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Rich Walker
*California Department of Forestry and Fire Protection*, rich.walker@fire.ca.gov

Chris Keithley
*California Department of Forestry and Fire Protection*, chris.keithley@fire.ca.gov

Russ Henly
*California Department of Forestry and Fire Protection*, russ.henly@fire.ca.gov

Scott Downie
*California Department of Fish and Game*, sdownie@dfg.ca.gov

Steve Cannata
*California Department of Forestry and Fire Protection*, scannata@dfg.ca.gov

# Ecosystem Management Decision Support (EMDS) Applied to Watershed Assessment on California's North Coast [1]

**Rich Walker,[2] Chris Keithley,[3] Russ Henly,[2] Scott Downie,[4] and Steve Cannata[3]**

## Abstract

In 2001, the state of California initiated the North Coast Watershed Assessment Program (2003a) to assemble information on the status of coastal watersheds that have historically supported anadromous fish. The five-agency consortium explored the use of Ecosystem Management Decision Support (EMDS) (Reynolds and others 1996) as a means to help assess overall watershed and in-stream conditions for fish. EMDS is expert system software developed by the USDA Forest Service for similar efforts with the Northwest Forest Plan (2000). NCWAP developed models to help assess key watershed characteristics that contribute to shaping channel morphology and to evaluate the present stream habitat conditions in terms of suitability for anadromous salmonids. The stream condition model uses data collected during DFG stream surveys to evaluate the present stream habitat conditions for migrating, spawning and rearing anadromous fish. Factors evaluated by the model include percent of reach in moderately deep pools, pool shelter complexity, streamside canopy density, and spawning gravel embeddedness. We also developed a model addressing indirect terrestrial influences on anadromous fish in a watershed. The Potential Sediment Production Model estimates the impacts of both natural background and human-related effects on in-stream sediment delivery. NCWAP scientists learned several important lessons from using EMDS. Critical aspects of EMDS include the hierarchical structure of the model, the selection of the operators at the nodes of the networks, and the selection of breakpoints used in evaluating specific environmental data.

*Key words: California salmon, ecosystem decision support, watershed assessment*

## Introduction

The North Coast Watershed Assessment Program (2003a) was a California state government program from 2001 to 2003. Five state agencies participated in its mandate to assess watershed conditions for salmonids on the north coast. The Departments of Fish and Game, Forestry and Fire Protection, California Geological Survey, Water Resources and the state Environmental Protection Agency (EPA) brought their expertise together to gather existing environmental data and to evaluate watersheds.

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Through basin wide assessments of salmonid habitat, and identifying the likely causes of habitat impairment, the program's thrust was to assist prioritization of both in-stream and upland area watershed restoration and recovery efforts. The Ecosystem Management Decision Support (Reynolds 2003) expert system software, developed in connection with the Northwest Forest Plan, was selected by NCWAP to aid in the watershed evaluations. This paper reports on the successes and challenges encountered during program's use of EMDS.

## Background

EMDS 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 (for details see Reynolds 2003). The software can produce a synthesis from a variety of environmental data, but requires that a custom hierarchical model (termed 'knowledge base') be built to simulate the particulars of the ecosystem functioning. Models utilize data stored in a Geographic Information System (GIS – ArcView™) to perform the assessments of watershed conditions and facilitate rendering the results into maps and tables. The results can then be interpreted by professionals and the public, in terms of their implications for ecosystem management. Clearly, the results of the EMDS models will be strongly affected by the adequacy of the knowledge base in representing real ecosystem functioning, and the completeness and accuracy of the data fed into the models.

