BATTLE CREEK WATERSHED ASSESSMENT: Characterization of stream conditions and an investigation of sediment source factors in 2001 and 2002.

Prepared for the

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ABSTRACT

Terraqua, Inc. conducted an assessment of stream condition and sediment sources in the Battle Creek watershed in 2001 and 2002 on behalf of the Battle Creek Watershed Conservancy with funds provided by the federal Anadromous Fisheries Restoration Program.[1] The purposes of this assessment were 1) to document existing stream conditions and develop a baseline against which future conditions can be compared and 2) to identify and prioritize for treatment sediment sources within Battle Creek. This assessment used field protocols and decision support modeling developed by the U.S. Forest Service for its Aquatic and Riparian Effectiveness Monitoring Program (AREMP) to monitor implementation of that agency's Northwest Forest Plan. Correlation analysis and generalized additive models were used to statistically test hypothesized relationships between stream channel condition metrics and sediment source factors. The extensive data set collected and analyzed in this study provides a strong foundation on which to build an understanding of conditions within the Battle Creek watershed as well as a watershed monitoring program. Average site conditions were moderately favorable for salmonid production when considering one or more of the stream condition indices: substrate (fine sediment and median particle size), pool frequency, wood frequency, and four biological metrics. We believe that a storm event in January 1997 was the primary sediment source factor affecting aspects of stream condition such as fine sediment levels, particle size, pool frequency, pool depth, and geomorphic channel conditions like bank erosion and channel avulsions. While we were unable to rule out roads or other land uses as possible sediment sources, there was little direct evidence that road factors (density, near-stream density, road-stream crossing frequency) or other land-use factors (forest cover and near-stream meadow area) played a significant role in explaining the variability of three key stream condition indices at the watershed scale. Restoration actions taken to reduce sediment delivery to Battle Creek and its tributaries may be able to improve conditions for salmonid production because conditions for salmonid production are not completely favorable at all or most sites. None of the potential sediment sources that we set out to prioritize were found to be significant sediment sources at the watershed scale. However, we anticipate that sediment sources at the site-specific scale may be identified in the future, though the significance of these sources will be difficult to discern.

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INTRODUCTION

Battle Creek drains a watershed area of approximately 370 square miles in central Northern California. The watershed includes the southern slopes of the Latour Buttes, the western slope of Mt. Lassen, and mountains south of Mineral, California. Nearly 350 miles of streams in the Battle Creek watershed drain land at elevations as high as 10,400 feet and cascade steeply down through basalt canyons and foothills to the confluence with the Sacramento River near Cottonwood, California at an elevation of 335 feet. Approximately 250 miles of stream are fish bearing and 87 miles of stream were historically accessible to anadromous fishes such as Chinook salmon and steelhead. Land use in Battle Creek ranges from dense residential development to undeveloped wilderness areas of Lassen National Park and is predominated by industrial timber harvesting, livestock ranch lands, and agricultural development.

Battle Creek and its tributaries have long been noted for its ability to support a productive assemblage of anadromous and resident fishes (Rutter 1904; Ward and Kier 1999[2]). Development activity in the 20th century dramatically altered the abundance and distribution of fish populations in the Sacramento River and Battle Creek. The construction of impassable dams within the Sacramento River watershed severely restricted the distribution of winter-run Chinook salmon, spring-run Chinook salmon, and steelhead, while hydroelectric power development and construction of Coleman National Fish Hatchery (CNFH) on Battle Creek interfered with the use of the stream by these fish as well as fall-run and late-fall-run Chinook salmon, and non-salmonid fishes. Efforts to restore salmon and steelhead in the Sacramento River watershed have specified Battle Creek as a high priority where streamflows, migratory passage at diversion dams, and operations at CNFH as the factors limiting anadromous salmonid populations in this stream.

Stream channel conditions (e.g., gravel distribution and abundance, sedimentation, channel morphology) in Battle Creek during the late 20th century have been considered to be suitable for salmonid production (Ward and Kier 1999 review several restoration plans that state or imply the presence of suitable stream channel conditions). For example, USBR (2003) assumed that key stream channel habitat conditions were of sufficient quality that the abundance of threatened or endangered salmonid populations could be substantially increased by increasing instream flows and constructing fish passage facilities at the Battle Creek Hydroelectric Project diversion dams. Similarly, land management activities occurring in the watershed have also been assumed to have little impact on the potential to restore anadromous salmonids to this system (USBR 2003; Ward and Kier 1999).

The Battle Creek Watershed Conservancy is a non-profit group of landowners and watershed residents dedicated to preservation of the environmental and economic resources of the Battle Creek watershed through responsible stewardship, liaison, cooperation, and education. The Battle Creek Watershed Conservancy commissioned this watershed assessment in recognition of the likelihood that in-channel stream conditions, in addition to the more widely recognized hydropower- and hatchery-related limiting factors, may also influence the productive

[2] Ward and Kier (1999) contains a comprehensive summary of 20th century information pertaining to fisheries ecology, management, and restoration in Battle Creek.

capacity of Battle Creek. The purposes of this assessment are to 1) document existing stream conditions and develop a baseline against which future conditions may be compared, and 2) to identify and prioritize for treatment sediment sources within Battle Creek.

Sediment eroded and transported from stream banks and upland areas into stream channels plays a role in determining the nature and quality of salmonid habitat in streams (Spence et al. 1996). The development and persistence of stream channel features used by fish depend on the rate at which sediment is routed through the channel and the composition of deposited materials. Local variation in topography, geology, vegetation, and hydrology determines the influence of sediment on the type, quality, and distribution of fish habitat within a given watershed. Natural sediment delivery to streams can be affected by land-use practices if they significantly alter the dominant aspects of sediment transport processes including soil structure, vegetation, hydrology, or surface erosion and mass wasting. Land use activities occurring in Battle Creek have been shown to be significant sources of sediment in other watersheds include timber harvest (e.g., Reeves et al. 1993 link timber harvest with stream habitat complexity and fish diversity; Jones and Grant 1996 link vegetation cover changes from timber harvest and road construction with changes in hydrology), roads (McGurk and Fong 1995 link road building and timber harvest to stream channel disturbance including changes in macroinvertebrate communities; Jones and Grant 1996; Cederholm et al. 1980; Armentrout et al. (1998) note road effects in nearby Northern California watersheds), and livestock grazing (Meehan 1991). In the absence of timber harvest data Keithley (1999) found that vegetation cover data provides a useful surrogate while Roy et. al. (2003) found that land cover disturbance can affect biological communities in streams through, in part, changes in sediment processes. Sediment delivery may also be affected by hydrologic phenomena such as rain-on-snow storms (Jones and Grant 1996; Heeswijk et al. 1995; Berris and Harr 1987; Harr 1986, 1981) and geologic phenomena including soil types (Armentrout et al. 1998; Napper 2001).

Scientific Approach

The following portions of this Introduction provide an overview of how we approached the development of baseline knowledge of stream conditions and the identification of sediment sources. Assumptions and uncertainties inherent in our approach are listed and an introduction to our methodology is provided.

Assumptions and Uncertainties

Stream condition characterization and sediment source identification was approached with a recognition of the following assumptions:

- We could not investigate all possible sediment sources within the 350 mile stream network of the Battle Creek nor within the 370 square mile watershed area that is used for a variety of purposes such as wilderness areas, residential housing, agriculture, livestock grazing, timber harvest, and at least 1,300 miles of roads.

- In-channel conditions, which physically integrate upstream sediment sources and sediment delivery processes, were assumed to be the most likely and relevant aspect of the watershed through which evidence of sediment sources would be found.

- We assumed that statistically valid subsampling of the stream network, constrained by accepted scientific protocols and time/budget limitations, could be used to characterize in channel conditions at the watershed scale.

- Characterization of in-channel conditions were based on standards in the Aquatic and Riparian Effectiveness Monitoring Program (AREMP) Ecosystem Management Decision Support (EMDS) model.

- Geographical Information System (GIS) analysis of existing information layers was assumed to generate meaningful metrics of land-use and potential sediment sources that could be compared with in-channel conditions to test previously identified relationships between land-use and in-channel conditions.

- Relationships between land-use, sediment delivery processes, and in-channel conditions that have been established through research in Battle Creek and other watersheds were hypothesized to also occur in Battle Creek.

- Formal hypotheses were generated and these hypotheses were tested, through a statistical process of elimination using linear, pair-wise correlation analysis, to see if these previously-recognized sediment sources were significant in Battle Creek.

- Formal hypothesis testing was augmented by graphical and statistical exploration of geographical effects on observed stream conditions and with multivariate statistical modeling of potential sediment source factors because, in part, we recognized that assumptions of linearity or lack of co-variance inherent in the correlation analysis used for hypothesis testing were unlikely to be completely valid. Therefore, we used statistical tools, including Generalized Additive Models (GAMs), for further data exploration because these tools are not restricted by assumptions of linearity, independence among interactions, and the absence of covariance.

- A relatively low sample size (50 sites), constrained by time/budget, and a high number of possible candidate sediment source factors meant that the statistical power and ability to draw strong conclusions regarding models generated from GAMs was limited.

- Where evidence for multiple significant sediment sources was found, we assumed we could qualify the strength of these relationships based on statistical testing and other field-based evidence to prioritize the importance of each sediment source.

Other uncertainties within this study approach were identified in addition to the assumptions listed above:

- The applicability to Battle Creek of reference standards used to assist stream condition characterization from AREMP and other sources, especially those developed in other watersheds, was unknown.
- The applicability to Battle Creek of hypothesized sediment source relationships, derived from previous research, was unknown. This is the main uncertainty tested in this study.
- Process linkages between in-channel metrics and sediment sources are largely unknown or theoretical.
- We assumed that in-channel metrics could be measured in an unbiased fashion and that measurement error would not obscure the true variability of interest (i.e., that resulting from variation in sediment sources).
- The relative bias of sample-based mean stream condition characterizations compared to actual conditions typical of all habitat in a given reach remains unknown because we surveyed samples versus a complete census, despite the fact that the study design we used for sample site selection was not biased by stream conditions or geomorphic variables.
- We assumed that our sample size was sufficient to allow proper model development and statistical discrimination among models.

Measurements and Analysis

We characterized stream conditions by using field protocols developed by the U.S. Forest Service (Gallo 2001) for their AREMP. Stream conditions were characterized by measuring several physical and biological aspects of stream reaches at 50 sites randomly located within the fish bearing waters of the Battle Creek watershed. Physical stream channel data from sample sites were interpreted using the EMDS model (Reynolds 1999a, 1999b) based on empirical relationships described in Gallo et al. (2001). At the time this study was initiated, the AREMP version of the EMDS model (Gallo et al. 2001) was a pilot model that we judged to be the best available working tool for use in this watershed assessment. Reference criteria used in the 2001 version of the EMDS tool, and adopted for use in this report, were developed by AREMP for use in forested watersheds throughout Northern California, the Pacific Northwest, and the west slope of the Cascade Mountains (Gallo et al. 2001). We chose to use the AREMP reference criteria (Gallo et al. 2001) because they were integrated with field and EMDS-modeling protocols and because we were confident that AREMP performed a thorough review of existing standards and chose standards suitable for west-side Cascade Mountain watersheds.

Macroinvertebrate data collected at sample sites was characterized by comparison to reference criteria developed Hafele and Mulvey (1998) and Karr (1991): the Benthic Index of Biotic Integrity (B-IBI), the Oregon Department of Environmental Quality's Biotic Index, (ODEQ-BI), Percent Sediment Tolerant Taxa, and Sediment Sensitive Taxa Richness. The applicability of these reference criteria used to interpret macroinvertebrate communities in Battle Creek is described in more detail in Ward and Kvam (2003).

Upland watershed conditions were briefly summarized as they pertain to our analysis of sediment sources but were not exhaustively analyzed because such a full evaluation of upland watershed conditions was outside the scope of this study.

We compared three aspects of these instream sampling sites that are influenced by sediment delivery –fine sediment in pool tails, median substrate particle size, and residual pool depth –to several factors previously demonstrated to influence sediment delivery to streams – road density, near-stream road density, road-stream crossing frequency, susceptibility to "rain-on-snow" storms, the presence of erosive rhyolitic soils, forest cover, and the amount of near-stream meadow areas. We used empirical, causal relationships between these dependent in-channel response variables and independent sediment source factors to infer the location and extent of sediment sources in Battle Creek. When empirical, causal relationships were not found, we inferred that the hypothesized causal mechanisms were not significant sediment sources in the Battle Creek watershed and that, if they occurred at all, occurred at such a localized extent that other site-specific tools would need to be employed.

Our analysis of causal relationships between dependent, in-channel response variables and independent, sediment source factors was guided by several hypotheses (Table 1). These hypotheses were tested using pair-wise Spearman's ranked correlation tests corrected for multiple testing and tied ranks. In addition to testing relationships between stream channel condition and sediment source factors, we also included site elevation, watershed area, and stream gradient in our hypothesis testing as these situational variables have also been shown to influence the in-channel indices that we chose to explore. In addition to formal hypothesis testing, we used multivariate data exploration tools (including GAMs) to further examine relationships between sediment source factors and in-channel response variables. The use of GAMs avoids assumptions of linearity that are inherent in classical correlation analysis like the Spearman's tests and allows for the exploration of possible multivariate interactions between sediment source factors.

