency (not implemented), and 2) pool quality including pool depth and pool complexity.

Pool Frequency (not yet implemented)

Proposition: The number of pools observed during stream surveys is within the suitable frequency range for the channel type, gradient, bankfull width, and channel confinement of the stream reach.

Definition: The number of pools observed per unit length of stream reach.

Explanation: (Not implemented)

Reference Values: The proposition is fully true if the observed pool frequency has a high degree of similarity to the expected frequency range and fully false if it has a low similarity. (Reference values have not yet been developed for this parameter.)

Pool Quality

The pool quality network is composed of an evaluation of pools depth and pool shelter complexity rating.

Pool Depth

Proposition: The percent of the stream reach length in primary pools is suitable to support anadromous salmonids.

Definition: Primary pools have a maximum depth of 2.5 feet or greater in first and second order streams and have a maximum depth of 3 feet or greater for third order streams.

Explanation: The percent by stream reach of adequately deep pools or primary pools is determined according to stream order. For this analysis, stream order is determined from streams displayed as solid blue lines on 1:24,000 USGS topographic maps. The percent reach of primary pools is calculated by length of primary pool habitat per stream reach length (Flosi et al. 1998).

Data Sources: Measurements from field observations collected during DFG stream surveys.

Reference Values: The proposition for the pool depth evaluation is fully true if 30 to 55 percent of the reach is in primary pools and fully false if there is less than 20 percent or more than 90 percent primary pool habitat (Figure 35).

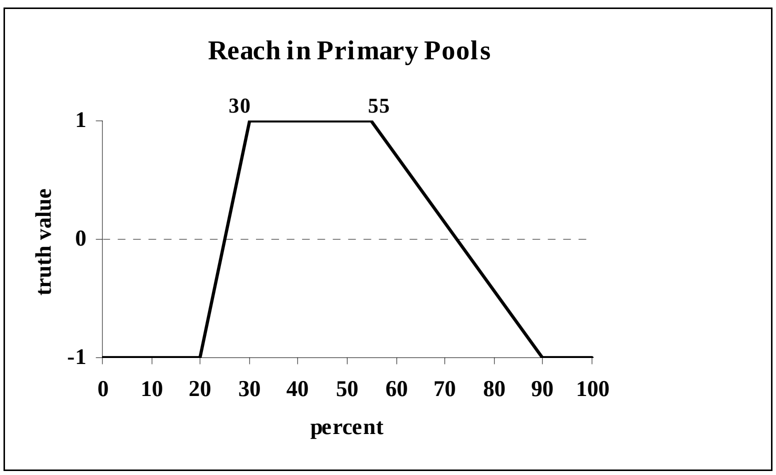


Figure 35. Breakpoints for Percent Reach in Primary Pools

Pool Shelter Complexity

Proposition: The average pool shelter complexity is suitable to support anadromous salmonids.

Definition: A DFG field procedure rates pool habitat shelter complexity (Flosi et al. 1998). The pool shelter rating is a relative measure of the quantity and composition of LWD, root wads, boulders, undercut banks, bubble curtain, and submersed or overhanging vegetation that serves as instream habitat, creates areas of diverse velocity, provides protection from predation, and separation of territorial units to reduce density related competition. The rating does not consider factors related to changes in discharge, such as water depth.

Data Sources: Measurements from field observations collected during DFG stream surveys.

Reference Values: The proposition for the pool shelter complexity evaluation is fully true if the pool shelter rating is 100 or greater and fully false if the pool shelter rating is 30 or less (Figure 36).

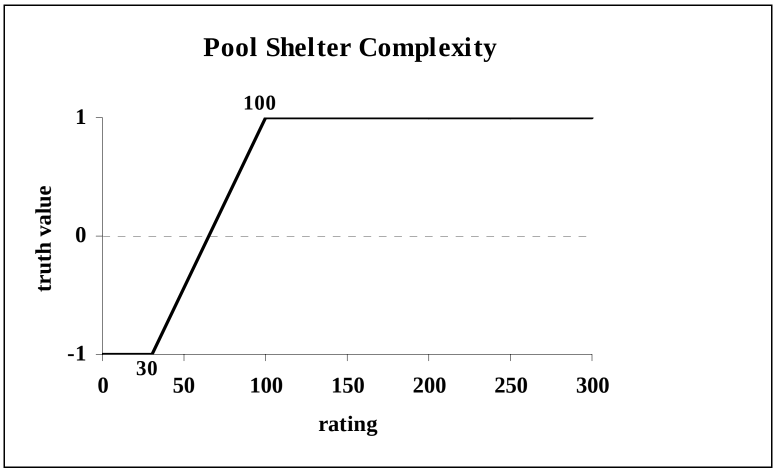


Figure 36. Breakpoints for Pool Shelter Complexity

Winter Habitat (not yet implemented)

Proposition: The amount of backwater pools, deep pools and side channel habitats is suitable (especially as winter refuge) to support healthy anadromous salmonid populations.

Definition: Refugia for this evaluation is composed of backwater pools, side channel habitat, and deep pools (>4 feet deep) identified from DFG's stream habitat surveys.

Explanation: The majority of juvenile coho in coastal streams appear to over winter in deep pools, backwater habitats or alcoves within the stream channel that have substantial amounts of cover in the form of woody debris and/or provide shelter from high winter flows (Bustard and Narver 1975, Scarlett and Cederholm 1984, Murphy et al 1989, Brown and Hartman 1988). Swimming ability decreases with temperature and as water temperature falls below 9 C, juvenile coho become less active (Stillwater Sciences 1997) and require rearing habitat that provides shelter during high winter flows.

Data Sources: Measurements from field observations collected during DFG stream surveys.

Reference Values: The proposition for the winter habitat evaluation is fully true if there is 10 percent of the stream reach in side channel or backwater pools and fully false if there is no such habitat in the stream reach (Figure 37).