## Methods

As a starting point, NCWAP referred to an EMDS knowledge base model developed by the USDA Forest Service to evaluate watershed conditions for salmon in coastal Oregon (Reeves and others 2000). The NCWAP team then constructed two knowledge base networks reflecting the best available scientific studies and information on how various environmental factors combine to affect anadromous fish in California's north coast watersheds. These networks can be graphed to resemble branching tree-like flow charts, to show the logic and types of data used in the assessment:

- The Stream Reach model *(fig. 1)* addresses conditions for salmon at the stream reach scale and is largely based on habitat data collected under the Department of Fish and Game's stream survey protocols;

- The Potential Sediment Production model *(fig. 2)*, evaluates the magnitudes of the various sediment sources in the basin according to whether they are natural or management related.
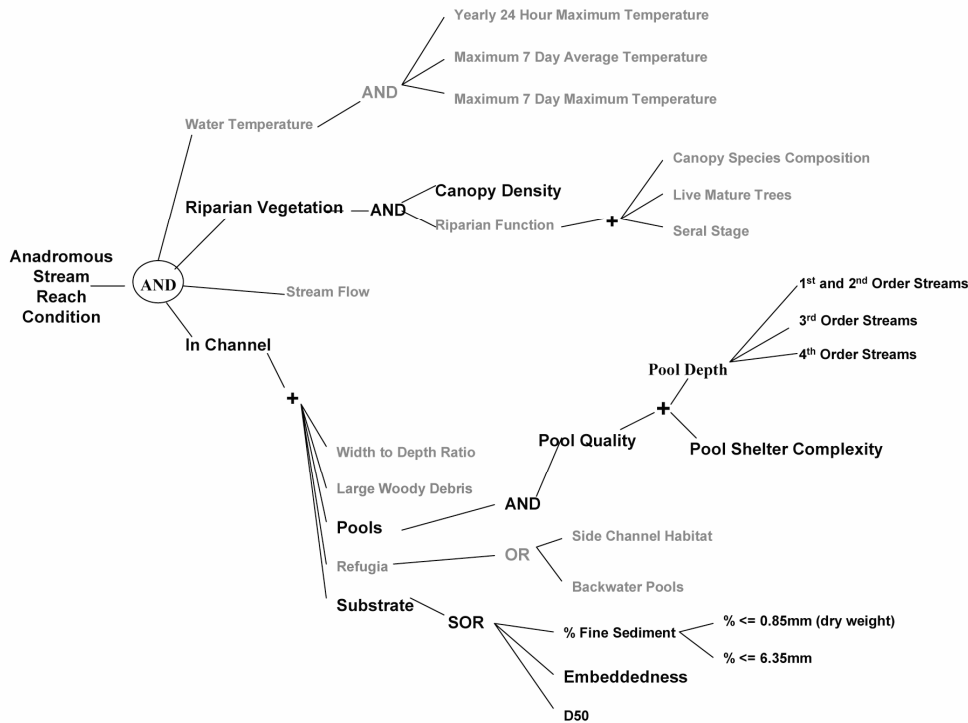
26

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**Figure 1**—NCWAP EMDS anadromous reach condition model. Objects in black were populated with data and evaluated for NCWAP reports, objects in grey were considered important characteristics, but data or reference curves were not developed for the assessment. EMDS evaluates these missing data to 0 (or uncertain), which contributes to a conservative estimate of the overall stream condition.