Table 1. Hypotheses used to guide the identification of sediment sources based on empirical relationships between three dependent in-channel response variables and seven independent sediment source factors and three situational variables. The alternative hypotheses of interest are positive forms of these statements.

Relationships Tested in the Battle Creek Watershed Assessment (Null Hypotheses)
Fine sediment measured in scour pool tails of Battle Creek is: • not positively correlated to road density. • not positively correlated to near-stream road density. • not positively correlated to the frequency of road-stream crossings. • not negatively correlated to forest cover. • not positively correlated to the area of near-stream meadows. • not positively correlated to the area susceptible to “rain-on-snow” storm events. • not positively correlated to the amount of rhyolitic soils. • not correlated to watershed area, elevation, or stream gradient.
Median substrate particle size (D_{50}) in Battle Creek is: • not negatively correlated to road density. • not negatively correlated to near-stream road density. • not negatively correlated to the frequency of road-stream crossings. • not positively correlated to forest cover. • not negatively correlated to the area of near-stream meadows. • not negatively correlated to the area susceptible to “rain-on-snow” storm events. • not negatively correlated to the amount of rhyolitic soils. • not correlated to watershed area, elevation, or stream gradient.
Residual pool depth in Battle Creek is: • not negatively correlated to road density. • not negatively correlated to near-stream road density. • not negatively correlated to the frequency of road-stream crossings. • not positively correlated to forest cover. • not negatively correlated to the area of near-stream meadows. • not negatively correlated to the area susceptible to “rain-on-snow” storm events. • not negatively correlated to the amount of rhyolitic soils. • not correlated to watershed area, elevation, or stream gradient.

METHODOLOGY

Field Protocols

Sample Site Selection

Sample sites at which field measurements were performed were randomly selected for this study by the Western Ecology Division of the Environmental Protection Agency (Olsen 2001). The sampling universe from which these sites were selected included all fish bearing stream reaches of the Battle Creek watershed. In choosing these sample sites, Olsen (2001) used an unequal probability random tessellation stratified survey design for a continuous linear network population (Olsen 2001) which has become the standard in selecting randomized locations for ecological sampling based on geographical considerations. This site selection method generated a randomized oversample list[3] of 100 site locations of which the first 50 sites meeting sampling criteria were visited and surveyed. Sampling criteria specified that a site would be sampled if the stream channel was wet at the time of sampling and if access permission had been granted by the landowner. If a site on the oversample list did not meet these criteria, it was rejected and then the next site on the list was considered. Altogether, the first 63 sample sites from the oversample list were considered; of these, thirteen sites failed to meet sampling criteria and were rejected. A total of 50 were sampled and used for watershed-scale stream condition characterization.

Another site from within this sampling universe (but not on the Olsen (2001) oversample list; site #101) was intentionally selected and sampled for direct comparison with a nearby site. Although this direct comparison is not described in this report, site #101 was included in the analysis of sediment sources because 1)the Generalized Additive Models used in this analysis did not depend on the assumption of randomly selected sample sites, 2) site #101 did not appear to be particularly influential in any of the models, and 3) because statistical power was improved by adding an additional sample site.

The extent of "fish bearing waters," used as the sampling universe from which samples sites were randomly selected, was determined prior to site selection by interviewing Mr. Hank Pritchard, a rancher, naturalist, angler, and resident of the Battle Creek watershed. Mr. Pritchard's information concerning fish distribution stems from a life-time of exploring and angling throughout the Battle Creek watershed, as well as a keen interest in ecological characteristics of this area. Field observations during the watershed assessment of wetted and dry channels during two hydrologic seasons generally substantiated Mr. Pritchard's description of the extent of "fish bearing waters." Likewise, fish presence/absence surveys reported by Lassen National Forest (2001) confirmed our understanding of the limit of fish distribution in the upper Battle Creek watershed. Those waters that would be accessible to anadromous salmonids if fish passage were provided at man-made obstacles (e.g., hydroelectric project diversion dams, dewatered reaches, etc.; see CDFG 1998d as summarized in Ward and Kier 1999) have also been identified in maps used in this document (e.g., Figure 1) in light of much recent interest in the anadromous salmonids of Battle Creek.

[3] The randomized list of sites, including more sites than will eventually be surveyed, is known as an "oversample."

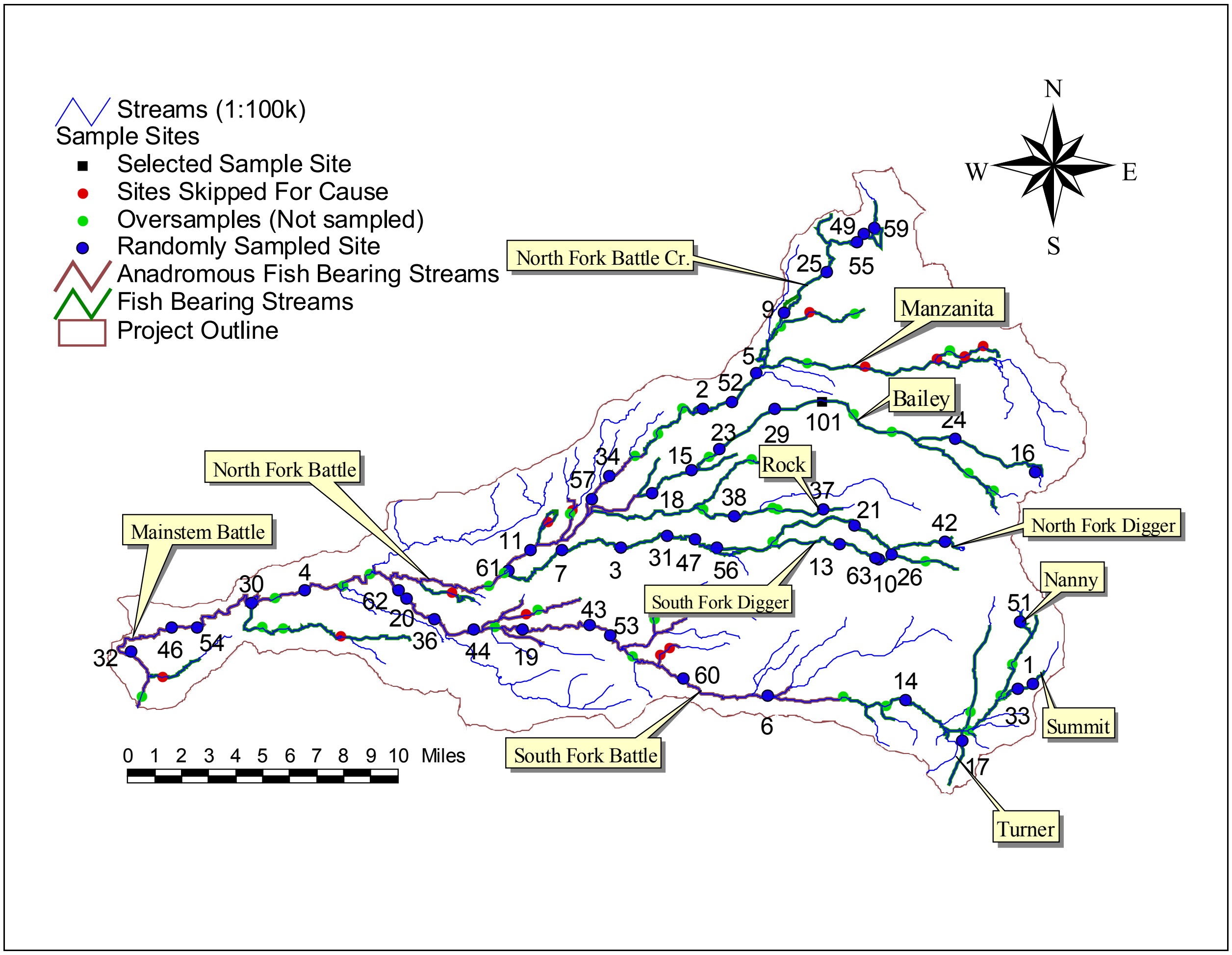

Figure 1. A map of the Battle Creek watershed depicting sample sites locations (blue and black), site numbers, and the names of streams with sites that were sampled. Oversamples (green) and sites skipped for cause (red) are also depicted. The depicted stream network is based on a 1:100,000 scale hydrography layer.

Physical and Biological Measurements

This section provides an overview of those physical and biological measurements made at each sampling site during low stream flow conditions in 2001 and 2002. Specific measurement protocols of U.S. Forest Service's AREMP program, with few exceptions noted herein, were strictly followed and are described in great detail in Gallo (2001).[4] Field equipment recommended by Gallo (2001) was used. This methodology overview identifies and explains those cases where the methods used in this assessment deviated from those of Gallo (2001).

At each site, we surveyed either six or eleven channel cross sections, surveyed the longitudinal profile of selected channel features, quantified stream bed particle size at eleven transects per site, quantified fine sediment, counted large woody debris pieces and collected

[4] To insure consistency with AREMP protocols, we employed, as a field crew member, a former USFS crew leader who had worked with AREMP protocols for several months. This AREMP-trained crew member trained Terraqua, Inc. staff in AREMP protocols at the first 12 sample sites.

aquatic macroinvertebrate samples from which a number of variables were derived. The following AREMP variables did not meet the study scope and were not measured: stream discharge, water chemistry, benthic periphyton, and aquatic vertebrates.

Site Layout – Physical and biological measurements were made at locations within sites as specified by Gallo (2001). The length of sampled sites depended on the bankfull channel width. The default length of stream sampled was equal to 20 times the bankfull width. A minimum length of 150 meters and a maximum length of 500 meters of stream were sampled at sites less than 7.5 meters wide or greater than 25 meters wide, respectively.

Gallo (2001) specified surveying cross sections at either six or eleven transects, depending on whether a site was "constrained" or "nonconstrained,"[5] respectively, as determined in the field prior to site surveying. Only one site (site #046) was determined to be nonconstrained prior to surveying and eleven transects were surveyed at this site. Final survey results indicated that this site did meet the criteria for "constrained" reaches and was treated as "constrained" in subsequent analyses. One other site (site #051) was surveyed as if it was "constrained" but was later determined to be "nonconstrained" from survey results. Survey protocols at all other sites followed those for "constrained" sites per Gallo (2001).

Physical Habitat Mapping – Methods used for physical habitat mapping closely followed Gallo (2001) with the following exceptions:

- Gallo (2001) specified surveying longitudinal profiles at increments of approximately 1/5 of the average bankfull width along the stream thalweg in addition to surveying longitudinal pool features. According to AREMP analysis protocols at the time of our field work, the information collected at these fine increments was not being used to derive any site-descriptive variables.[6] We recognized the lack of utility of these fine longitudinal increments after analyzing the first 12 sampled sites (and confirmed this with AREMP personnel; Moyer pers. comm.) and dropped these fine increments from our longitudinal profiles at the 39 subsequent sampled sites. Longitudinal surveys at all sampled sites included pool features specified by Gallo (2001).

- Gallo (2001) assumed that multiple channels separated by islands higher than bankfull stage were "unusual situations" and recommended surveying the cross

[5] "Constrained" reaches are those with relatively narrow floodplains (i.e. floodplains are constrained by a narrow valley bottom) whereas "nonconstrained" reaches have well developed flood plains. Nonconstrained reaches are defined as reaches that have an entrenchment ratio (flood prone width:bankfull width) greater than 2.2 and a slope gradient less than 3 %. All other reaches were considered constrained.

[6] After we completed field sampling, AREMP changed how they calculate sinuosity from using only those thalweg points measurements at cross sectional transects to using thalweg measurements at the fine increments (Moyer, pers. comm.). Our calculations of sinuosity use only those thalweg points measured at cross sectional transects.

We question the validity of using sinuosity as a descriptive tool, especially when sinuosity is used to evaluate stream condition and make potentially costly decisions, unless a standardized protocol for measuring stream length becomes widely accepted and used consistently. Sinuosity is a descriptive variable based on knowledge of the length and slope of a stream reach. Stream length and slope have the quality of other fractals whereby the determination of the magnitude of stream length is dependent on the size of the increments at which it is measured (Gleick 1987). Variation in the value of sinuosity at a site, based solely on differences in measurement increments, could erroneously influence site characterization.

section of only the channel "with the most flow." In our surveys, we observed that multiple channels were not uncommon and occurred at 12 sample sites though not all transects at these sites necessarily had multiple channels. In most cases, determination of which channels had the most flow (especially at bankfull stage when flow and channel geomorphology are most closely related) was particularly difficult. We believed that it was more appropriate to survey the cross section of the stream spanning all channels. Variables, such as bankfull width and average depth, were determined individually by channel and were summed across all channels for transect-specific values. This complicated surveying and data processing but provided a more consistent and geomorphologically more appropriate characterization of stream reaches with multiple channels.

- Specific definitions of pools were obtained from AREMP (Moyer pers. comm.) because they were not provided in Gallo (2001). Pools were identified in the field if they were 1) longer than the average wetted width, 2) channel spanning, and 3) at least 25 percent of the surface area was scoured. In addition to pools meeting these criteria, low gradient habitat units in high gradient stream reaches were classified as "pools" if they provided biologically significant fish habitat[7] compared with other habitat within the reach. Scour pools (where fine sediments were sampled) were defined as pools where depth was controlled by depositional materials but not by wood, bedrock or boulders.