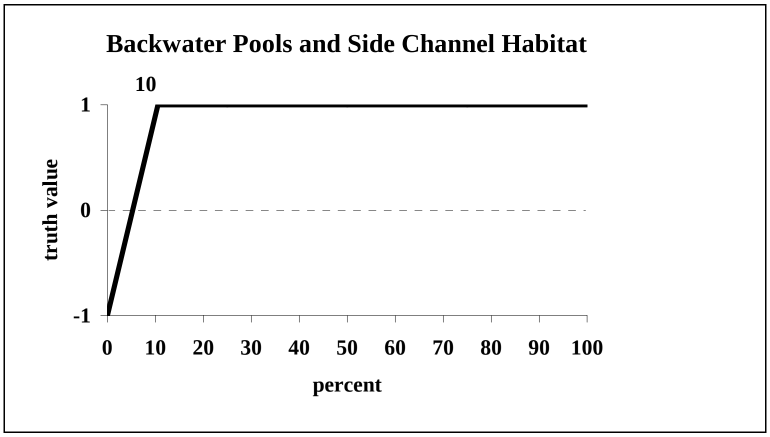


Figure 37. Breakpoints for Percentage in Backwater Pools and Side Channel Habitat

Substrate Composition

Pool tail Embeddedness

Proposition: Pool tail substrate provides suitable spawning material and promotes survival of salmonid eggs to emergence of fry.

Definition: Pool tail embeddedness is a measure of the percent of small cobbles (2.5 to 5 inches in diameter) buried in fine sediments. Percent cobble embeddedness is determined at pool tail-outs where spawning is likely to occur. Average embeddedness values are placed into one of five embeddedness categories.

1 = 0 to 25%

2 = 26 to 50%

3 = 51 to 75%

4 = 76 to 100%

5 = unsuitable for spawning (impervious)

Explanation: The EMDS uses a weighted sum of embeddedness category scores to evaluate the pool tail substrate suitability for survival of eggs to emergence of fry. The percent embeddedness categories are weighted by assigning a coefficient to each category. EMDS rates embeddedness category 1 as fully suitable for egg survival and fry emergence and assigns a coefficient of +1 to the percent of embeddedness scores in category 1. Category 2 is considered uncertain and given a coefficient of 0. Categories 3 and 4 are considered unsuitable and are assigned a coefficient of -1. Category 5 values are omitted since they are composed of impervious substrate such as boulders, bedrock or log sills. The values for each category are summed and evaluated by EMDS. The summed score ≤ -0.8 evaluates to fully unsuitable and ≥ 0.8 evaluates to fully suitable.

Data Sources: Measurements from field observations collected during DFG stream surveys.

Reference Values: See Figure 38.

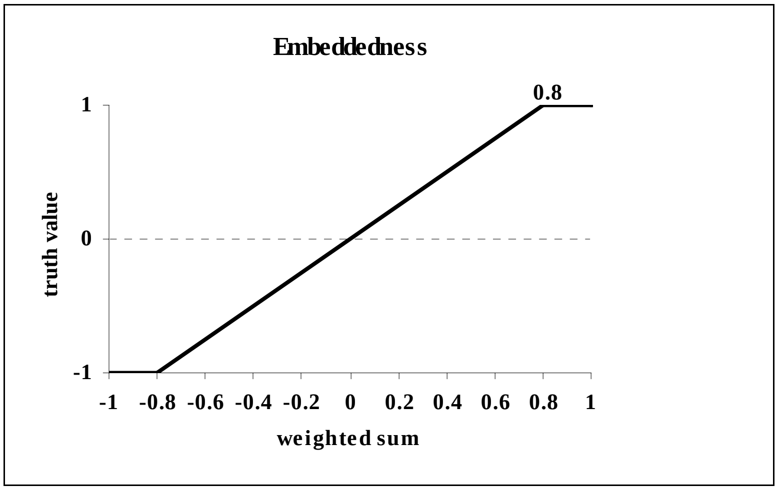


Figure 38. Breakpoints for Embeddedness

Percent Fine Sediment

Explanation: Substrate composition is used as a suitability measure for survival of eggs to the emergence of fry. Sedimentation resulting from land use activities is recognized as a fundamental cause of salmonid habitat degradation (FEMAT 1993). Excessive accumulations of fine sediments reduces water flow (permeability) through gravels in redds. The percent of fine sediments is higher in watersheds where the geology, soils, precipitation or topography create conditions favorable for erosional processes (Duncan and Ward 1985). Fine sediments are typically more abundant where land use activities such as road building or land clearing expose soil to erosion and increase mass wasting (Cederholmn et al 1981; Swanson et al 1987; Hicks et al 1991). McHenry et al. (1994) found that when fine sediments (<0.85mm) exceeded 13% (dry weight) salmonid survival dropped drastically. Bjornn and Reisner (1991) show that the salmonid embryo survival drops considerably when the percentage of substrate particles smaller than 6.35 mm exceeds 30 percent.

Data Sources: Substrate samples collected from instream sites.

Reference Values: Reference values curves for percent fine sediment are presented in Figure 39 and Figure 40.