In creating the EMDS models listed above, NCWAP scientists used what is termed a 'top-down' approach. This approach is perhaps best explained by way of example. The NCWAP Stream Reach Condition model began with the proposition: *The overall condition of the stream reach is suitable for maintaining healthy populations of native coho and Chinook salmon, and steelhead trout.* A knowledge base (network) model was then designed to evaluate the truth of that proposition, based upon data from each stream reach. The model design and contents reflect the hypotheses of the NCWAP scientists. The goal was to start with a simple model structure that addressed the proposition through evaluation of key stream habitat characteristics. Refinements, adaptations, and the addition of new habitat elements would occur as needed and as data collection protocols were developed to populate and expand the knowledge base architecture. Broad-based reference curves were developed by consensus of the science team for use in multi-basin assessments, but were not intended as thresholds or targets. They formed generally accepted points of agreement about critical habitat functions for salmonid production.
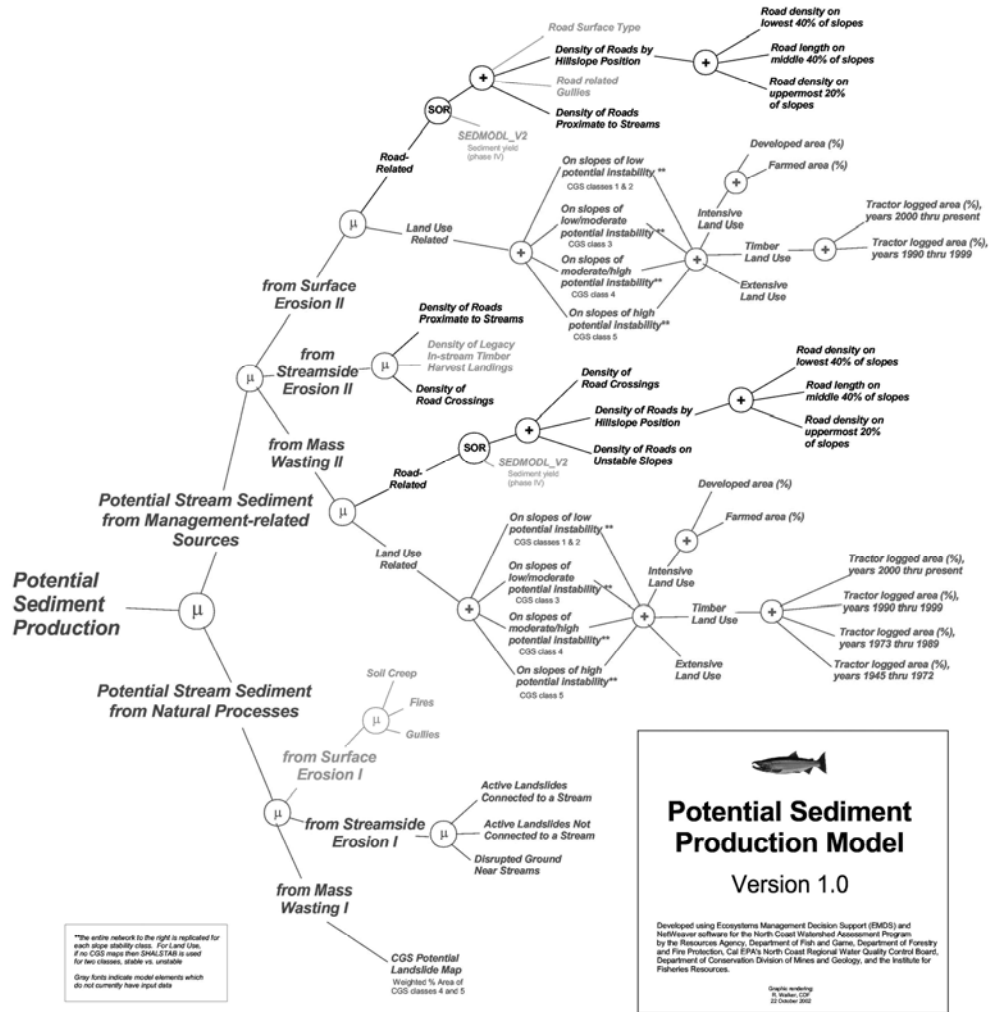
**Figure 2**—NCWAP EMDS potential sediment production model.

To evaluate stream reach conditions for salmonids, the conceptual model used data on several environmental factors. The first branching of the knowledge base network *(fig. 1)* shows that information on environmental conditions (stream flow, riparian vegetation, water temperature, and in-channel stream characteristics) are all used as inputs in the stream reach condition model.

In turn, each of the four branches is progressively broken into more basic data components that contribute to it. Each object in the branch is evaluated, synthesized according to the knowledge base structure, and passed forward towards final decision node. The process is repeated until the knowledge base network incorporates all information that experts believe to be important (independent of data availability) to the stream reach evaluation.