Particle Size and Fine Sediment – Stream bed particle size was measured following pebble count protocols in Gallo (2001) except that we apportioned the 10 pebble counts per transect among all channels at transects with multiple bankfull channels relative to the total transect bankfull width as described above. Fine sediment was sampled by counting fine sediment under a string grid per Gallo (2001) except that fine sediment counts were not made in cases where algae or other debris obscured the streambed. Site-averaged quantification of fine sediment was determined only using those string intersections where the streambed was not obscured by algae or other debris. We used a mask and snorkel to better observe the stream bed at all but the shallowest locations.

Large Woody Debris – Protocols in Gallo (2001) specified collecting much more information than are actually used in the EMDS model, so we chose to forego characterization of debris configuration, type, and location. We collected data for all wood that met the minimum size criteria and measured those pieces that were close to criteria cut-off values, but otherwise estimated whether pieces met size criteria. We did not conduct the size estimation validation procedure described in Gallo (2001). Because we counted or estimated the number of pieces within debris jams and included these in total site counts, our counts of large wood could be positively biased compared to counts of wood by other researchers using Gallo (2001) protocols at sites with large debris jams.

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[7] The "biological significance" of step pools that determined whether a low gradient habitat unit in a high gradient reach was determined by subjective professional judgement. In rare cases, we considered a low gradient habitat unit in high gradient reaches as a "pool", if it was deeper or appeared to provide more resting habitat or cover habitat than pools in the same reach that met the formal definition for pools.

Aquatic Macroinvertebrates – We collected aquatic macroinvertebrates using the River InVertebrate Prediction And Classification System (RIVPACS) sampling protocol advocated by Gallo (2001) and developed by Hawkins et al. (2001). Protocols used for processing and analyzing aquatic macroinvertebrate samples are described in Ward and Kvam (2003).

Stream Condition Characterization

Stream condition was characterized at each of 51 sample sites by measurements of six physical variables and four biological metrics derived from analysis of macroinvertebrate communities (Table 2). Four of the six physical variables (fine sediment, particle size, pool frequency, and large woody debris) were characterized and displayed as EMDS model output (Figure 2). Residual pool depth was not incorporated into the version of AREMP's EMDS model available in 2002; therefore, this variable is characterized and displayed in this study using other techniques and reference criteria. As described in the Discussion Section, the channel morphology portion of the EMDS was found to be an inadequate methodology and was not used in the analysis. Although the four biological metrics were not included in the 2001 version of AREMP's EMDS model, sufficient justification from the literature (Hafele and Mulvey 1998; Karr 1991) allowed us to evaluate macroinvertebrate indices and metrics using linguistic modeling in EMDS (Table 2).

Understanding EMDS Truth Values

EMDS is a linguistic model which evaluates the "truth" of a premise about an observed condition and returns a measure of certainty (a "truth value") that the premise is true or false. The AREMP version of the EMDS model is structured to test premises that fit the following pattern: *"At site number X, the magnitude of variable Y is favorable for salmonid production"* (Gallo pers. comm.; Reeves pers. comm.; Gallo et al. 2001). The EMDS model compares the magnitude of variable Y at site X against known relationships between that variable and the related aspects of salmonid production. From this comparison to known relationships, EMDS determines how certain we can be that variable Y "fully favorable for salmonid production," or, at the opposite end of the spectrum, how certain we can be that variable Y may be "fully unfavorable for salmonid production." The output of each of these tests in EMDS are numerical "truth values" that range between –1.0 and 1.0. EMDS truth values are calculated for each measurement variable and evaluation node included in the model (Figure 2).

EMDS evaluation criteria curves may take many shapes (Table 2). In this analysis, most evaluation curves (e.g., fine sediment, macroinvertebrate metrics and indices) are linear relationships that map a high and low value to +1 and –1 in a one-to-one linear relationship. The evaluation curve for particle size is bell-shaped (Figure 3; Table 2). Evaluation curves for pool frequency and large woody debris are based on logarithmic relations and are described more fully in the Results and Discussion sections in the context of observed data. Table 3 describes how EMDS truth values generated with Battle Creek data are interpreted in this study and serves as a legend for maps of truth values displayed in the Results Section.

Truth values have the following properties in regard to a stated premise:

- The larger the truth value (i.e., the closer the truth value is to 1.0) the higher the certainty in the support for the premise,
- The smaller the truth value (i.e., the closer the truth value is to -1.0) the higher the certainty in the lack of support for the premise,
- Positive truth values indicated the level of certainty associated with support for the premise; negative truth values indicate the level of certainty associated with rejection of the premise,
- Positive truth values > 0.50 indicate a reasonably high degree of certainty that the premise is supported,
- Negative truth values < -0.50 indicate a reasonably high degree of certainty that the premise is unsupported,
- Truth values between –0.50 and 0.50 indicate moderate support for the premise and may reflect a low degree of certainty. Low certainty can be the result of missing information, ambiguous individual data, ambiguous evaluation criteria, or conflicting values from different measurements.

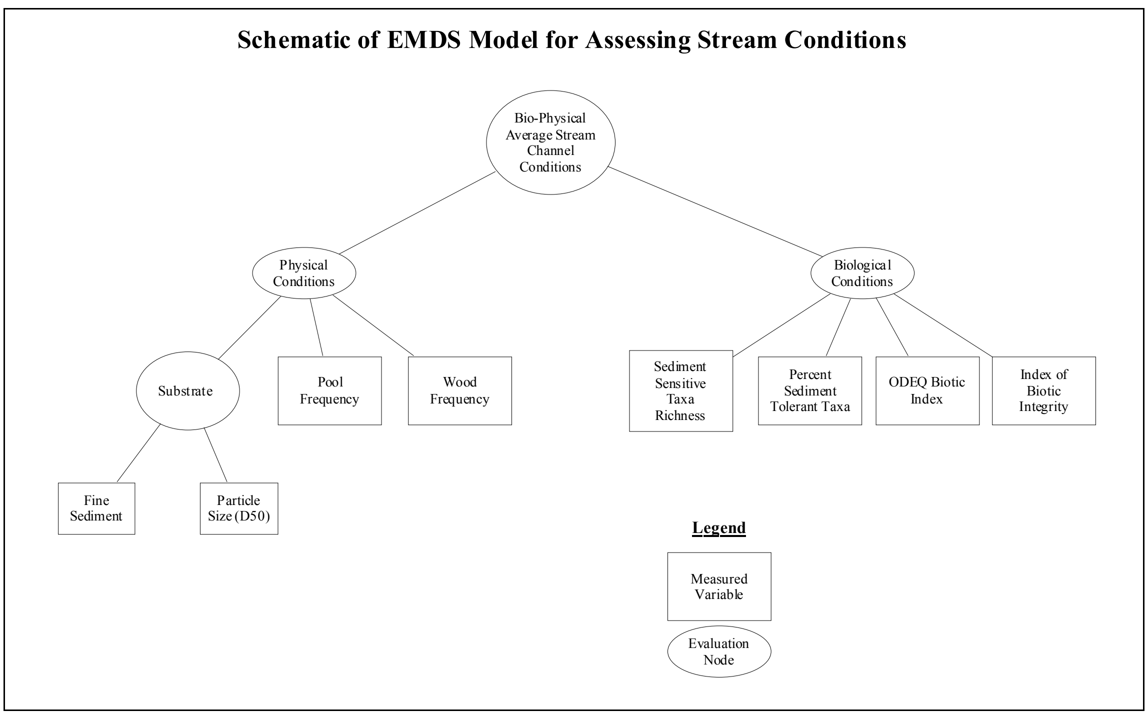

Figure 2. Schematic of the EMDS model used to assess stream conditions in the Battle Creek watershed. Truth values for each measurement variable are determined based on evaluation criteria (e.g., see Table 2). Truth values at each evaluation node equal unweighted averages of all nodes/variables in the next subordinate tier. For example, the truth value for "physical condition" equals the unweighted average of "substrate," "pool frequency," and "wood frequency."

Table 2. Evaluation criteria used in the EMDS model based on AREMP reference standards.

Variable	Lower Value: Fully Unfavorable	Lower Value: Fully Favorable	Upper Value: Fully Favorable	Upper Value: Fully Unfavorable	Source
Physical Habitat					
Fine Sediment	≥17%	≤11%	na	na	Hicks 2000 per Gallo et al. 2001
Median Particle Size (D_{50})	≤45 mm	>65 mm	<95 mm	≥ 128 mm	Knopp 1993 per Gallo et al. 2001
Pool Frequency	Logarithmic curve dependent on bankfull width				Gallo et al. 2001; Bilby and Ward 1991
Large Wood Frequency	Logarithmic curve dependent on bankfull width				Gallo et al. 2001; Bilby and Ward 1991
Biological/Macroinvertebrate					
Percent Sediment Tolerant Taxa (PSTT)	≥25%	≤10%	na	na	Hafele and Mulvey 1998 per Ward and Kvam 2003
Sediment Sensitive Taxa Richness (SSTR)	0	≥2	na	na	Hafele and Mulvey 1998 per Ward and Kvam 2003
Oregon Department of Environmental Quality Biotic Index (ODEQ-BI)	≤20	≥39	na	na	Hafele and Mulvey 1998 per Ward and Kvam 2003
Benthic Index of Biotic Integrity (B-IBI)	≤27	≥44	na	na	Karr 1991 per Ward and Kvam 2003

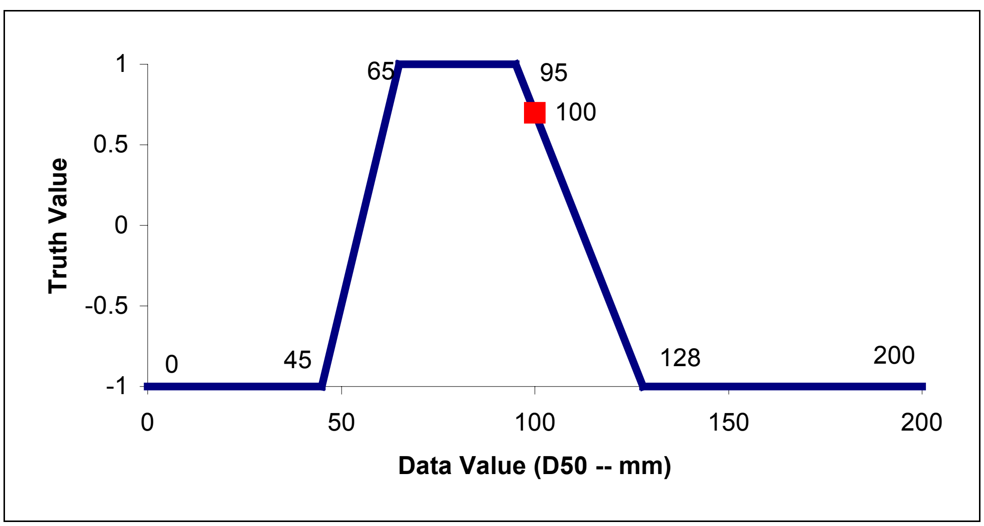

Figure 3. An example of a bell-shaped EMDS evaluation curve. In this case (the red point on the curve), the EMDS model returns a truth value of 0.70 for a D_{50} of 100 mm.

Table 3. Interpretations of truth values generated by the EMDS model as applied to data collected in Battle Creek in 2001 and 2002.

Truth Value	Formal Linguistic Meaning (pertaining to linguistic premise)	Interpretation (pertaining to a specific condition for salmonid production)	Color of Symbols in Maps and Graphs
1.0	Observed conditions provide high certainty that the premise is true	Fully favorable	Dark Green
0.5 to 0.99	Observed conditions provide reasonable certainty that the premise is true	Likely favorable	Light Green
-0.5 to 0.5	Observed conditions provide low certainty regarding the premise	Moderately favorable	Grey
-0.99 to –0.5	Observations provide reasonable certainty that the premise is false	Likely unfavorable	Light Red
-1.0	Observations provide high certainty that the premise is false	Fully unfavorable	Dark Red

Residual Pool Depth

Evaluation criteria for residual pool depth were not incorporated into the AREMP EMDS model. The reference criteria against which residual pool depths were compared was 3 feet for pools in anadromous reaches and 1 foot for pools not accessible to anadromous salmonids; pools less than 3 feet deep (anadromous) or 1 foot deep (trout) were interpreted to be fully unfavorable for anadromous salmonid or trout production, respectively. Anadromous pool quality was assessed according to pool depth parameters for adult spring Chinook salmon, which require pools with depth between 3 feet to 10 feet for over-summer holding (G. Sato unpublished data and Marcotte 1984 as cited in CDFG 1998). Non-anadromous pool quality was evaluated according to pool depth parameters described by Behnke (1992) who found that a lack of adult trout habitat generally limits the population biomass of resident trout in most streams and that adult trout need slow water with depths of 0.3 meters or greater.

Aquatic Macroinvertebrates

Attributes of the macroinvertebrate community sampled in 2001 and 2002 were derived from taxon-specific abundance data (Ward and Kvam 2003). Two metrics that are known to change in response to anthropogenic, sediment-related habitat disturbance are used in this report to further characterize stream channel conditions including: the Percent Sediment Tolerant Taxa (PSTT) index and the Sediment Sensitive Taxa Richness (SSTR; Hafele and Mulvey 1998, Ward and Kvam 2003). Two multimetric indices are also used to assess general stream condition and may be influenced by disturbances other than sediment (e.g., water temperature or other aspects of water quality) including the Oregon Department of Environmental Quality Biotic Index (ODEQ-BI; Hafele and Mulvey 1998) and the Benthic Index of Biotic Integrity (B-IBI; Karr 1991).