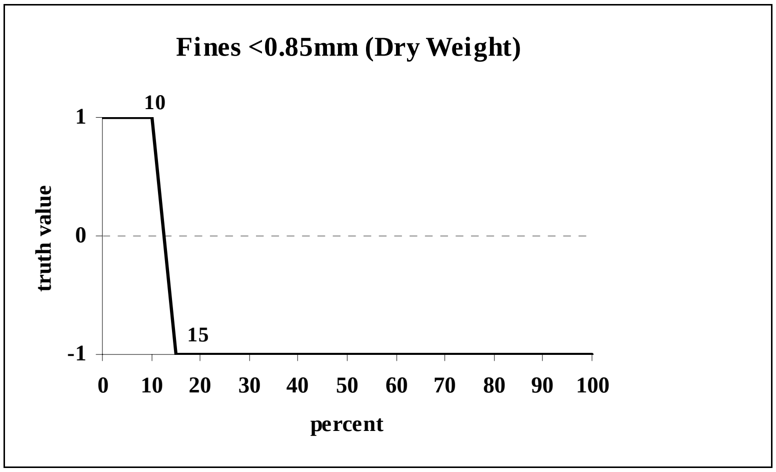


Figure 39. Breakpoints for Percent Dry Weight of Fine Sediments <0.85mm

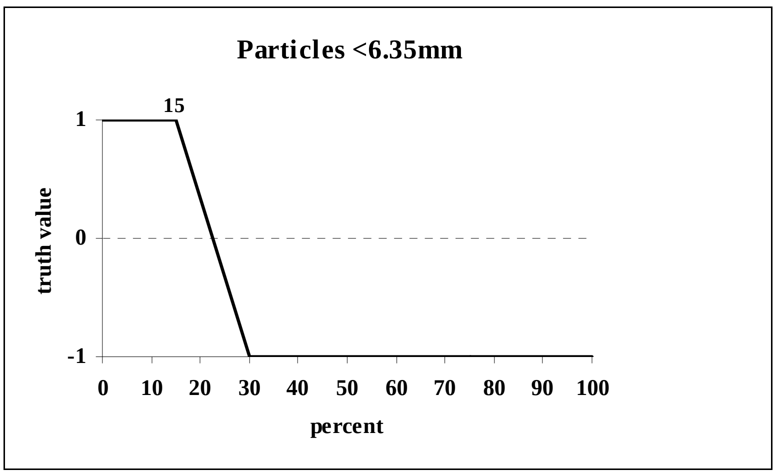


Figure 40. Breakpoints for Percent of Sediments <6.35mm

APPENDIX H: POTENTIAL SEDIMENT PRODUCTION EMDS MODEL

In June of 2001, watershed and fisheries scientists, NCWAP agency personnel and others began construction on a Watershed Condition knowledge base network for EMDS that reflected the interrelationships of environmental factors which affect populations of salmonids on California's north coast. In April of 2002, an independent panel of scientists reviewed the first draft Watershed Condition model. The panel recognized the model as a good initial step and recommended significant changes. In response to the panel comments, NCWAP scientists have split the first draft model into four separate pieces (as explained in Appendix G): The Potential Sediment Production Model; the Fish Habitat Quality Model; the Water Quality Model and the Fish Food Availability Model. While the Potential Sediment model assesses current hazards, all of the other EMDS models assess current conditions in the watersheds. This appendix provides details on the first three models (the fourth has yet to be designed), summarizing the NCWAP EMDS knowledge base components and how they are combined into the synthesis of watershed condition.

Note that some metrics (e.g., Road Density by Hillslope Position) are used in more than one place in the model. In all cases the metric will be identical, although the relative weightings can be different in each instance of use.

The Potential Sediment Production model is evaluated from two equally-weighted branches: Potential Stream Sediment from Natural Processes (Figure 41) and Potential Stream Sediment from Management Activities (Figure 42). The final decision node of the model is the mean truth value returned by the two branches.

In the Potential Sediment Production model, all parameters currently use empirical distributions for the break points in the evaluations (see Figure 40 for example). The literature is rich in many aspects regarding the effects of roads, riparian condition, stream flows and land use on water quality and salmonid habitat (see references). However, very few studies provide direct guidance on where to set breakpoints for the specific parameters required in the model (e.g., what constitute good versus poor conditions for anadromous salmonids vis-à-vis length of road near to streams). In light of this fact, NCWAP scientists decided that while an objective evaluation may not be possible (or at least scientifically defensible) on an absolute scale for all watersheds, evaluation of relative conditions within a basin would be more robust, while still being informative. Thus for each hydrologic area (e.g., the Mattole River) breakpoints are determined based upon the normalized distance from the mean (i.e., percentiles) from the statistics of the distribution of given parameter. Within this framework it is still possible with most parameters to look beyond a hydrologic area to larger regions by aggregating the statistics. However, extrapolating in this manner may be more tenuous than looking more locally, due to the likelihood of changes in data quality and availability from one area to another.

As stated above, for the longer-term model development, the science review panel suggested that statistics for breakpoints be generated from a set of reference watersheds in the region. At this point, however, we have not identified such watersheds, and consequently have not been able to collect the relevant information.

Below is a more detailed explanation of the technical workings of the NCWAP Potential Sediment Production model.

Potential Stream Sediment from Natural Processes

Proposition: Potential delivery of sediments to streams from mass wasting events, independent of management activities, does not significantly threaten the planning watershed's ability to sustain healthy populations of anadromous salmonids.

Definition: The Potential Stream Sediment from Natural Processes node evaluates the mean truth value returned from three sub networks: 1) mass wasting I; 2) surface erosion I; and 3) streamside erosion I. Figure 41 shows the diagram on the potential stream sediment from natural processes part of the potential sediment production model.

Explanation: Potential stream sediment from natural processes represents the potential impacts of the natural landscape on a watershed's sediment loads, and, by extension, on native anadromous fish. Three metrics, listed above, provide surrogates of potential sediment delivery. The metrics are derived using digital data on geology and recent fires. Planning watersheds that have truth values that are at or near +1 show the most positive ratings for sediment risk (i.e., low sediment risk) from natural processes, while conversely those approaching –1 have the most negative characteristics with regard to natural sediment risk.

From Mass Wasting I

Proposition: Potential delivery of coarse sediments to streams from mass wasting events, independent of management activities, does not significantly threaten the planning watershed's ability to sustain healthy populations of anadromous salmonids.

Definition: From Mass Wasting I is evaluated for planning watersheds using a single parameter: the weighted percentage area within zones of extreme (class 5) or high (class 4) landslide potential. Area of class 5 is weighted 0.8 and area of class 4 is weighted 0.2.