EMDS models assess the degree of truth (or falsehood) of each evaluated proposition. Simple reference curves use "fuzzy logic" to determine its degree of truth/falsehood, according to the data's implications for salmon. *Figure 3* shows an example reference curve for the proposition *the stream temperature is suitable for salmonids*. 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 on the continuum in-between (>–1 and <+1). 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 3* example occur at 45, 50, 60 and 68 °F. For the Stream Reach model, NCWAP fisheries biologists determined these temperatures by a review of the scientific literature and empirical studies (Armour 1991, Hines and Ambrose 2000, Klamt and others 2000, Welch and others 2000). In this way, similar numeric reference curves were developed for other propositions evaluated in the NCWAP Stream Reach Condition Model.
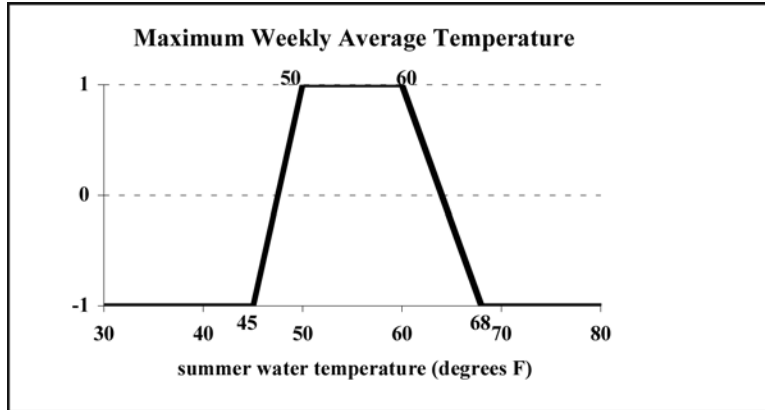


**Figure 3**—Generalized EMDS reference curve for summer water temperature measured by maximum weekly average temperatures (MWAT). EMDS uses this type of reference curve in conjunction with data specific to a stream reach. This example curve evaluates the proposition that the stream's water temperature is suitable for salmonids. Break points can be adapted for specific species, life stage, or season of the year.

For NCWAP parameters relating to upland geology and management activities, little scientific literature was available to assist in determining breakpoints to evaluate the watersheds. As a result, we computed the mean and standard deviation for all planning watersheds in a basin, then selected breakpoints to rank each planning watershed for that parameter, using a simple linear approximation of the standardized cumulative distribution function [with the 10th and 90th percentiles serving as the low and high breakpoints *(fig. 4)*]. (Is there some reason these breaks were used?) (Purely empirical—they where the linear approximation of the CDF where intercepts y = 0 and y = 1) The relative rankings were valid only within the basin and did not serve as an absolute measure of the suitability of a given planning watershed for salmon spawning and rearing. However, they did provide an indication of relative conditions for fish within the basin with regard to specific environmental factors.
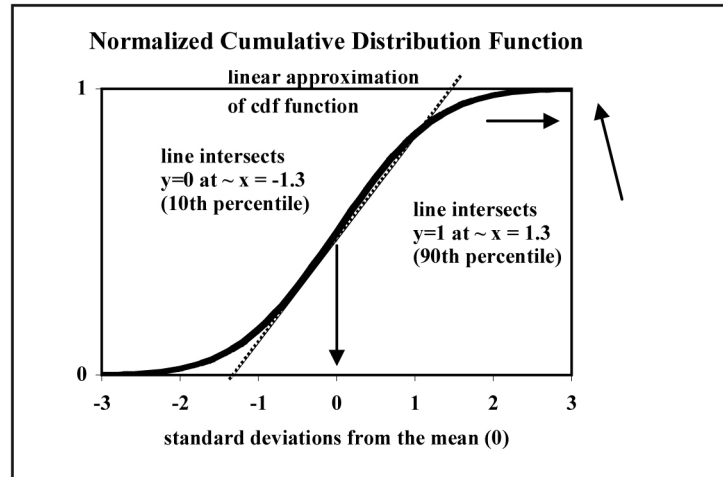
**Figure 4**—Normalized cumulative distribution function, and EMDS empirical breakpoints. Using the 10th and 90th percentiles as breakpoints (as with Land Use) is a linear approximation of the central part of the normalized cumulative distribution function.