Evaluation curves for PSTT, SSTR, ODEQ-BI, and the B-IBI were created based on scoring criteria and interpretive categories in Hafele and Mulvey (1998) and Summers (2001). These evaluation curves were used to characterize site-specific macroinvertebrate data in the EMDS model (Table 2).

Sediment Source Identification

The assessment of sediment source conditions was performed through the analysis of geographic information system (GIS) data. These data were assembled for the Battle Creek Watershed Conservancy by Kier Associates in a project called KRIS Battle Creek. KRIS Battle Creek displays and analyzes electronic mapping data using Arc Info and Arc View programs and includes data characterizing a wide array of natural resource phenomena, only some of which were used to assess sediment sources. Selected data were extracted from KRIS Battle Creek for specific use in testing the sediment source hypotheses developed in this study (Table 1).

Site-Specific Watersheds

The statistical tools that we used to examine relationships between stream channel conditions and possible sediment source factors (see discussion of generalized additive models below) required that we generate one-to-one characterizations of sediment source conditions for each site at which stream channel condition data were collected. We assumed that all stream channel conditions (flow, geomorphic processes, sediment delivery, etc.) at any given site are integrated products of only those conditions and processes which take place within the watershed or catchment area specific to that site. Therefore, for each stream channel sampling site, we aggregated upland condition data from any area, and only those areas, that drained past the sample site, and called these areas “site-specific watersheds.”

To identify site-specific watersheds, we used ArcView 3.1, Spatial Analyst 1.1, an Elevation Grid with sinks filled, a Flow Direction Grid, a Flow Accumulation Grid and a USGS 30 meter digital elevation model (30 m DEM) to calculate the catchment area and other catchment statistics for each user-defined point on the stream. GIS data for each sediment source factor were summarized, for each sample site, within these sites-specific watershed polygons.

Additional processing was required to generate final site-specific watersheds at a few sites. The lack of a clear topographic divide near site #003 confounded application of the Elevation Grid so that the final polygon for this site had to be manually adjusted to match elevation contours produced from the 30 m DEM. A similar phenomena occurred in the creation of the site-specific watershed for site #011.

Finally, a significant exception to the premise that all sediment source conditions upslope from a particular site are integrated at that site, occurs at sites located downstream of reservoirs and lakes. Large water-storage dams, such as those that form Macumber and North Battle Creek reservoirs, clearly intercept small to large bedload particles. The effect of these two dams on the delivery of suspended fine sediment is less clear (some silt settles out in the reservoirs but some may be transported through the reservoirs under certain conditions) as is their effect on channel-forming flows. At times when they are not at full pool, reservoirs likely have a significant effect on channel-forming flows at downstream sites and this effect would be negatively related to distance downstream of the dam. While this flow effect might not be important when these reservoirs are at full pool, in either case was not possible to estimate the actual effect.

In recognition of the effect of these two dams on in-channel, sediment delivery processes, watersheds for all sites located downstream of these dams in North Fork Battle Creek and Mainstem Battle Creek were adjusted to exclude the site-specific watersheds of Macumber Dam and North Battle Creek Reservoir Dam. We did not exclude, however, watersheds upstream of the few lakes in the Battle Creek watershed (e.g., Manzanita Lake, Heart Lake, Soda Lake, etc.). We assume that the error introduced by not making this correction will be small because these lakes are all located near headwaters and because the drainage area intercepted by these lakes is relatively small compared to the watershed areas of most sites. We also did not make adjustments for the effects of run-of-the-river water diversions (e.g., other irrigation diversions or hydroelectric project diversions besides the two storage dams). The effect of these diversions on channel forming flows and sediment transport is unknown but believed to be negligible at the watershed scale (Ward 2004) though possibly significant at the site-specific scale.

Hydrography

A hydrography data layer developed by USGS at the scale of 1:100,000, modified to exclude artificial waterways like diversion canals and penstocks, was used in the derivation of many sediment source factors. While this coverage is more limited that other available hydrography layers (e.g., see Strahler stream layer in KRIS Battle Creek), the 1:100,000 data layer provides a fairly close approximation of the stream network that is wetted at summer low-flow conditions. Where the 1:100,000 data layer errors, it tends to include stream channels that are dry in summer rather than excluding channels that are wet. Therefore, it is adequate for characterizing the sampling universe within which our sample sites were located. However, this layer may underestimate the stream network that comes in contact with sediment sources like roads, especially because the wetted stream network is much larger in winter conditions when sediment is being transported from upland areas. A quality-controlled hydrography data layer at the often-used 1:24,000 scale was not publicly available at the time of this analysis.

The extent of coverage of the 1:100,000 stream network is likely adequate for identifying those near-stream areas that would contain riparian plant communities but error arises because of the coarse scale of this data layer, from differences between the location of mapped streams relative to their actual position on the ground. This error may affect estimates of the density of near-stream vegetation cover, used in the calculation of near-stream meadow areas, and could influence estimates of near-stream road density.

Sediment Source Factors

Three road-related metrics – watershed-scale road densities, near-stream road densities, and the number of road-stream crossings – were derived to assess road-related influences on sediment input to Battle Creek. A metric – forest cover – was developed as a surrogate for the distribution and magnitude of timber harvest in the Battle Creek watershed. A metric – near-stream meadow areas – was developed as a surrogate for the distribution and magnitude of livestock grazing in the riparian areas of the Battle Creek watershed. The influence of rain-on-snow storm events on sediment delivery to Battle Creek was characterized by a metric which calculated the proportion of watershed area affected by the rain-on-snow phenomenon. The influence of highly-erosive rhyolitic soils on sediment delivery to Battle Creek was characterized by a metric which calculated the proportion of watershed area comprised of rhyolite soils.

Road Density – Road information used for sediment source analysis on lands owned by Sierra Pacific Industries (SPI), the U.S. Forest Service (USFS), and the National Park Service were derived using data provided by each of these landowners. Road information obtained from USGS was used on lands owned by other parties. Data from these four sources were merged to form one road data layer.

Mapping data for roads in Battle Creek are incomplete and inconsistent across ownership which may be a source of error in estimating road-related sediment source factors. For example, USGS roads represent data mapped when the last topographic map series was generated and are outdated. Many roads on National Forest lands are not included in National Forest maps while other roads, since abandoned, remain on their map. SPI road maps are much more accurate. None-the-less, even the most detailed road data provided by SPI seems to consider only main hauls roads and does not include spur and temporary roads, skid trails and landings which might also be sources of sediment.

Road densities were derived by dividing the linear miles of road by the area of the watershed in square miles and are expressed in units of miles per square mile (mi/mi^2).

Near-Stream Road Density – Road data used in this analysis are described above in "Road Density." Road densities were also calculated for "near-stream" subsets of each site-specific watershed which were created to approximate riparian areas. The "near-stream" area was defined as all area within 100 meters of the stream on both sides of the channel. The length of only those segments of roads within this 200 meter-wide zone were divided by the "near-stream" portion of the site-specific watershed to derive near-stream road densities. Near-stream road densities are expressed in units of miles of near-stream roads per square mile of near-stream watershed area.

Road-Stream Crossing Frequency – Road data used in this analysis are described above in "Road Density." The number of intersections of roads and streams were summed and divided by the number of stream miles. The frequency of road-stream crossings was expressed in units of the number of crossings per stream mile.

Forest Cover – Sufficient data to characterize historical timber harvest in Battle Creek do not exist in a format useful for direct comparison with stream condition data. As a surrogate, we developed the metric "forest cover" as a proxy for previous timber harvests and also postulated that road density metrics are likely correlated with the amount of past timber harvests. Variability in the potential amount of sediment delivery has been related to variation in vegetation density and canopy cover in watersheds affected by timber harvest (e.g., Jones and Grant 1996; Reeves et al. 1993). Keithley's (1999) analysis suggested that vegetation data obtained through remote sensing methods may be used as a proxy for canopy cover.

Remotely-sensed vegetation data were derived by the USFS Pacific Southwest Regional Remote Sensing Lab in cooperation with the California Department of Forestry (CDF) Fire and Resource Assessment Program from a Landsat multi-spectral image taken in 1996. These data are accurate to a one hectare scale which we considered to be sufficient resolution for characterization at the watershed and site-specific watershed scale.

The forest cover variable was derived from the USFS vegetation data to estimate the amount of forested land as a percentage of the site-specific watershed area. Areas characterized as forest cover included all areas vegetated with trees greater than or equal to 20 inches in diameter.[8]

Near-Stream Meadow Area – Meadows and tree-less areas (e.g., pastureland and natural meadows) in close proximity to stream channels are prominent features of the Battle Creek watershed. These locations are often typified by livestock grazing that we hypothesized was a source of sediment in Battle Creek. We assumed that livestock grazing, and its potential effects on sediment delivery to streams, varies in proportion to the availability of these meadow areas. Therefore, variability in the extent of these meadow areas was treated as a surrogate for actual livestock grazing and was examined as a potential sediment source factor.

The USFS vegetation data, as described above in "Forest Cover," were also used to identify near-stream meadow areas. The "near-stream" area was defined as above in "Near-Stream Road Density." Areas characterized as meadows included all areas predominated by vegetation less 5 inches in diameter.

Rain-on-Snow Area – Areas within the transient snow zone, the portion of the watershed where snow accumulates and melts on a seasonal basis, are sometimes referred to by hydrologists as the "rain-on-snow" zone. Rain storms that occur within this area at certain times of year may precipitate rain onto an existing snow pack in storms known as "rain-on-snow" events. Rain-on-snow events have the potential to influence the amount and timing of runoff and sediment delivery because of the combination of precipitation and melting of the snow pack. Runoff and sediment delivery potential can increase in the presence of factors that increase the rate of snow melt, particularly in unvegetated areas within the rain-on-snow zone which may be relatively warmer, are subject to higher winds, and exposed to higher levels of solar radiation (Harr 1986; Berris and Harr 1987; and Heeswijk et al. 1995).

Armentrout et al. (1998) considered the elevation band from 3,600 to 5,000 feet above sea level to be the "dominant rain-on-snow zone" in nearby Deer, Mill and Antelope creeks. They characterized a watersheds sensitivity to the rain-on-snow phenomenon by calculating the percent of a watershed within this zone. For our analysis of rain-on-snow the proportion of each site-specific watershed within the rain-on-snow zone was calculated as the area of overlap between the individual site-specific watershed and the elevation band between 3,500 and 5,000 feet.

[8] For this analysis, we considered trees larger than 20 inches as indicating mid- to late-seral conditions. This size class break was the closest approximation within the USFS vegetation data to the 24 inches size class break chosen by Keithley (1999). Keithley (1999) characterized trees from 24- to 36 inches in diameter as mid-seral and those greater than 36 inches as late-seral.

Rhyolitic Soils – Rhyolitic soils are recognized as being the most erodible soil type in the Battle Creek watershed (Napper 2001) and in the watersheds of Mill, Deer and Antelope creeks to the south (Armentrout et al. 1998). Data on the distribution of rhyolitic soils were obtained from the Chico State University and were digitized from U.S. Geologic Survey maps or incorporated from USFS surveys. The proportion of each site-specific watershed influenced by rhyolitic soils was calculated as the area of overlap between the individual site-specific watershed and rhyolitic soils polygons divided by the site-specific watershed area.

Other Factors – Three other factors were included in the modeling analysis of sediment source factors including site elevation, watershed area (corrected for reservoirs), and stream gradient. Site elevations were estimated from the 30 m DEM. The site-specific watershed areas were estimated as described above in "Site-Specific Watersheds" and were corrected for the effects of reservoirs. Stream gradient was determined in the field as described above.

Response of Stream Conditions to Sediment Source Factors

Hypothesis Testing – Formal testing of the hypotheses described in Table 1 was executed by examining pair-wise Spearman's rank correlation coefficients and examination of 95 percent confidence intervals around the estimate of the correlation coefficients (Zar 1984; Van Sickle pers. comm.). Significance testing and calculation of confidence intervals were corrected for tied-ranks (Zar 1984) and for multiple testing (Van Sickle 2003; Van Sickle pers. comm.).

Multivariate Data Exploration – Possible multivariate linear and non-linear relationships among sediment source factors and three channel condition indices were assessed using several data exploration methods to augment the techniques used for formalized hypothesis testing because linear correlation techniques generally must make unrealistic assumptions about the observed data that are often not appropriate. Generalized additive models[9] (GAMs; Hastie and Tibshirani 1990) can be used to define predictive relationships, are not hindered by the usual assumptions of normality and linearity that constrain classic statistical approaches, and are useful for finding features of non-linear relationships such as threshold or step functions such as those alluded to in Cederholm et al. (1980) and discussed in McGurk and Fong (1995).

For each channel condition index, GAMs were fit to the data, using forward and backward stepwise model selection as applicable, to detect any potentially informative predictors or relationships. To interpret GAM fittings, we examined basic statistical summaries (e.g., scatterplots for each pairwise comparison of each channel condition index with each sediment source factor; correlation statistics), initial GAM results used to determine the form of the model search, summary results of the stepwise search, and final model summaries. GAM modeling and related statistics were performed in SPLUS for Windows.