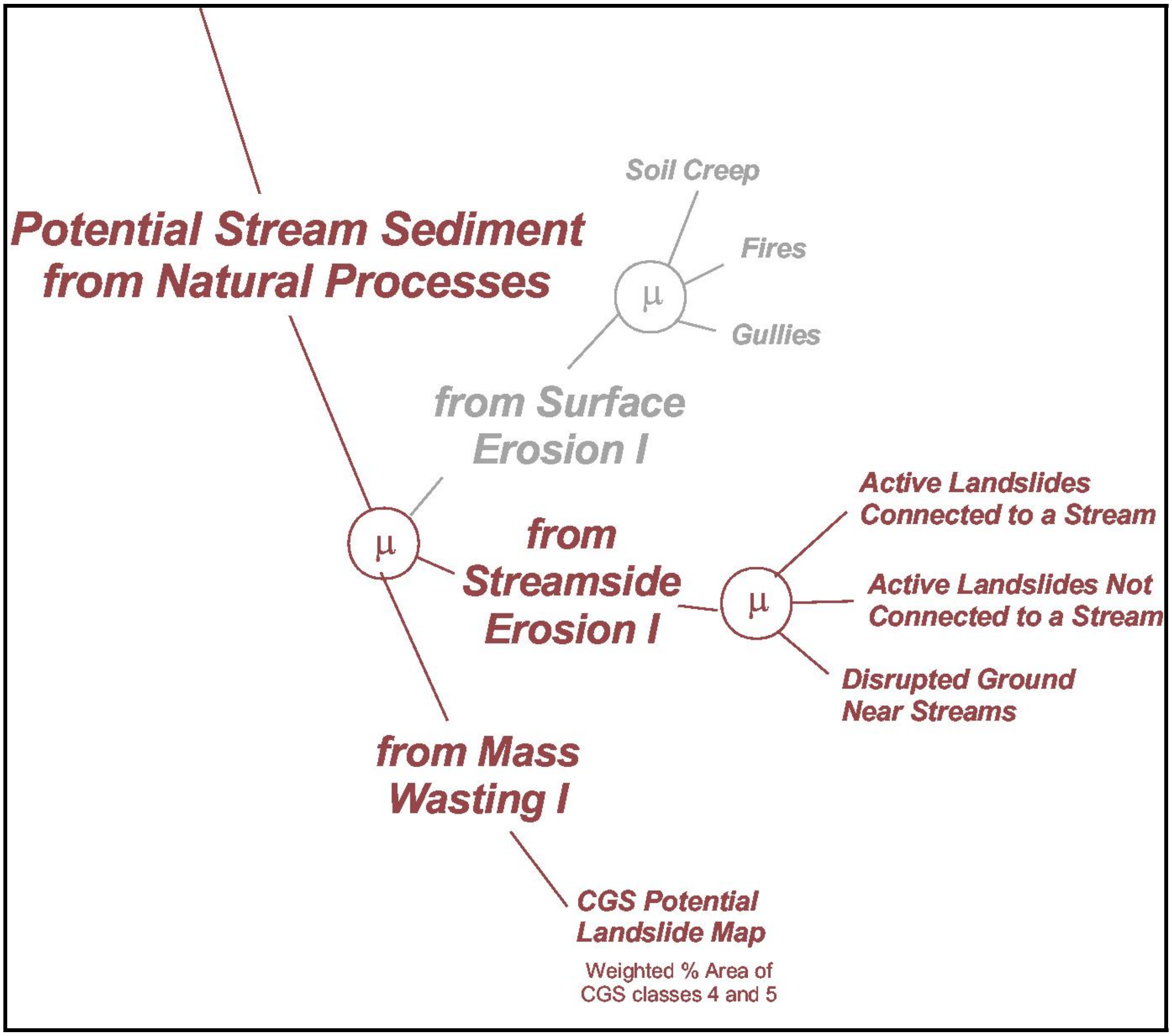


Figure 41. The Potential Sediment from Natural Processes section of the EMDS Model

Note: This section of the model takes data related to geology (and in the future, recent fires) and combines them into an evaluation of their relative importance in each planning watershed. Gray text denotes parts of the model that are not yet implemented and were not used for this basin.

Explanation: This metric is designed to represent the risk of mass wasting events from natural processes which deliver sediments to streams. Mass wasting events typically deliver coarse sediments that can cause aggradation in the stream, and have a detrimental effect upon salmonid habitat.

Data Source: The California Geological Survey's (CGS) Landslide Potential Model GIS coverage.

Reference Values: Break points: <10th percentile highest potential suitability; >90th percentile lowest potential suitability.

From Surface Erosion I

Proposition: Potential delivery of fine sediments to streams, independent of management activities, does not significantly threaten the planning watershed's ability to sustain healthy populations of anadromous salmonids. Currently this network has no data provided to the model.

Definition: From Surface Erosion I will be the mean truth value returned from 3 parameters: 1) soil creep; 2) natural gullies and 3) recent fires.

Explanation: Surface erosion and delivery of fine sediments to streams occurring from natural processes has the potential to negatively impact stream condition through delivery of fine sediments. Increased fine sediments can create higher rates of embeddedness, which can cause problems for the reproduction of anadromous fish. They can also cause high rates of turbidity, which can make foraging and feeding more difficult for fish.

Reference Values: Break points: <10th percentile highest potential suitability; >90th percentile lowest potential suitability.

Soil Creep (no data yet available)

Proposition: Potential delivery of fine sediments to the stream from natural soil creep does not significantly threaten the planning watershed's ability to sustain healthy populations of anadromous salmonids.

Data Sources: CGS coverage.

Natural Gullies (no data yet available)

Proposition: Potential delivery of fine sediment to the streams from natural gullies does not significantly threaten the planning watershed's ability to sustain healthy populations of anadromous salmonids.

Data Sources: CGS coverage.

Fires (no data yet available)

Proposition: Potential delivery of fine sediment to the streams from recent fires do not significantly threaten the planning watershed's ability to sustain healthy populations of anadromous salmonids.

Data Sources: CDF fires coverage.

From Streamside Erosion I

Proposition: Potential delivery of coarse and fine sediments to streams, independent of management activities, from streamside erosion does not significantly threaten the planning watershed's ability to sustain healthy populations of anadromous salmonids.

Definition: From Streamside Erosion I will be based upon the summation of 3 parameters: 1) active landslides connected to streams; 2) active landslides not connected to streams and 3) disrupted ground near streams.

Explanation: Streamside erosion occurring from natural processes has the potential to negatively impact stream condition through delivery of both coarse and fine sediments. Increased coarse sediments can cause excessive sediment loading and aggradation of the streams, particularly in the lower response reaches. Aggradation causes more of the water to flow through gravels and rocks below the riverbed, and can effectively reduce flow. Increased fine sediments can create higher rates of embeddedness which can cause problems for the reproduction of anadromous fish. They can also cause high rates of turbidity, which can make foraging and feeding more difficult for fish.