## Results

For each of the three initial NCWAP watersheds (Gualala, Mattole and Redwood Creek), the EMDS models produced a number of tables and maps that were examined by the team of agency experts for that basin. For example, *figure 5* shows Stream Reach model results for the middle subbasin of Redwood Creek for four factors—embeddedness, canopy density, pool shelter and pool depth. The map shows each reach of the subbasin rated for its suitability for salmonids, from fully suitable to fully unsuitable. (Is there a map which integrates all of these? Unfortunately, no.) *Figure 6* shows the results of the Natural Mass Wasting limb of the upland-oriented Potential Sediment Production model for the Gualala River basin. Similar maps were created of all evaluated EMDS parameters.

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.

Opinions varied among the agency scientists working in the program as to whether the EMDS models performed well in synthesizing the existing data and coming up with accurate and useful results. Overall, the Stream Reach Condition Model *(fig. 1)* was viewed as a generally accurate tool to assess individual habitat elements and it provided an accurate assessment of overall stream condition. In some cases, the EMDS results required further interpretation and explanation because of data limitations in the knowledge base structure. The model would be improved if it included data input for critical habitat elements such as water temperature that were not populated with data in the knowledge base. (Due to disagreements among NCWAP scientists on the adequacy of water temperature samples, and extrapolating them to stream reaches, water temperature proved to be a difficult parameter to accurately display on EMDS spatial map outputs. On the other hand it serves here as an easily understood example for illustrating how NCWAP EMDS worked).

The potential sediment model *(fig. 2)* relied upon data generated from maps and models that were not necessarily field verified. There also was a lack of scientific literature and data sources to develop representative reference curves. This necessitated the use of a more empirically-based approach to defining reference curves, using cumulative distribution functions based upon the data. Where data quality was high, the models sometimes yielded insights into the factors most affecting a given planning watershed. In other cases the results were not regarded as accurate.
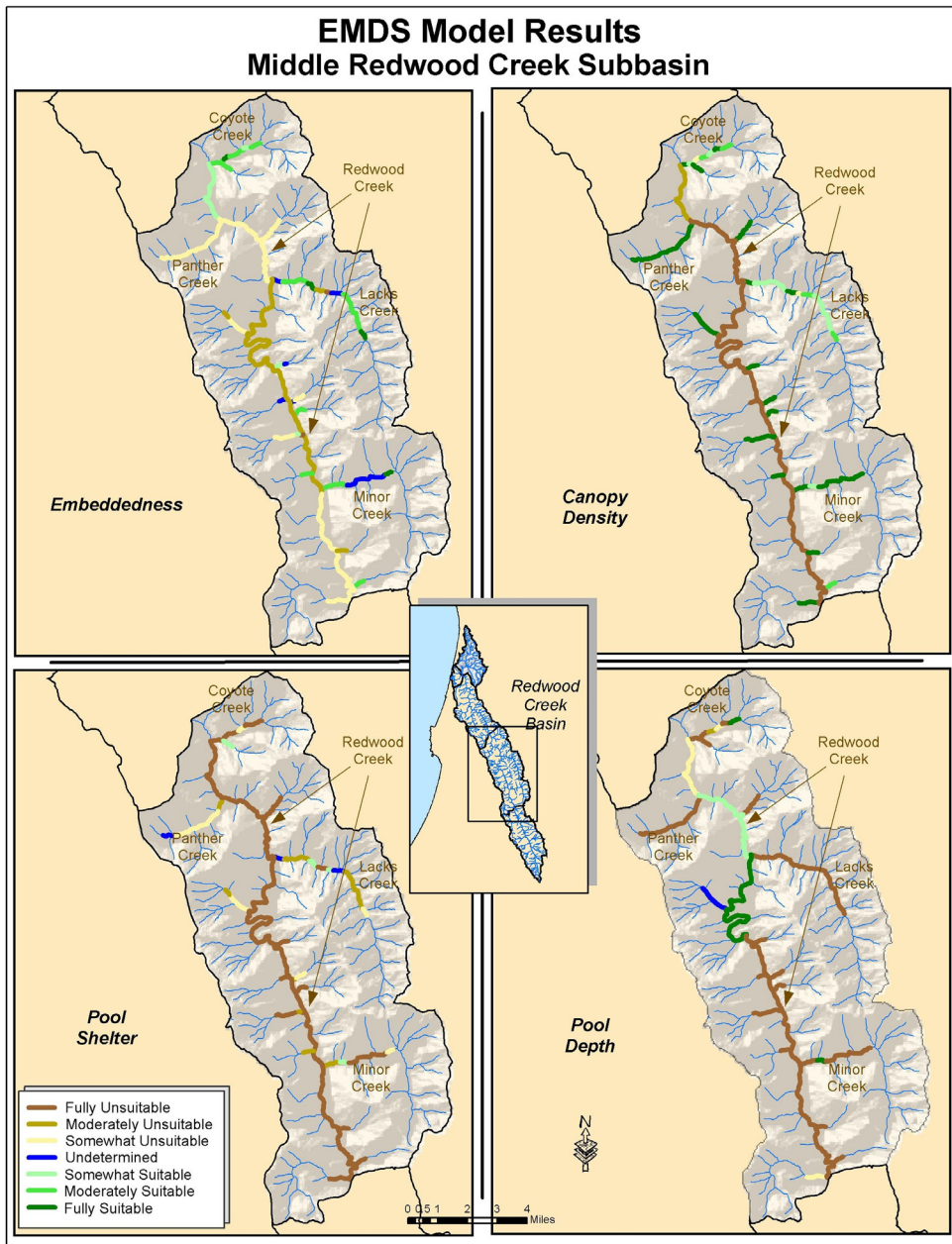