[9] GAMs use nonparametric smoothers to identify and estimate linear and/or nonlinear relationships between each predictor and the response, and, therefore, are more robust than standard regression/correlation statistics in cases where linear relationships cannot be assumed.

RESULTS

Stream Condition

Watershed-Averaged Conditions – Four physical and four biological metrics were summarized by averaging site-specific truth conditions for all metrics at 50 sites sampled in the Battle Creek watershed (Table 4; these metrics are reported individually below). The watershed-averaged truth value for these eight metrics was 0.08 (scale from –1.0 to 1.0), which means that there is moderate support for the premise that "biological and physical conditions in the Battle Creek watershed are favorable for salmonid production"; on average, biological and physical conditions were moderately favorable for salmonid production. The distribution of truth values from all 50 sites was skewed toward positive values (Figure 4).

The moderate magnitude (0.08) of the watershed-averaged truth value is the result of 1) conflicting values from different measurements (e.g., ODEQ Biotic Index and Sediment Sensitive Taxa Richness truth values were high, on average, but several physical condition truth values were low), 2) ambiguous individual data (e.g., truth values for metrics like fine sediment and Index of Biotic Integrity were ambiguous – conditions were not fully favorable nor fully unfavorable; see Figure 4), or 3) missing information (e.g., missing macroinvertebrate samples at 7 of 50 sites reduced the level of certainty about 10 percent for the ODEQ Biotic Index and Sediment Sensitive Taxa Richness truth values). Site-specific truth values for these eight metrics were moderately favorable at 47 sites, were likely favorable at two sites, and were likely unfavorable at 1 site (Figure 4).

Table 4. Watershed-averaged stream conditions based on four physical and four biological metrics averaged over 50 sites sampled in 2001 and 2002 within the Battle Creek watershed.

EMDS Goal	Watershed Averaged Truth Value	Interpretation
Bio-Physical Average Stream Channel Conditions (average of physical & biological conditions)	0.08	Bio-physical conditions are moderately favorable for salmonid production.
Physical Conditions (average of substrate, pool frequency, and wood frequency)	-0.25	Physical stream channel conditions are moderately favorable for salmonid production.
Substrate (average of fine sediment and D_{50})	-0.36	Substrate conditions are moderately favorable for salmonid production.
Fine Sediment	-0.27	Fine sediment conditions are moderately favorable for salmonid production.
Particle Size (D_{50})	-0.44	Particle size conditions are moderately favorable for salmonid production.
Pool Frequency	-0.73	Pool frequency conditions are likely unfavorable for salmonid production.
Wood Frequency	0.33	Wood frequency conditions are moderately favorable for salmonid production.
Biological Conditions (average of four metrics below)	0.41	Biological conditions are moderately favorable for salmonid production.
Sediment Sensitive Taxa Richness	0.64	SSTR is likely favorable for salmonid production.
Percent Sediment Tolerant Taxa	0.10	PSTT is moderately favorable for salmonid production.
ODEQ Biotic Index	0.67	ODEQ Biotic Index is are likely favorable for salmonid production.
Index of Biotic Integrity	0.24	Index of Biotic Integrity is moderately favorable for salmonid production.

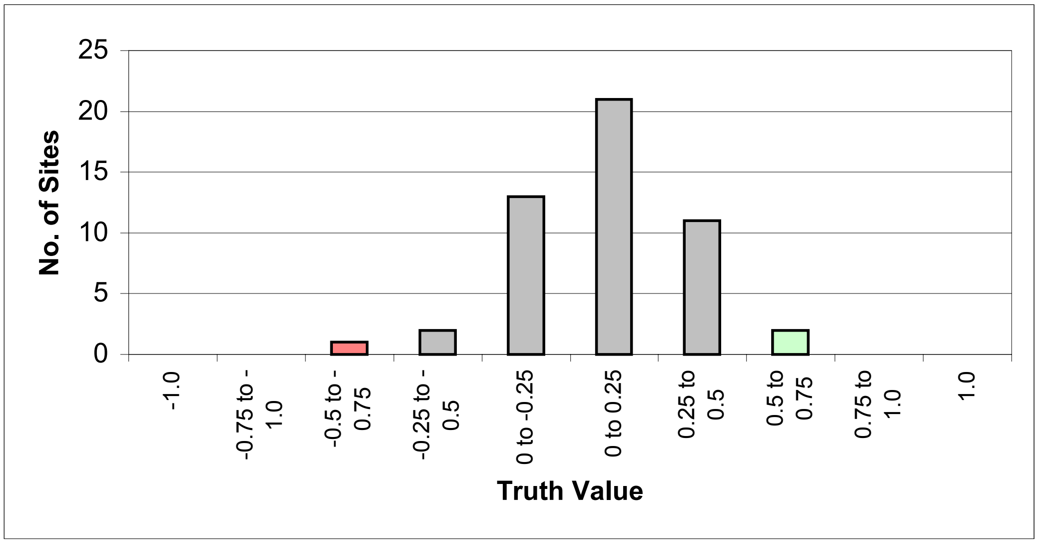

Figure 4. Histogram of 50 site-specific truth values resulting from EMDS analysis of four physical and four biological metrics in 2001 and 2002 within the Battle Creek watershed, color coded by EMDS category.

Fine Sediment – Fine sediment was quantified at 35 sample sites as the percent of streambed (measured in scour pool tails) comprised of particles less than 2.0 mm and was expressed in percent. Percent fine sediment could not be visually quantified at 7 sites because the substrate was obscured by algae and at 8 sites because of the absence of scour pools.

Among all sampled sites, the mean percent fine sediment was 31 percent (Table 5) while percent fine sediment at individual sites ranged from 4 to 85 percent. Mean percent fine sediment was significantly greater in response versus transport[10] reaches (t-test, $p < 0.001$; Table 5) but was not significantly different between basins (ANOVA, $p = 0.77$, Table 5).

EMDS analysis of percent fine sediment indicates, with reasonable or high certainty, that fine sediment conditions at 8 of 35 sites were fully or likely favorable for salmonid production while fine sediment conditions at 22 sites rated as fully or likely unfavorable (Figure 5). Sites with favorable levels of fine sediment were distributed throughout the watershed and were not clustered in any particular portion of the watershed (Figure 6). Likewise, sites with unfavorable fine sediment levels were also not particularly clustered in any one portion of the watershed.

Table 5. Percent of streambed in scour pool tails comprised of particles less than 2.0 mm in size [mean ± SEM (n)] by basin and reach type.[10]

Basin	Response Reaches	Transport Reaches	All Sites
Mainstem Battle Creek	32 ± 18 (4)	(0)	32 ± 18 (4)
North Fork Battle Creek	50 ± 21 (9)	16 ± 13 (15)	29 ± 23 (24)
South Fork Battle Creek	58 ± 25 (3)	20 ± 11 (4)	36 ± 26 (7)
Battle Creek Watershed	47 ± 22 (16)	17 ± 12 (19)	31 ± 23 (35)

[10] In this context, response reaches were defined as reaches with stream gradient <3% while transport reaches had stream gradients ≥3% (Montgomery and Buffington 1993).

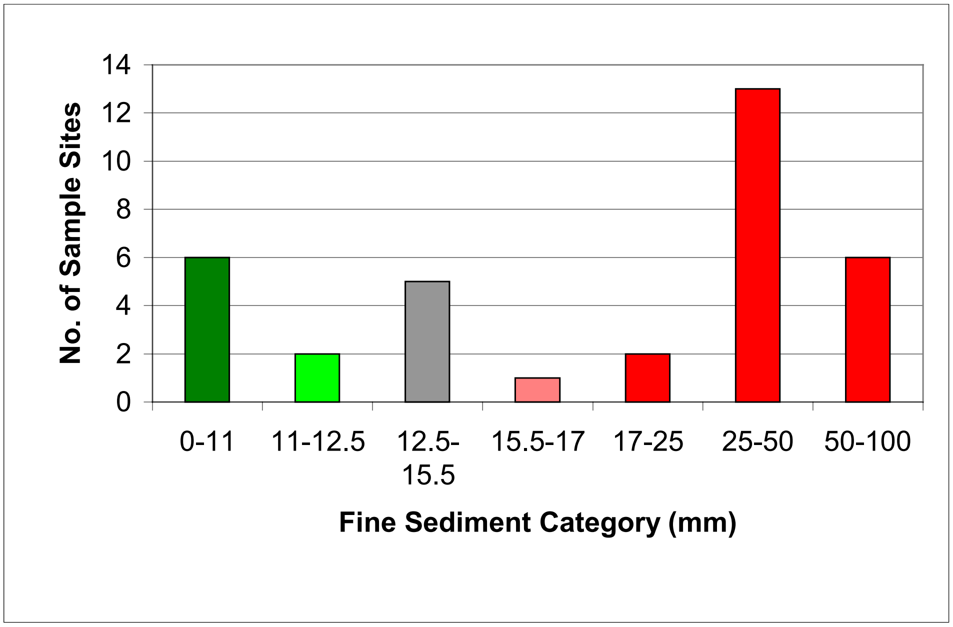

Figure 5. Histogram of fine sediment at 35 sample sites, color coded by EMDS category.

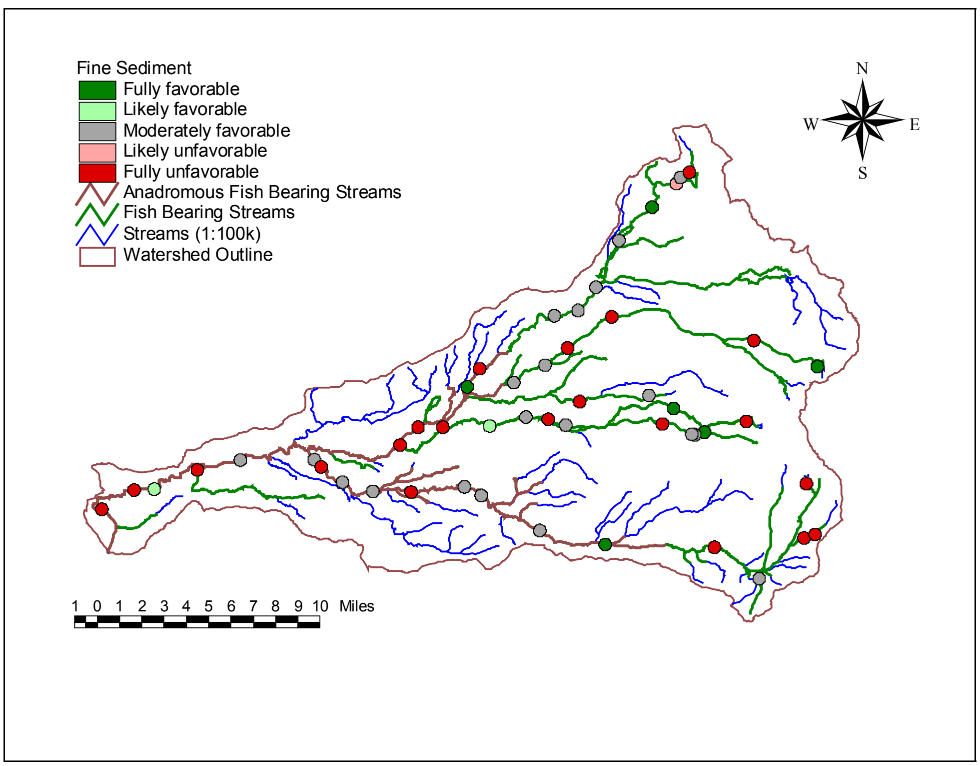

Figure 6. Map depicting EMDS truth values for fine sediment goal at sample sites within Battle Creek watershed.

Particle Size – Median particle size, D_{50}, was quantified at 49 sample sites. The D_{50} for all sampled sites ranged from 1 to 356 mm and averaged 92 mm. Mean D_{50} values were highest in the South Fork basin and varied significantly between basins (Table 6; ANOVA, $p = 0.04$; Figure 8) but a statistically less-powerful Tukey multiple comparison test could not unambiguously determine which means(s) were significantly different from the others (Zar 1984).

EMDS analysis indicates, with reasonable or high certainty, that D_{50} conditions at 11 of 49 sites were fully or likely favorable for salmonid production while D_{50} conditions at 33 sites were fully or likely unfavorable (Figure 8). Of the sites with unfavorable D_{50} values, the median particle size was too small at 20 sites and too large at 13 sites (Figure 7).

Table 6. Median particle size (mm) [mean ± SEM (n)] by basin and reach type.

Basin	Response Reaches	Transport Reaches	All Sites
Mainstem Battle Creek	47± 46 (4)		47± 46 (4)
North Fork Battle Creek	46 ± 42 (12)	97 ± 90 (18)	77 ± 78 (30)
South Fork Battle Creek	154 ± 93 (9)	117 ± 150 (4)	143 ± 108 (13)
Battle Creek Watershed	85 ± 82 (25)	101 ± 99 (22)	92 ± 90 (47)

Particle size frequency distributions for individual sites were often bimodal illustrating that fine sediment comprised a large percentage of the substrate at these sites (for example, see particle frequency histograms for sites #009, #016, #019 in Appendix B). Fine sediment comprised greater than 15 percent of all substrate particles at 37 of 49 sample sites and comprised greater than 45 percent of all substrate particles at 6 sites (Figure 9).