Reference Values: Break points: <10th percentile highest potential suitability; >90th percentile lowest potential suitability.

Active Landslides Connected to Streams

Proposition: Potential delivery of coarse and fine sediments to the stream from active landslides connected to streams does not significantly threaten the planning watershed's ability to sustain healthy populations of anadromous salmonids.

Data Sources: CGS coverage.

Active Landslides Not Connected to Streams

Proposition: Potential delivery of coarse and fine sediments to the streams from active landslides not connected to streams does not significantly threaten the planning watershed's ability to sustain healthy populations of anadromous salmonids.

Data Sources: CGS coverage.

Disrupted Ground

Proposition: Delivery of coarse and fine sediments to the streams from disrupted ground near streams does not significantly threaten the planning watershed's ability to sustain healthy populations of anadromous salmonids.

Data Sources: CGS coverage.

Potential Stream Sediment from Management-Related Sources

Figure 42 shows the EMDS model framework for sediment from management-related sources.

Proposition: Potential delivery of coarse and fine sediments to streams from management-related activities do not significantly threaten the planning watershed's ability to sustain healthy populations of native anadromous salmonids.

Definition: Potential stream sediment from management-related sources node evaluates the mean truth value returned from three sub networks: 1) mass wasting II; 2) surface erosion II; and 3) streamside erosion II. Figure 42 shows the diagram on this part of the EMDS Potential Sediment Production model.

Explanation: Stream sediment from management-related sources represents the potential impact of management activities in the landscape on the planning watershed's sediment loads, and upon native fish. Three metrics, listed above, provide surrogates of sediment delivery risk. The metrics are derived using digital data on roads and land use (current and historic) in combination with the data on geology. Planning watersheds that have truth values that are at or near +1 show the most positive ratings for sediment risk (i.e., low sediment risk) from management-related sources, while conversely those approaching –1 have the most negative characteristics with regard to sediment risk for this parameter.

This section takes data related to current management and management history, and geology and combines them into an evaluation of their relative importance in each planning watershed. Gray text denotes parts of the model that are not yet implemented and were not used for this basin.

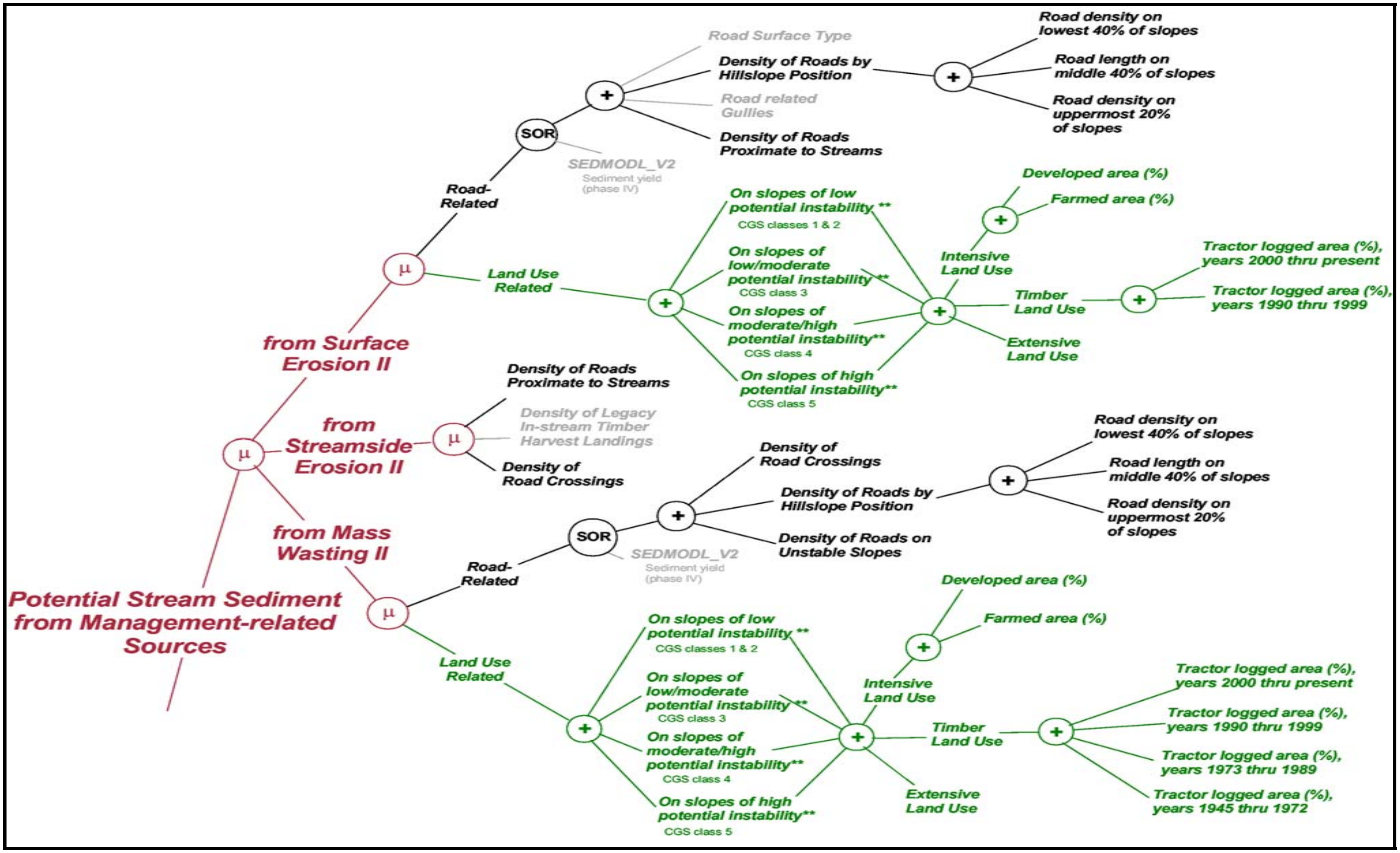


Figure 42. The Potential Sediment from Management-related Sources section of the EMDS Model

This section takes data related to current management and management history, and geology and combines them into an evaluation of their relative importance in each planning watershed. Gray text denotes parts of the model that are not yet implemented and were not used for this basin.