**Figure 5**—Map of results of part of the Stream Reach model for the middle subbasin of Redwood Creek.
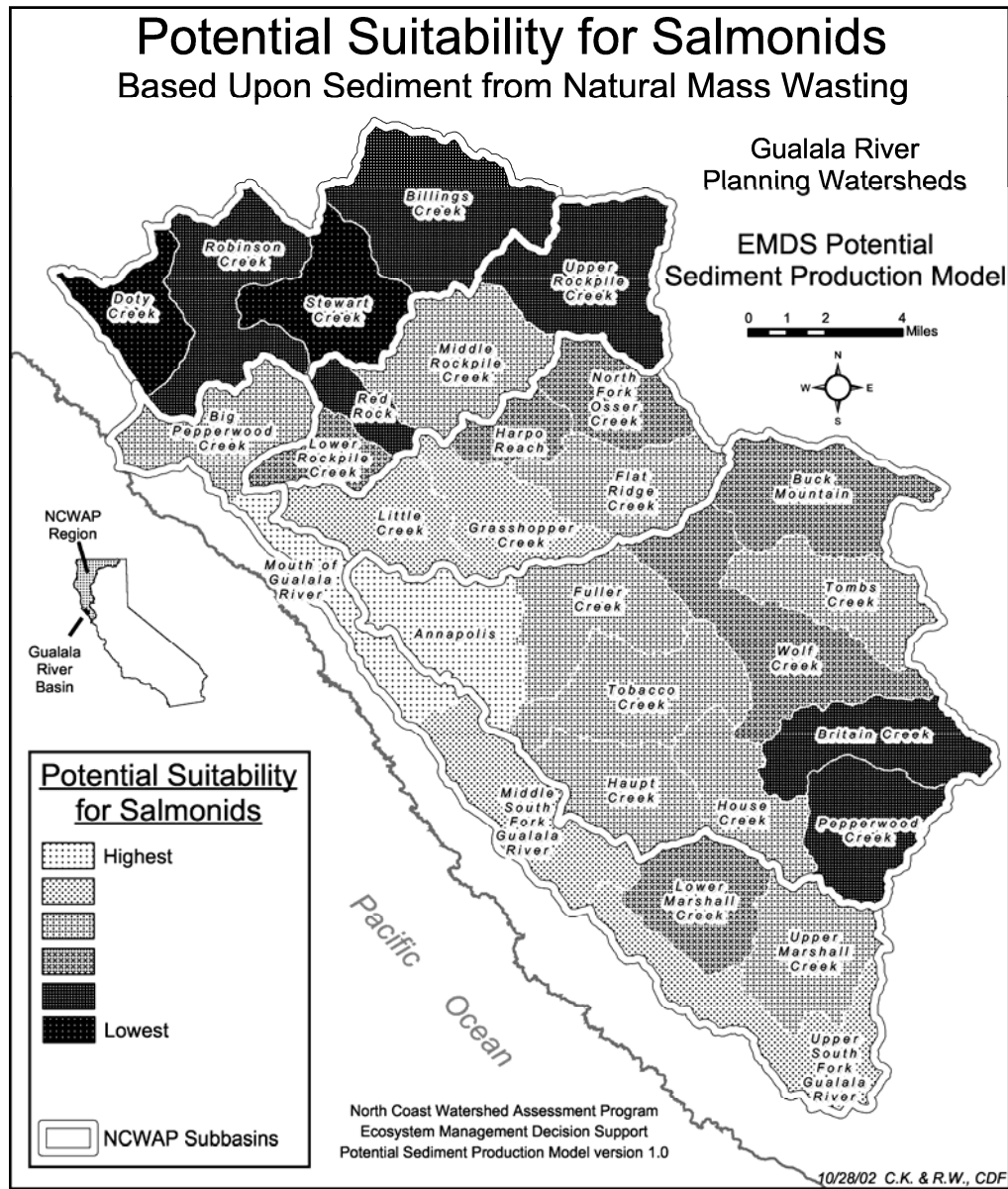
**Figure 6**—EMDS graphical output from Potential Sediment Production Model.