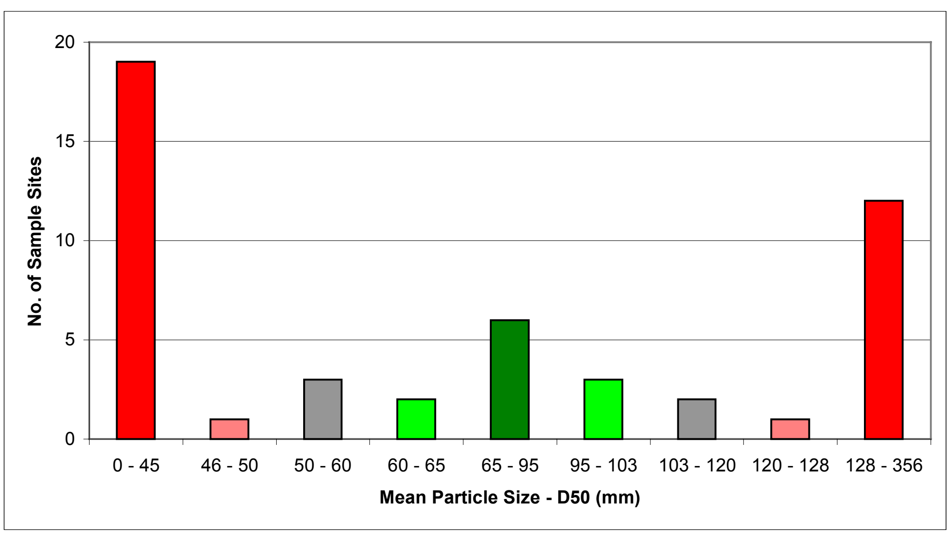

Figure 7. Histogram of median particle size at 49 sample sites, color coded by EMDS category.

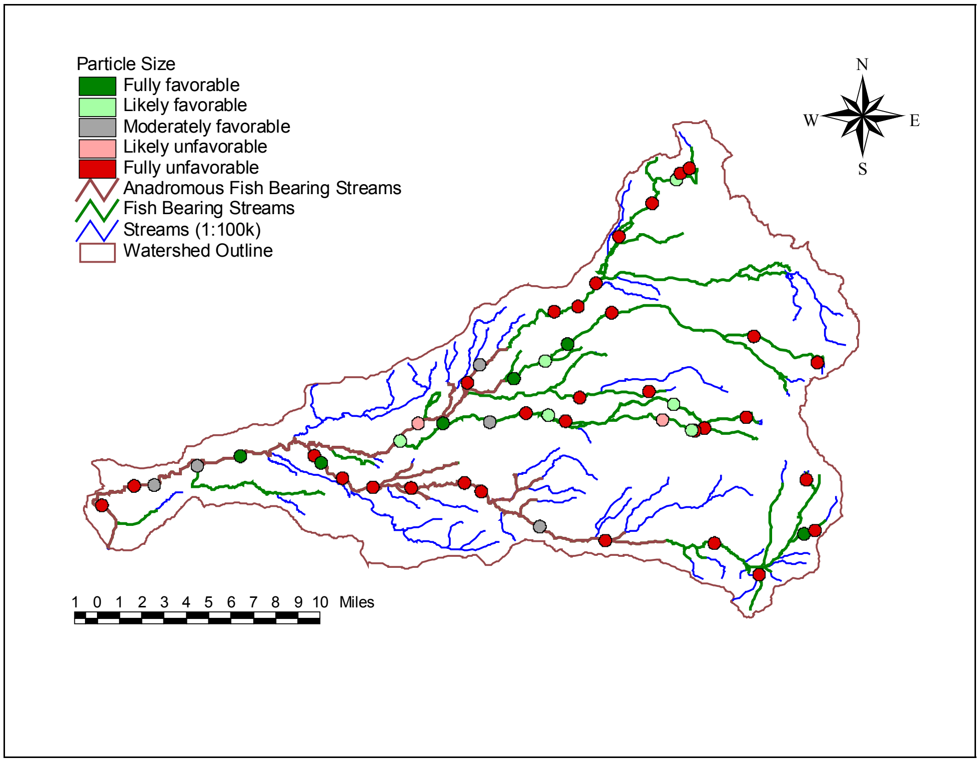

Figure 8. Map depicting EMDS truth values for particle size at sample sites within Battle Creek watershed.

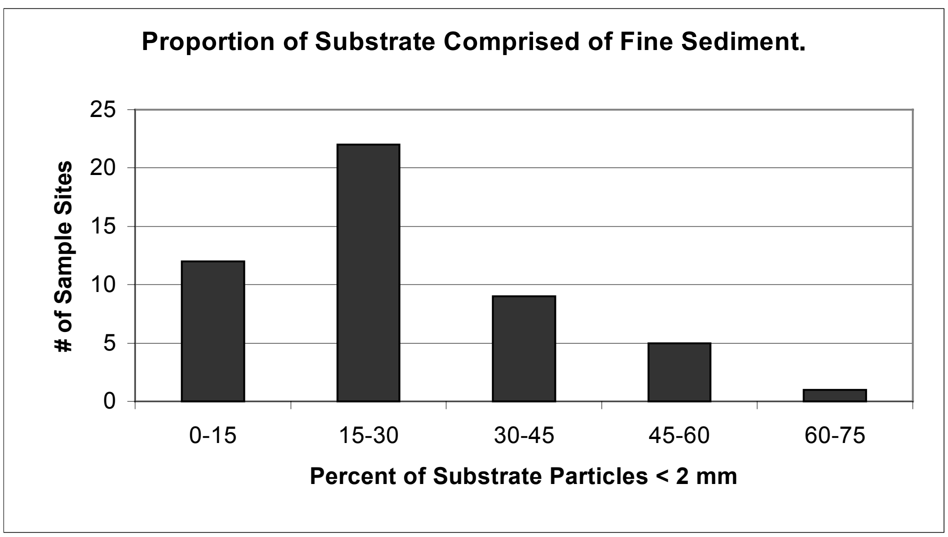

Figure 9. Histogram showing proportion of substrate comprised of fine sediment at 49 sample sites based on pebble counts.

Pool Frequency – Scour pools were characterized at 50 sample sites in the watershed. Additionally, non-scour formed pools (e.g., wood- or bedrock-controlled pools) were characterized at 38 of 50 sample sites. Scour pools made up 76 percent of the total pools at the 38 sites where scour and non-scour pools were both assessed.

All pools were further characterized as occurring in anadromous or non-anadromous habitats. Of the 191 pools observed; sixty three (33%) were located in the 17 sample sites occurring in anadromous habitats, and 128 pools (67%) occurred in the 33 non-anadromous sample sites. Pools occurred at about the same rate for anadromous (3.7 pools/site) and non-anadromous (3.9 pools/site) sites.

Pool frequency (based on scour pools only) was described at 49 sample sites as the number of scour pools per 100 meters of stream. Among all sites within the Battle Creek watershed, the mean pool frequency was 1.7 scour pools per 100 meters of stream while pool frequency at individual sites ranged from 0 to 6.9 scour pools per 100 meters of stream.

Pool frequency decreased significantly with increasing bankfull width (F-test; $p = 0.02$; Figure 10) although this relationship is notable for its weakness (small coefficient of determination, $r^2 = 0.18$; and small regression coefficient, b=-0.06) and for the fact that pool frequency was not lognormally distributed, as was expected.[11]

Statistically significant differences in pool frequency between subbasins was not observed. Residual differences between observed pool frequencies and those predicted by the regression equation of pool frequency on bankfull width were examined. Chi-square analysis of these residuals indicated that positive and negative residuals within each of three geographical areas (North Fork Battle Creek, South Fork Battle Creek, Mainstem Battle Creek) occurred in proportions predicted by the regression equation.

Residual Pool Depth – The mean pool depth in habitat accessible[12] to anadromous salmonids was 0.92 meters, and the maximum observed pool depth was 2.46 meters. At sites accessible to anadromous salmonids, 60 percent of the pools were considered fully unfavorable (depths < 1.0 meter) for adult spring Chinook salmon holding (Table 7). We found 25 pools fully favorable for adult spring Chinook holding within the 5,168 meters of habitat accessible to anadromous salmonids that we surveyed. If this is extrapolated to the entire 76,411 meters accessible to anadromous salmonids (Ward and Kier 1999), then it is possible that as many as 368 pools deep enough to accommodate adult spring Chinook holding existed within the anadromous portion of the Battle Creek watershed. However, only about 150 of these pools were likely located in the reaches otherwise considered suitable for adult spring Chinook holding in terms of water temperature and access.[13]

[11] Data used in this regression were not logarithmically transformed (as in Bilby and Ward 1991) because the observed heteroscedasticity in the data did not justify using this transformation. According to Zar (1984), the use of the logarithmic transformation is not valid in cases such as this when the variance of Y at any X does not increase in proportion to the value of Y.

[12] These results define "accessible habitat" as that habitat that would be accessible to anadromous salmonids upon completion of the Battle Creek Salmon and Steelhead Restoration Project (USBR 2003).

[13] In this instance we consider "suitable" those reaches Ward and Kier 1999 classified as either A, B, or C grade for spring Chinook. See Ward and Kier (1999) for details regarding their classification system.

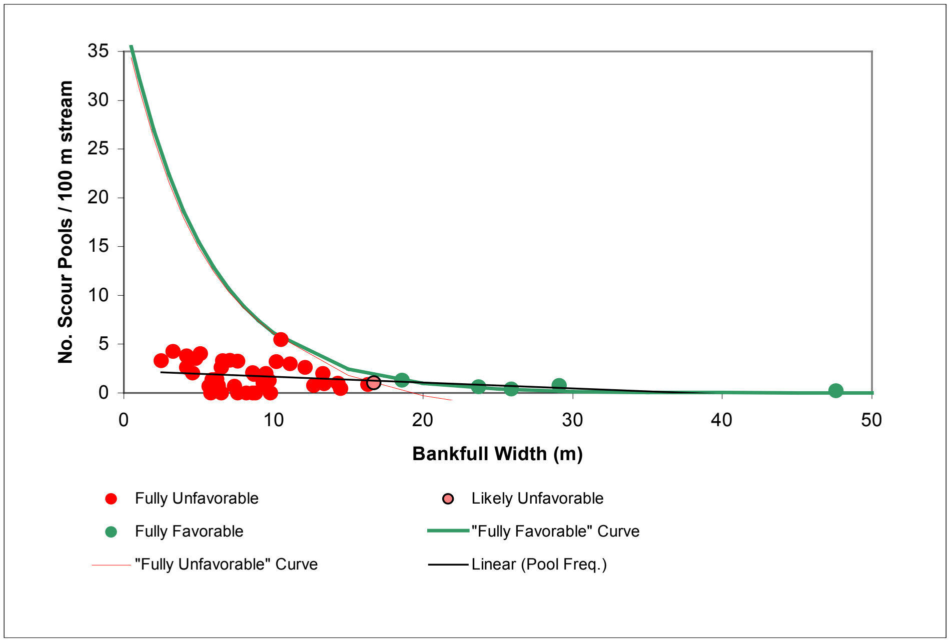

Figure 10. Pool frequency and EMDS interpretive curves as a function of bankfull width at 49 sample sites.

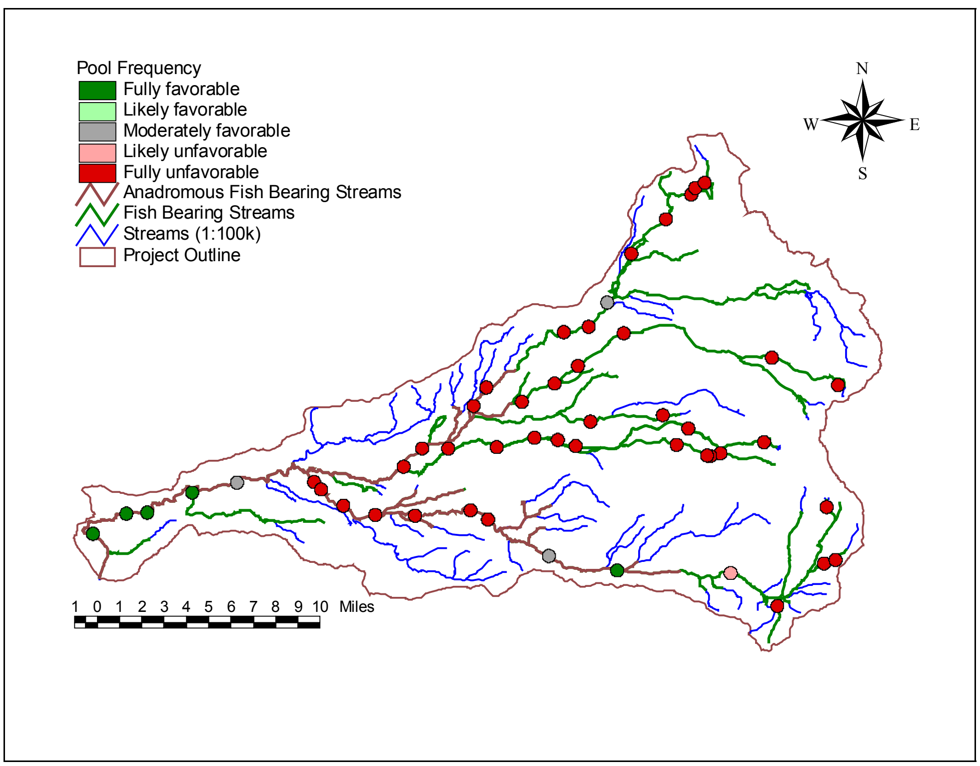

Figure 11. Map depicting EMDS truth values for pool frequency at sample sites within Battle Creek watershed.