From Mass Wasting II

Proposition: Potential of delivery of coarse sediments to streams from mass wasting events management activities does not significantly threaten the planning watershed's ability to sustain healthy populations of anadromous salmonids.

Definition: From Mass Wasting II is evaluated for planning watersheds using 2 equally weighted parameters: 1) road-related and 2) land use-related.

Explanation: This metric relates to the risk of mass wasting events from management-related activities that deliver sediments to streams. Mass wasting events typically deliver coarse sediments that can cause aggradation in the stream, and have a detrimental effect upon salmonid habitat.

Reference Values: Break points: <10th percentile highest potential suitability; >90th percentile lowest potential suitability.

Road-Related Mass Wasting

Proposition: Potential delivery of coarse sediments to the stream from road-related erosion does not significantly threaten the planning watershed's ability to sustain healthy populations of anadromous salmonids.

Definition: This road-related parameter will be derived from SEDMODL_V2, a model that is under development. Currently road-related mass wasting is computed as the mean truth value returned from 3 sub networks: 1) density of roads crossing streams, 2) road density by hillslope position (weighted as a function of hillslope position), and 3) road density on unstable slopes.

Explanation: This parameter measures the potential of road-related mass wasting to deliver coarse sediments to streams in a planning watershed. Three metrics, listed above, are used to represent the intensity of road use and the degree to which roads are hydrologically connected to streams. The metrics are derived using digital road, stream, landslide potential and elevation data. All are influenced by the level of detail provided in the roads database. The minimum coverage for a basin corresponds with roads found on 1:24,000 scale USGS topographic maps. In most cases, these databases are augmented with roads interpreted from air photos and those recorded in timber harvest plans. Planning watersheds that have truth values that are at or near +1 strongly support the proposition that Road-related Mass Wasting does not represent a potential threat to the streams.

Data Sources: CDF-enhanced 1:24K Roads GIS coverages; CDF-enhanced 1:24K digital hydrography (blue line streams); CGS Landslide Potential Models; 10m resolution Digital Elevation Models.

Density of Road Crossings of Streams

Proposition: Potential coarse sediment delivery to streams, due to the number of crossings (per kilometer) of stream by roads, does not significantly threaten the planning watershed's ability for sustaining healthy populations of anadromous salmonids.

Definition: Evaluated as the number of stream crossings by roads per kilometer of stream.

Explanation: Where roads cross streams there is often a high potential to deliver coarse sediments into the streams during and after precipitation events. Other impacts associated with this (but not considered in this model) include: alteration of runoff processes, removal of canopy cover and impediments to fish passage. This metric evaluates potential impacts due to coarse sediment delivery. (Road improvements and information on culverts can be incorporated into the model through a "Switch" node, which would reduce from the set of potential impacts those crossings that have been repaired and are no longer considered to have an impact. Currently all crossing are weighted equally, for lack of more detailed information.)

Data Sources: Road crossings per kilometer of stream in a given planning watershed are derived in GIS from existing roads and streams coverages.

Reference Values: Break points: <10^{th} percentile highest potential suitability; >90^{th} percentile lowest potential suitability.

Density of Roads by Hillslope Position

Proposition: Potential sediment delivery to streams by mass wasting events related to roads as a function of their hillslope position does not significantly threaten the ability of the planning watershed to sustain healthy populations of native salmonids.

Definition: Weighted density of roads by hillslope position for each planning watershed. The weights are: Roads on lowest 40% of slopes: 0.6; roads on middle 40% of slopes 0.3; and roads on the uppermost 20% of slopes 0.1. Measurement units are (weighted) mi/mi^2.

Explanation: Each planning watershed is divided into three hillslope positions: low slope (valley bottom), mid slope and upper slope (ridge top). Previous studies have shown that road impacts differ, all other factors being equal, depending on the location of the road in the watershed. A recent USFS study on Bluff Creek watershed, Six Rivers National Forest, found that roads near streams, in lower hillslope positions, had a much higher failure rate, and thus a greater potential to generate sediment to streams. Based on the Bluff Creek study, slope position was defined as stated in the definition (above).

Data Source: Slope Position is derived from a 10 meter digital elevation model (DEM). Road Data comes from a variety of sources including: USGS 1:24,000 scale map digital line graph (DLG) data, 1 meter Digital Ortho Quads and digitized timber harvest plans.

Reference Values: Break points: <10th percentile highest potential suitability; >90th percentile lowest potential suitability.

Density of Roads on Unstable Slopes

Proposition: Potential sediment delivery to streams by mass wasting events related to roads as a function of slope stability does not significantly threaten the ability of the planning watershed to sustain healthy populations of native salmonids.

Definition: Calculates kilometers of road on unstable upland slopes per hectare of management unit. Unstable slope are defined by CGS Landslide Potential Model.

Explanation: Roads crossing steep and potentially unstable slopes can contribute to and accelerate the frequency of mass wasting on upland slopes. Where data exists, detailed landslides maps (developed by Division of Mines and Geology) are overlain with roads within a GIS to evaluate the risk roads on steep and unstable slopes.

Data Sources: Digital CDF-enhanced 1:24K roads data; Landslide Potential Model from CGS

Reference Values: Break points: <10th percentile highest potential suitability; >90th percentile lowest potential suitability.

Land Use-related Mass Wasting

Proposition: Potential delivery of coarse sediments from mass wasting events related to land use management activities, as measured by the percentage area (by slope instability) of the planning watershed with 1) intensive use or management; 2) timber land use and 3) extensive land use does not significantly threaten the ability of the planning watershed to sustain healthy populations of native salmonids.