## Discussion

It was a challenge to validate the two complex 'expert system' models. Data inconsistency (for example, missing, out-of-date, sparsely sampled) was common in the basins, affecting the model results in ways that were difficult to quantify but certainly deleterious. In some model branches, no data was available for the EMDS model. The missing data tends to move higher-level model evaluations towards the uncertain range (in other words, 0 values), thus making overall assessments conservative. EMDS provides a tool to assess the relative value of missing data, based upon the model architecture. This can help to drive data needs and priorities in future sampling.

Several core considerations emerged in the course of using EMDS in NCWAP. These included:

- Model propositions: Semantics used must be precise to define criteria

- Model architecture: Is the model an accurate reflection of the 'real world'?

- Breakpoints: Definition can be difficult, given dearth of scientific literature on many watershed characteristics, especially current and historic land use

- Parameter weightings: Relative weightings affect the influence of parameters

- Calibration and validation: Difficult to do with these non-standard models

- Data sampling: Is it representative of the entire reporting unit (stream or watershed)?

As EMDS does not produce statistical or deterministic model outputs, it was difficult to establish criteria by which to evaluate the model results. Scientific discipline would suggest that we take a sample of planning watersheds and compare the EMDS results against the best data and criteria available. However, as EMDS is intended to emulate expert opinion, which is based not only on data but other intangibles, the latter test may be inappropriately setting the bar too high. Also, a fundamental question arose in NCWAP as to whether the models' proper role was to simply confirm expert opinion (in other words, what was already known), or to provide new insights into the watershed conditions.