The mean residual pool depth at sites not accessible to anadromous salmonids was 0.4 meters, and the maximum depth observed was 2.3 meters. At sites not accessible to anadromous salmonids, 40 percent of the pools were considered fully unfavorable (depth < 0.3 meters) for adult trout production (Table 7).

Table 7. Number and percent of sampled pools by residual pool depth category and by habitat accessible to anadromous salmonids.

Residual pool depth (meters)	< 0.3	0.3 – 1.0	1.0 – 1.5	1.5 – 2.0.	> 2.0
Anadromous habitat	4 (6 %)	34 (54 %)	17 (27 %)	7 (11 %)	1 (2 %)
Non-anadromous habitat	51 (40 %)	75 (59 %)	1 (1 %)	0 (0.0%)	1 (1 %)
Total	55 (29 %)	109 (57 %)	18 (9 %)	7 (4 %)	2 (1 %)

Large Woody Debris – Large woody debris frequency was quantified at 48 sample sites. Large woody debris frequency ranged from 0 to 458 pieces per 1,000 meter of stream and averaged 97 pieces per 1,000 meter.

EMDS analysis indicates, with reasonable or high certainty, that wood conditions at 25 of 48 sites were fully or likely favorable for salmonid production while wood conditions at 7 sites were fully or likely unfavorable (Figure 12). Large woody debris conditions at the remaining sites were moderately favorable. However, an odd polynomial shape to the EMDS curve depicting unfavorable levels of wood seems to drive the classification of these sites as "unfavorable" for large woody debris (Figure 13). This odd relationship in the EMDS model, where the "unfavorable curve" is expressed as a function of the standard error associated with a relationship between wood and bankfull width described by Bilby and Ward (1991), casts doubt on the interpretation of these sites as "unfavorable." Sites with "unfavorable" levels of wood were clustered in the north central and west central portions of the watershed but no clear geographical pattern existed in the distribution of sites with favorable wood frequencies (Figure 12).

Channel Geomorphology – Stream channel geomorphology was characterized using Rosgen's Level I and II stream classification systems (Rosgen 1996) at 48 sample sites. The majority of sample sites were located in B and F stream channel types (Table 8).

During the course of using the portion of the AREMP EMDS model intended to evaluate stream channel geomorphology based on Rosgen classification, we found significant differences between this model and the Rosgen (1996) classification system. Therefore, we did not use this model to evaluate stream channel geomorphology (see the Discussion Section for more regarding our reservations with this portion of the EMDS model).

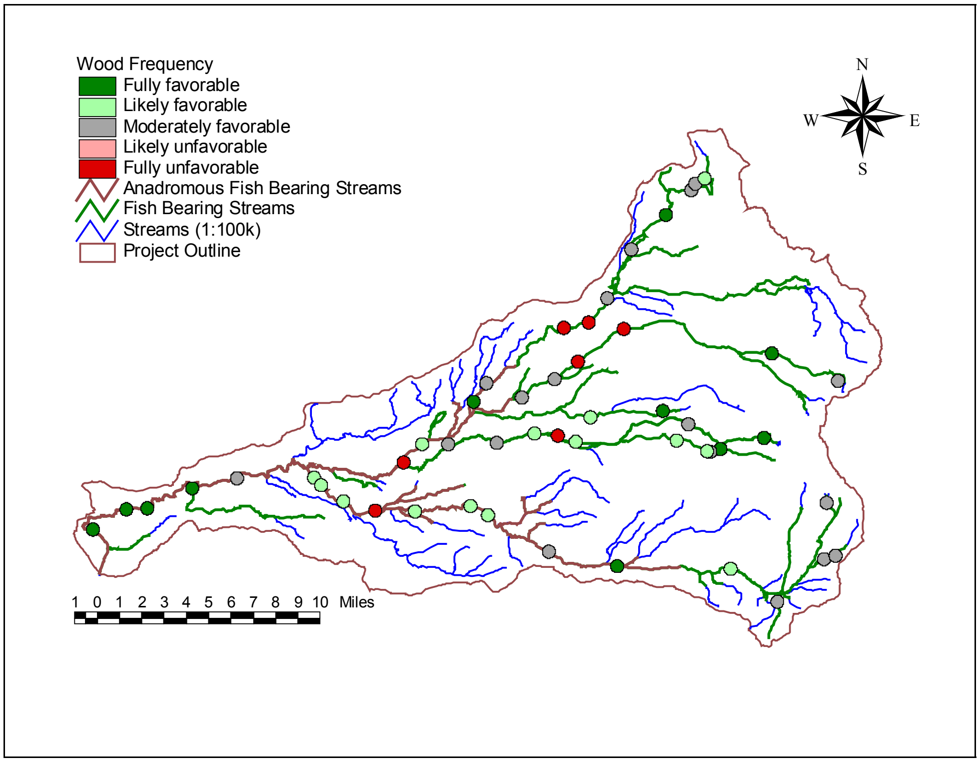

Figure 12. Map depicting EMDS truth values for large woody debris frequency at sample sites within Battle Creek watershed.

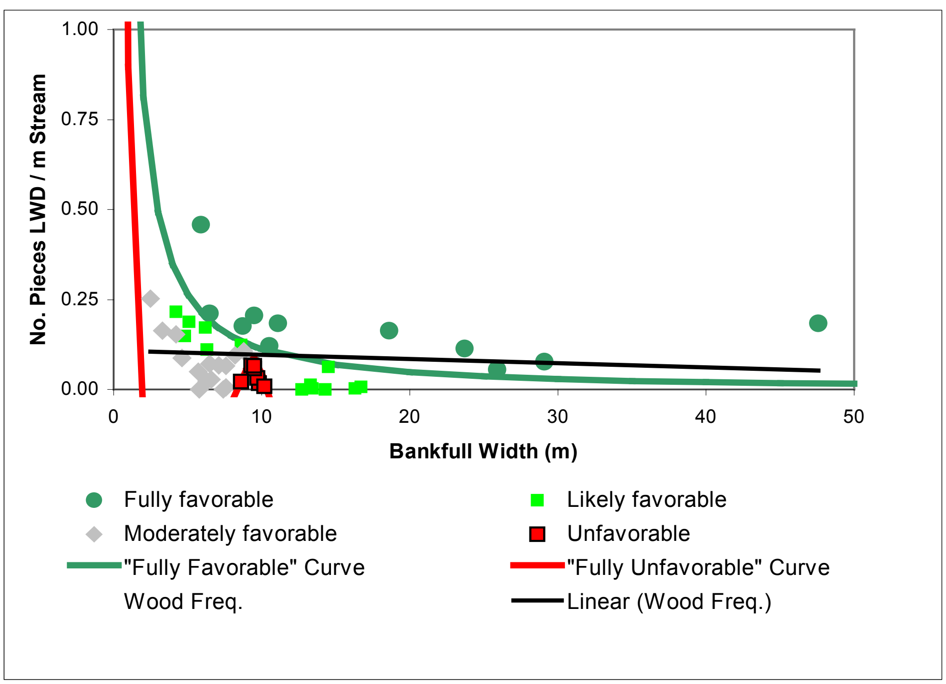

Figure 13. Plot of large woody debris frequency versus bankfull width, color coded by EMDS category, over EMDS evaluation curves which vary as a function of bankfull width. EMDS curves were derived from Bilby and Ward's (1991) data from second growth forests.

Significant stream avulsions and/or overflow channels were noted during field surveys at 12 of 49 sites. At these sites, multiple bankfull channels were separated by land higher than the bankfull elevation in at least one or more survey transects. Most of the disturbance at these sites appeared to be the result of recent flooding, probably the result of a large flood in January 1997. The two lowermost sites (sites #032 and #046) and a mid-elevation site located in a meadow (site #029), had multiple channels typical of low-gradient Rosgen D-type reaches and showed no apparent flood effects. Most sites with multiple channels were located at elevations above the dominant rain-on-snow zone (Figure 14) and also showed signs of significant bank erosion. Three mid-elevation sites with multiple channels, particularly site #057 on North Fork Battle Creek, did not show significant erosive effects of flooding (e.g., no significant bank erosion) but did show signs of bedload aggradation that forced the stream to carve multiple channels at higher flows.

Evidence of bank erosion was not surveyed as part of regular AREMP surveying. However, a survey of streams at conveniently accessible sites at mid to high elevations in North Fork Battle Creek drainage was conducted in 2003 to confirm trends apparent in the distribution of sites showing channel instability in the form of multiple bankfull channels. Of the 12 sites examined, 4 sites showed signs of flood-related bank erosion (Figure 14). Sites with significant flood-related bank erosion were located in Manzanita Creek near the USFS road "FS32N17" and the SPI road "F-Line," Bailey Creek at the SPI road "S-Line," and in a tributary to South Fork Digger Creek (but not in South Fork Digger Creek) upstream of the SPI road "A-Line." These sites were located at elevations ranging from about 4,200 to 5,200 feet. Spot-checked sites on these streams downstream of this elevation band did not exhibit significant bank erosion. Even within this elevation band, several sites near the SPI road "A-Line" did not exhibit significant bank erosion including sites in South Fork Digger Creek, North Fork Digger Creek, Rock Creek, and Onion Creek. This survey spot-checking for bank erosion was not conducted in South Fork Battle Creek.

Aquatic Macroinvertebrates – Aquatic macroinvertebrate samples were collected at 43 sample sites during the fall of 2001, summer of 2002, and fall of 2002. A separate document produced by Ward and Kvam (2003) specifically reports the data and site specific interpretations of the sampled aquatic macroinvertebrates.

Sediment sensitive taxa richness (SSTR) scores averaged 6 taxa and ranged from 0 to 17 taxa. EMDS analysis indicates, with high certainty, that SSTR scores were fully favorable for salmonid production at 36 sites and were fully unfavorable at 4 sites. Sites with unfavorable or moderately favorable SSTR values were located primarily in the lower South Fork and Mainstem Battle Creek in addition to one site with moderate scores in Bailey Creek (Figure 15). None of the sites with unfavorable or moderately favorable SSTR values were sampled in 2001.

Percent Sediment Tolerant Taxa (PSTT) scores averaged 16 percent and ranged from 0 to 37 percent. EMDS analysis indicates, with reasonable or high certainty, that PSTT scores were favorable for salmonid production at 20 sites and were unfavorable at 16 sites. No obvious geographical pattern exists in the distribution of sites with either favorable or unfavorable PSTT values (Figure 16). None of the sites with unfavorable PSTT values were sampled in 2001 (Figure 16).

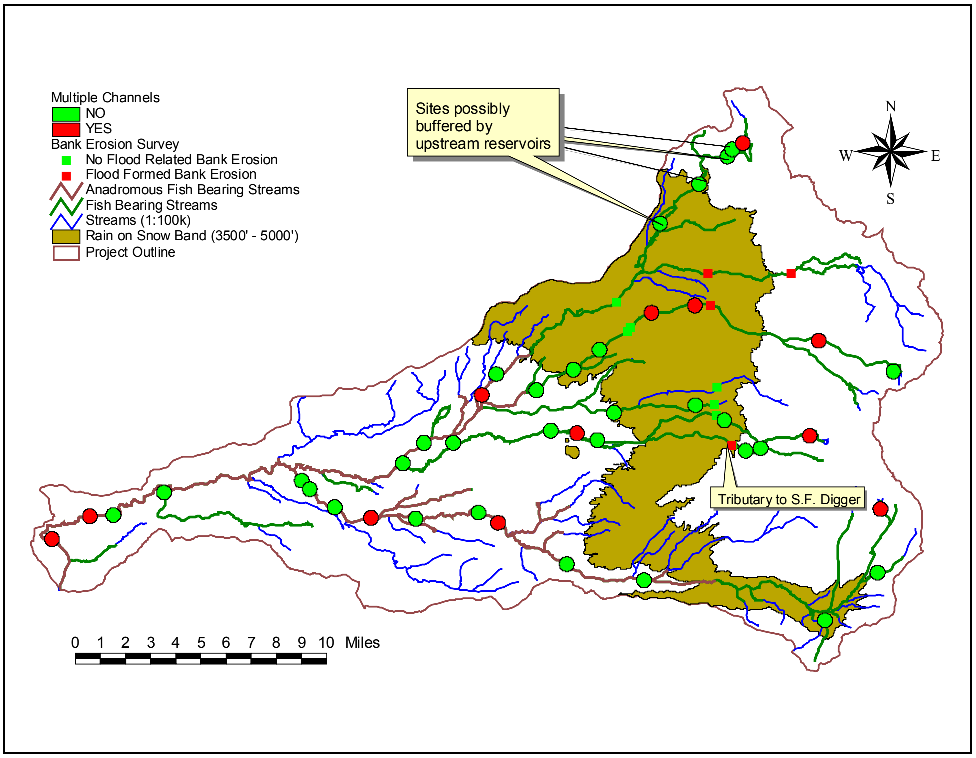

Figure 14. Map depicting sites with multiple channels (red circles) or single channels (green circles) and sites spot-checked for flood-related bank erosion (red squares with bank erosion, green squares without bank erosion) within Battle Creek watershed.

Table 8. Characterization of 48 sample sites by Rosgen stream channel type in Battle Creek watershed in 2001 and 2002.