Definition: The Land Use is the weighed sum of four parameters (sums to 1.0):

- Land use on slopes of low potential instability (weight: 0.04)
- Land use on slopes of low-moderate potential instability (weight: 0.09)
- Land use on slopes of moderate-high potential instability (weight: 0.17)
- Land use on slopes of high potential instability (weight: 0.7)

For each of the above slope instability classes, values are calculated according to the weighted area of intensive and extensive land use and timber harvest land use. The weights were based upon expert opinion:

Table 31. Weights Given To Land Use And Eras Of Timber Harvests

Land Use	***Weights***
Developed Area	0.2
Farmed Area	0.2

Land Use	Weights
Extensive LU Area	0.1
Timber Harvest LU Area, Era 0	0.2
Timber Harvest LU Area, Era 1	0.12
Timber Harvest LU Area, Era 2	0.06
Timber Harvest LU Area, Era 3	0.12

Explanation: Classes of slope instability were defined by the California Geology Survey Landslide Potential Model GIS coverages created for NCWAP. Aside from the split by slope instability classes and corresponding differences in weighting, the four Land Use parameters are defined identically and will be treated as one for the purposes of the discussions below. In the current model, CGS NCWAP personnel provided the weights (in definition above) given to land use as a function of respective slope instability.

Reference Values: Break points: <10th percentile highest potential suitability; >90th percentile lowest potential suitability.

Intensive Land Use

Definition: The sum of percentages of the watershed that is "developed area " and "farmed area".

Explanation: Developed areas are those that are urbanized or with clusters of buildings. Farmed areas are those with irrigated crops. This level of land use can create local hydrologic impacts such as high and short duration peak flows, which can cause more erosion and higher stream sediment loads. The combined effects are generally detrimental to the ability of the stream to support native salmonids.

With a few notable exceptions, little of the land in north coast watersheds is developed, and therefore developed areas are in general unlikely to have much influence on the model results (Botkin et al., 1995). This is also true for intensively cultivated areas. Only a few north coast watersheds (e.g., the Scott River, Lower Eel River, Middle Fork Eel) have a significant percentage of land under cultivation.

Data Sources: A GIS coverage from Region 5 of the USDA Forest Service and the Fire and Resource Assessment Program of CDF of current vegetation including county parcel coverages and four slope classes from the CGS Landslide Potential Model.

Timber Land Use

Definition: Timberland use is the percentage area affected by tractor-logging activities, weighted according to time of harvest (recent vs. historic) and slope instability.

Explanation: Time breakdowns were proposed by Walker based upon expert opinion of others. Weights were approximated using information from Jameson and Spittler (1995). Tractor logging has been broken into 5 eras (see Table 32).

Table 32. Model Weights Of Eras Of Human Disturbance

Period	Years	Reasoning	Weights and Functions*
Recent	<=2.5YBP	New Harvests and activities	y=0.2
Era0	YBP>2.5 to 1990	Digitized Timber Harvest Plans available; last 10 or so years of management still strongly affect current processes	0.4<=y<=1.0 $y=2.088x^{-0.7379}$ (y=0.12)
Era1	1973-1990	Era post implementation of Forest Practice Rules (FPR); also coincides with start of digital Landsat data enabling high quality change detection	0.2<=y<=0.4 $y=2.088x^{-0.7379}$ (y=0.06)
Era2	1945-1973	Main era of tractor logging before FPR; main era of aerial photograph record	0.3<=y<=0.6 y = -0.0085x + 0.8047 (y=0.12)

*x is Years Before Present; in () is single value weight approximation for era

The above breakdowns based on time (and the weighting functions) are an effort to reflect the different magnitudes of potential sediment from erosion relating to timber harvesting practices, and the time since harvesting according to those practices occurred. They are based largely upon a distillation of the opinions of experts such as Marc Jameson (CDF) and Tom Spittler (CGS) (Jameson and Spittler 1995). Other breakdowns are possible, such as those that coincide with major natural disturbance events including large floods and fires.

For this version of the model, we used the constants (in parentheses in the above table) for each respective era of timber harvest. With more time and resources, we will use the functions shown in the table, based upon years elapsed since the event(s).

Data Sources: Data sources included digitized Timber Harvest Plans, Landsat data (MSS change detection) (used to develop GIS coverages), aerial photographs (used to develop GIS coverages), historic maps (from timber companies), historic accounts, county parcel coverage (timber company holdings), and four slope classes from the CGS Landslide Potential Model.

Extensive Land Use

Definition: The percentage of the watershed that is managed for extensive land use activities, mainly livestock grazing.

Explanation: Extensive land use areas are primarily those that are used for livestock grazing. Grazed areas can increase delivery of sediment to streams from effects such as soil disturbance from trampling and from vegetation removal. The effects of grazing, when not in the riparian zone (i.e., in the upland), are believed to be generally less impacting than those of timber harvesting and more intensive land uses. This is reflected in the proposed weighting for this parameter (see Table 31).

Data Sources: Data sources include USDA Forest Service/FRAP coverage of current vegetation, county parcel coverages, and four slope classes from the CGS Landslide Potential Model.

From Surface Erosion II

Proposition: Potential delivery of fine sediments to streams due to management activities does not significantly threaten the planning watershed's ability to sustain healthy populations of anadromous salmonids. Currently this network has no data provided to the model.

Definition: Like From Mass Wasting II, From Surface Erosion II is the mean truth-value returned from 2 parameters: 1) road-related; and 2) land use-related.

Explanation: Surface erosion and delivery of fine sediments to streams occurring from management activities has the potential to negatively impact stream condition through increased delivery of fine sediments. Increased fine sediments can create higher rates of embeddedness that can cause problems for the reproduction of anadromous fish. They can also cause high rates of turbidity, which can make foraging and feeding more difficult for fish.

Road-Related Surface Erosion

Proposition: Potential delivery of fine sediments to the stream from road-related erosion does not significantly threaten the planning watershed's ability to sustain healthy populations of anadromous salmonids.

Definition: This road-related parameter will be derived from SEDMODL_V2, a model that is under development. Currently potential roads-related fine sediment delivery is computed as the mean truth value returned from 4 sub networks: 1) density of roads proximate to streams, 2) road density by hillslope position (weighted as a function of hillslope position); 3) density of road-related gullies; and 4) road surface type. However, the last two of the sub-networks listed currently have no data and are not operating at this time.