## Conclusions

EMDS served two main roles in NCWAP. First, the model results synthesized numerous factors, and provided insights into individual watershed characteristics at several spatial scales. The stream reach condition model identified specific reaches where habitat factors were currently in good or poor condition. This can help identify the type of instream or upslope management needed to improve habitat conditions for salmonids. The sediment production model assessed landuse factors at the planning watershed scale that have already accelerated erosional process or may do so in the future (in other words, risk assessment). These data help to guide land management decisions surrounding watershed ecosystem issues. Together the models help prioritize where and when management actions should occur.

Additionally, EMDS provided a de facto second 'result'. In requiring explicit model logical structure and data 'feeds', the process of developing and reviewing the two models facilitated a number of in-depth and useful discussions of precisely how these watersheds function, and the data needed to make such evaluations. The first relates to the more standard assessment of the accuracy and utility of the numbers and watershed assessment maps produced by the models, while the second looks at the utility of EMDS from the standpoint of the program as a whole.

While EMDS-based syntheses can be important tools for watershed assessment, they cannot by themselves yield a course of action for restoration and land

management. Any EMDS results require interpretation, and how they are employed depends upon other social and economic concerns. In addition to the accuracy of the EMDS model, the currency and completeness of the data available for a stream or watershed will strongly influence the confidence in the results. Where possible, the EMDS model should be validated using sensitivity analysis, independent data, expert opinion, and other information. One disadvantage of linguistically based models such as EMDS was that they do not provide results with readily quantifiable levels of error. Users of this tool need to be aware of this issue.

# References

Armour, C. 1991. **Guidance for evaluating and recommending temperature regimes to protect fish.** Biological Report 90 (22). U.S. Fish and Wildlife Service. Fort Collins, CO 13p. *Available at* http://www.krisweb.com/biblio/gen_usfws_armour_1991.pdf

Hines, D.; Ambrose, J. 2000 (Draft). **Evaluation of stream temperatures based on observations of juvenile coho salmon in Northern California streams.** Campbell Timber Management, Inc., Fort Bragg, CA, and National Marine Fisheries Service, Santa Rosa, CA. *Available at* http://www.krisweb.com/biblio/gen_afs_hinesetal_xxxx.pdf

Klamt, R.; Otis, P.; Seymour, G.; Blatt, F. 2000. **Review of Russian River water quality objectives for protection of salmonids species listed under the Federal Endangered Species Act.** Regional Water Quality Control Board, North Coast Region, 5550 Skylane Boulevard, Suite A, Santa Rosa, CA 95403. *Available at* http://www.krisweb.com/krisrussian/krisdb/html/krisweb/biblio/russian_scwa_ncrwqcb_2000.pdf

North Coast Watershed Assessment Program. 2003a. California Resources Agency, Sacramento, CA. *Available at* http://www.ncwap.ca.gov

North Coast Watershed Assessment Program. 2003b. **EMDS Appendix.** California Resources Agency, Sacramento, CA.

USDA Forest Service, Pacific Northwest Region. 2000. Northwest Forest Plan. *Available at* http://www.fs.fed.us/r6/nwfp.htm

Reeves, G.; Hohler, D.; Larsen, D.; Busch, D.; Kratz, K.; Reynolds, K.; Stein, K.; Atzet, T.; Hays, P.; Tehan, M. 2000. **Aquatic and riparian effectiveness monitoring plan for the Northwest Forest Plan.** *See* http://www.reo.gov/monitoring/watershed/cover-aremp-report.htm

Reynolds, K. 2003. EMDS. Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture, Corvallis, OR. *Available at* http://www.fsl.orst.edu/emds/

Reynolds, K.; Cunningham, C.; Bednar, L.; Saunders, M.; Foster, M.; Olson, R.; Schmoldt, D.; Latham, D.; Miller, B.; Steffenson, J. 1996. **A knowledge-based information management system for watershed analysis in the Pacific Northwest US.** Artificial Intelligence Applications 10: 9-22.

Welsh, Jr., H.H.; Hodgson, G.R.; Harvey, B.C.; Roche, M. E. 2001. **Distribution of juvenile coho salmon in relation to water temperatures in tributaries of the Mattole River, California.** North American Journal of Fisheries Management 21: 464-470.