Explanation: This parameter measures the potential of roads to deliver fine sediments to streams in a planning watershed. Four metrics, listed above, represent the intensity of road-related fine sediment issues and the degree to which roads are hydrologically connected to streams. The metrics are derived using digital road, stream, landslide potential, gully, and elevation data. All are influenced by the level of detail provided in the roads database. The minimum coverage for a basin corresponds with roads found on 1:24,000 scale USGS topographic maps. In most cases, these databases are augmented with roads interpreted from air photos and those recorded in timber harvest plans. Planning watersheds that have truth-values that are at or near +1 strongly support the proposition that the potential of fine sediments being delivery to the streams from roads does not present a significant threat to salmonids.

Data Sources: CDF-enhanced 1:24K Roads GIS coverages; CDF-enhanced 1:24K digital hydrography (blue line streams); CGS Landslide Potential Models; CGS gully data; 10m resolution Digital Elevation Models.

Density of Roads Proximate to Streams

Proposition: The potential for delivery of fine sediment from roads proximate to stream channels does not significantly threaten the planning watershed's ability to sustain healthy populations of native salmonids.

Definition: Calculates the percent of stream length in the planning watershed that has a road within 200 feet. For each planning watershed it is evaluated as the sum of all reach lengths that have a road within a buffer distance of 200 ft.

Explanation: This metric is a measure of hydrologic connectivity. Roads that are adjacent to streams are much more likely to put fine sediments into the stream channel and have a greater potential to negatively impact stream condition. While the main potential impact is increased sediment delivery, studies have also shown adverse effects on stream temperature and alteration of runoff processes. Effects also often extend into the adjacent riparian zone. This metric evaluates potential impacts. Road improvements and road abandonment could be incorporated into the model through a "Switch" node, which would reduce from the set of potential impacts those road segments that have been repaired or decommissioned and are no longer considered to have an impact.

Data Source: All sources of data are GIS-based including CDF-enhanced 1:24K digital roads data and CDF-enhanced 1:24K digital hydrography (i.e., blue line stream) data.

Reference Values: Break points: <10th percentile highest potential suitability; >90th percentile lowest potential suitability.

Density of Roads by Hillslope Position

(see explanation of road-related mass wasting)

Density of Road-related Gullies

Proposition: The potential for delivery of fine sediment from gullies related to roads to stream channels does not significantly threaten the planning watershed's ability to sustain healthy populations of native salmonids.

Definition: Calculates the number of road-related gullies per planning watershed.

Explanation: Roads can often alter the local hydrologic drainage, concentrating flow and causing gully erosion. Such gullies can be sources of fine sediment in the local stream channel. Currently there is no data used in the model, due to concerns about bias in the sampling techniques used to collect the available information.

Data Sources: None at present.

Reference Values: (When available) Break points: <10th percentile highest potential suitability; >90th percentile lowest potential suitability.

Road surface type

Proposition: The distribution of road surface types and its relationship to potential delivery of fine sediments to stream channels does not significantly threaten the planning watershed's ability to sustain healthy populations of native salmonids.

Definition: This parameter weights the potential for fine sediment delivery of roads according to their surface characteristics. Roads with asphalt paving will have the lowest weight, gravel roads will have an intermediate weight, and dirt roads will have the highest weight per unit length.

Explanation: Roads surface type influences the potential for the road to contribute fine sediments to streams. Roads paved with asphalt or rock general contribute less sediment than those dirt surfaces. Road use can also greatly influence the fine sediment yield, particularly in the winter (rainy season). At the current time we have incomplete information on road surface types, and no data on road use.

Data Sources: None at present.

Reference Values: (When available) Break points: <10th percentile highest potential suitability; >90th percentile lowest potential suitability.

Land Use-related Surface Erosion

Proposition: The potential for fine sediment delivery to streams from: 1) intensive use or management; 2) timber land use) and 3) extensive land use, does not significantly impair the watershed's ability to sustain healthy populations of native salmonids. (For a full description of the above, please refer to the Land Use-related in the Mass Wasting section, as the parameters used are identical).

From Streamside Erosion II

Proposition: Delivery of coarse and fine sediments to streams from management-related streamside erosion does not significantly threaten the planning watershed's ability to sustain healthy populations of anadromous salmonids.

Definition: From Streamside Erosion II is based upon the average of 3 parameters: 1) density of roads proximate to streams, 2) in-stream timber harvest landings, and 3) density of road crossings of streams.

Explanation: Potential streamside erosion occurring from management-related activities can negatively impact stream condition through delivery of both coarse and fine sediments. Increased coarse sediments can cause excessive sediment loading and aggradation of the streams, particularly in the lower response reaches. Aggradation causes more of the water to flow through gravels and rocks below the riverbed, and can effectively reduce flow. Increased fine sediments can create higher rates of embeddedness, which can cause problems for the reproduction of anadromous fish. They can also cause high rates of turbidity, which can make foraging and feeding more difficult for fish.

Density of Roads Proximate to Streams

(See above for a full description of this parameter, where it is used under Road-related Surface Erosion)

In-stream Timber Harvest Landings (not currently used)

Proposition: Delivery of coarse and fine sediments to the streams from legacy timber harvest landings that were located in the stream channels does not significantly threaten the planning watershed's ability to sustain healthy populations of anadromous salmonids.

Explanation: Potential streamside erosion of both coarse and fine sediments can occur from historic landfills constructed in stream channels for use as landings for timber harvest operations. In times of high flows the fill can be undermined and slough into the streams.

Data Sources: CDF coverage.

Density of Roads Crossings of Streams

Proposition: Potential delivery of coarse and fine sediments to the streams from road crossings does not significantly threaten the planning watershed's ability to sustain healthy populations of anadromous salmonids.

Definition: Evaluated as the number of stream crossings by roads per kilometer of stream.

Explanation: Road crossings of streams tend to interact with stream networks and have the potential to deliver fine sediments. Other impacts associated with road crossings include: alteration of runoff processes, removal of riparian canopy cover and blocked fish passage. Road improvements and information on culverts could be incorporated into the model through a "Switch" node, which would reduce the potential of fine sediment delivery from those crossings that have been repaired and are no longer considered to have an impact.

Data Sources: Data sources include CDF-enhanced 1:24K digital roads and hydrography coverage (from USGS blue lines).

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