Rosgen Stream Channel Type	Number of Sample Sites
A	1
B	27
C	7
D	3
F	10

Oregon Department of Environmental Quality Biotic Index (ODEQ-BI) scores averaged 40 and ranged from 28 to 48. EMDS analysis indicates, with reasonable or high certainty, that ODEQ-BI scores were favorable for salmonid production at 31 sites and were not unfavorable at any site. Of 12 sites with moderately favorable ODEQ-BI scores, 9 were in South Fork Battle Creek (Figure 17). No obvious temporal trends in ODEQ-BI scores were apparent based on sampling season (Figure 17).

Benthic Index of Biotic Integrity (B-IBI) scores averaged 38 and ranged from 24 to 48. EMDS analysis indicates, with reasonable or high certainty, that B-IBI scores were favorable for salmonid production at 20 sites and were unfavorable at 6 sites. Sites with favorable B-IBI scores were notably absent from most of South Fork Battle Creek (Figure 18). Three sites with unfavorable B-IBI scores were located in South Fork Battle Creek while the other three were scattered in North Fork Battle Creek including one high elevation site in the wilderness of Lassen Volcanic National Park. No obvious temporal trends in ODEQ-BI scores were apparent based on sampling season (Figure 18).

Sediment Source Factors

Road Density – The road density in Battle Creek watershed is approximately 3.7 mi/mi^2. The average road density at 51 sample sites was 3.5 (± 1.3 SEM; range 0 to 6.3) mi/mi^2 of site-specific watershed area (Figure 19). Sites with the highest road densities were generally located in the middle portion of the Battle Creek watershed. More specifically, sites with high road densities were located in upper Rock Creek, Summit Creek, lower Bailey Creek, lower Digger Creek, and the middle reaches of North Fork Battle Creek. Sites with the lowest road densities were generally near the Lassen National Park in upper Bailey Creek, upper South Fork Digger Creek, and upper North Fork Battle Creek.

Near-Stream Road Density – The near-stream road density in the Battle Creek watershed is approximately 3.4 mi/mi^2. The average near-stream road density at 51 sites was 4.3 (± 1.6 SEM; range 0 to 7.9) mi/mi^2 (Figure 20). Sites with the highest near-stream road densities were generally located in the middle portion of the Battle Creek watershed. More specifically, sites with high road densities were located in Rock Creek, Summit Creek, mainstem Digger Creek, and the upper reaches of North Fork Battle Creek. Near-stream road densities at sites in the mainstem, lower North Fork, and most of South Fork Battle Creek, and lower Bailey Creek, reaches which generally correspond to anadromous salmonid habitat, were lower than site-specific watershed road densities. This illustrates how topographic features have buffered these stream reaches from more direct land uses as asserted by previous authors (e.g., Ward and Kier 1999).

Road-Stream Crossing Frequency – The road-stream crossing frequency within the whole Battle Creek watershed is approximately 1.1 road-stream crossings per mile of stream. The average frequency of road-stream crossings at 51 sample sites was 1.3 (± 0.5 SEM; range 0 to 2.9) road crossing per mile of stream (Figure 21). The highest frequency of road-stream crossings generally occurred at the same sites which had high near-stream road densities.

Forest Cover – Approximately 10 percent of the Battle Creek watershed is vegetated with trees greater than or equal to 20 inches in diameter. On average, 20 percent (± 11 SEM; range 6 to 56) of each of 51 site-specific watersheds were vegetated with trees greater than or equal to 20 inches in diameter.

Near-Stream Meadow Area – Approximately 25 percent of all near-stream areas within the Battle Creek watershed are vegetated with vegetation smaller than 5 inches in diameter. On average, 18 percent (± 9 SEM; range 0 to 50) of each of 51 site-specific near-stream areas were vegetated with vegetation smaller than 5 inches in diameter.

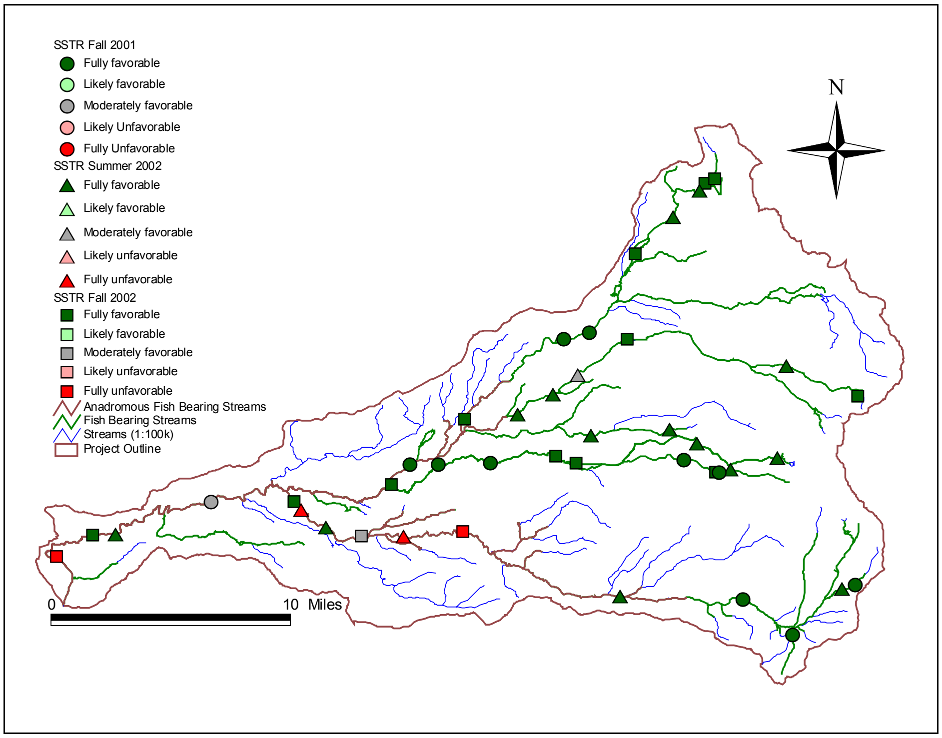

Figure 15. Map depicting EMDS truth values for sediment sensitive taxa richness (SSTR) at sample sites within Battle Creek watershed.

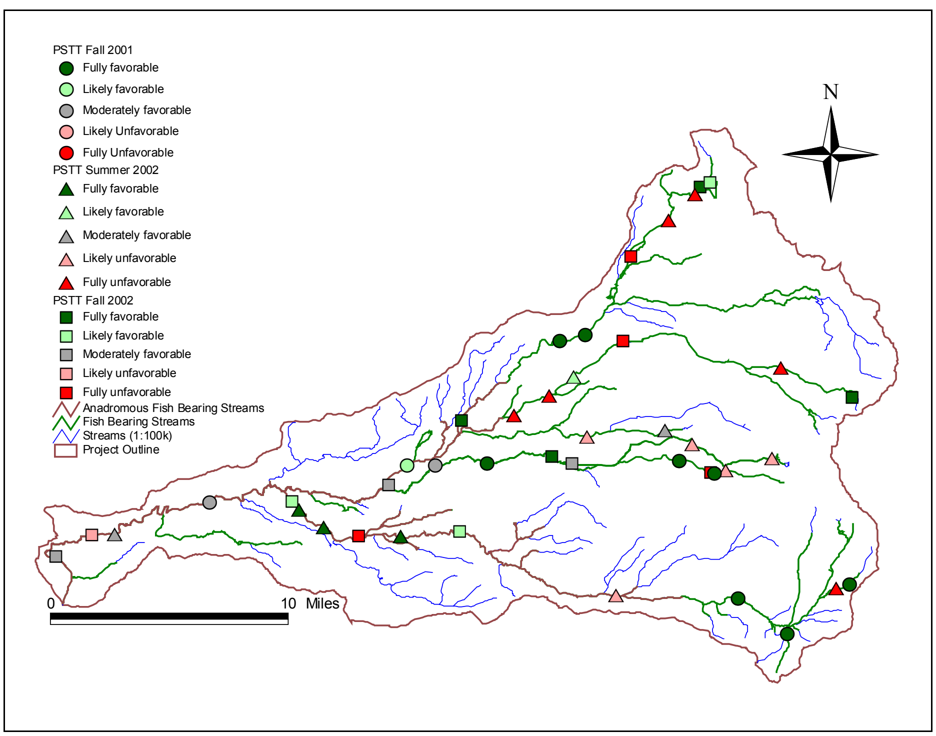

Figure 16. Map depicting EMDS truth values for percent sediment tolerant taxa (PSTT) at sample sites within Battle Creek watershed.

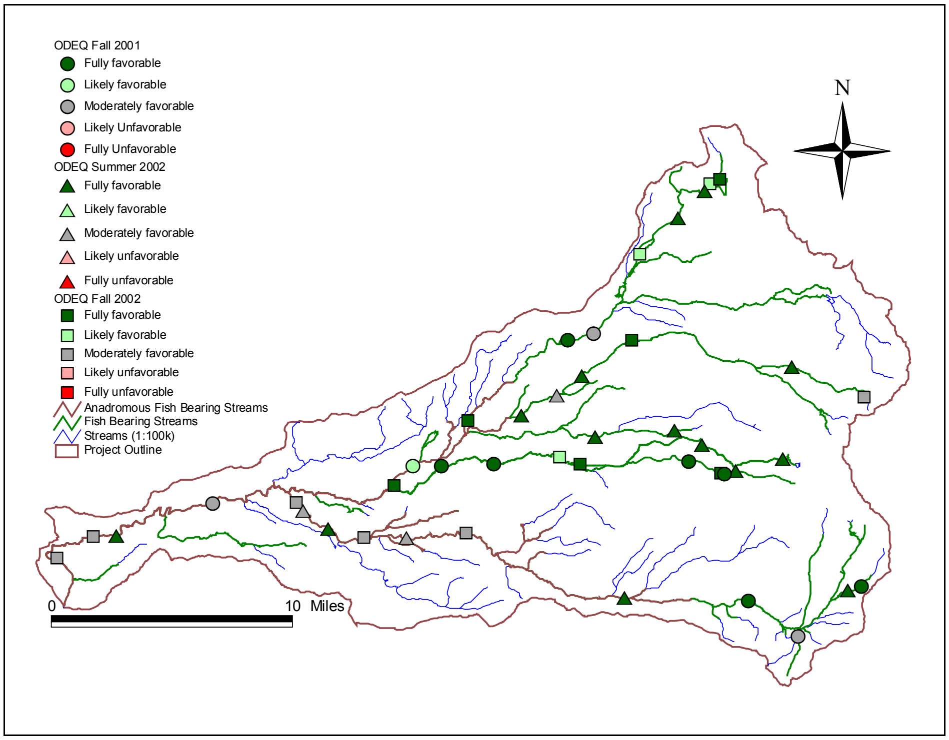

Figure 17. Map depicting EMDS truth values for Oregon Department of Environmental Quality Biotic Index (ODEQ-BI) at sample sites within Battle Creek watershed.

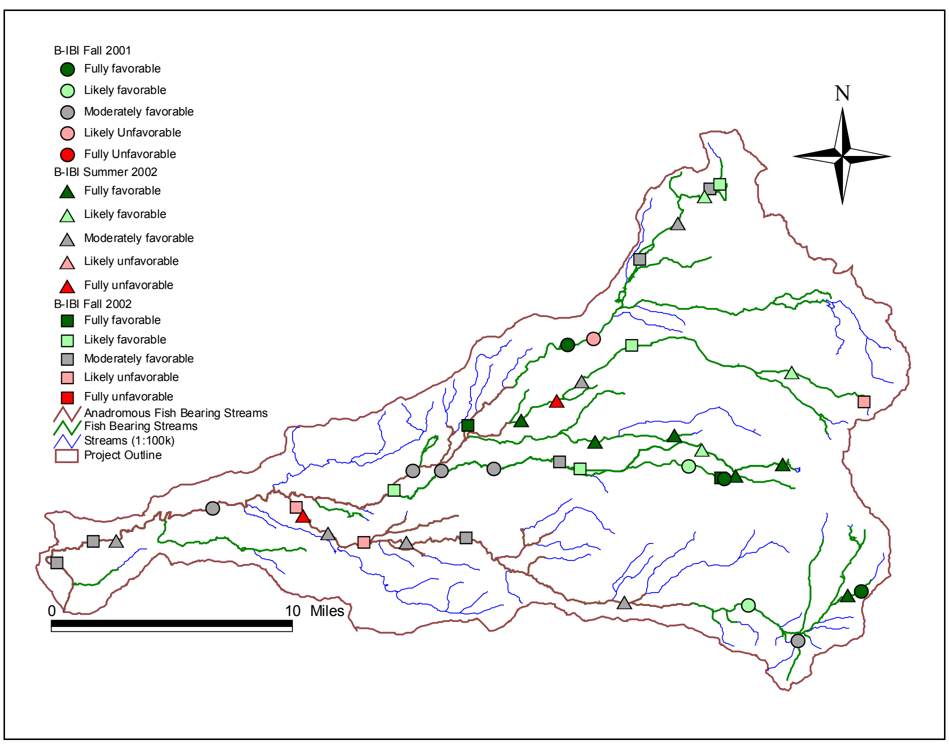

Figure 18. Map depicting EMDS truth values for Benthic Index of Biotic Integrity (B-IBI) at sample sites within Battle Creek watershed.

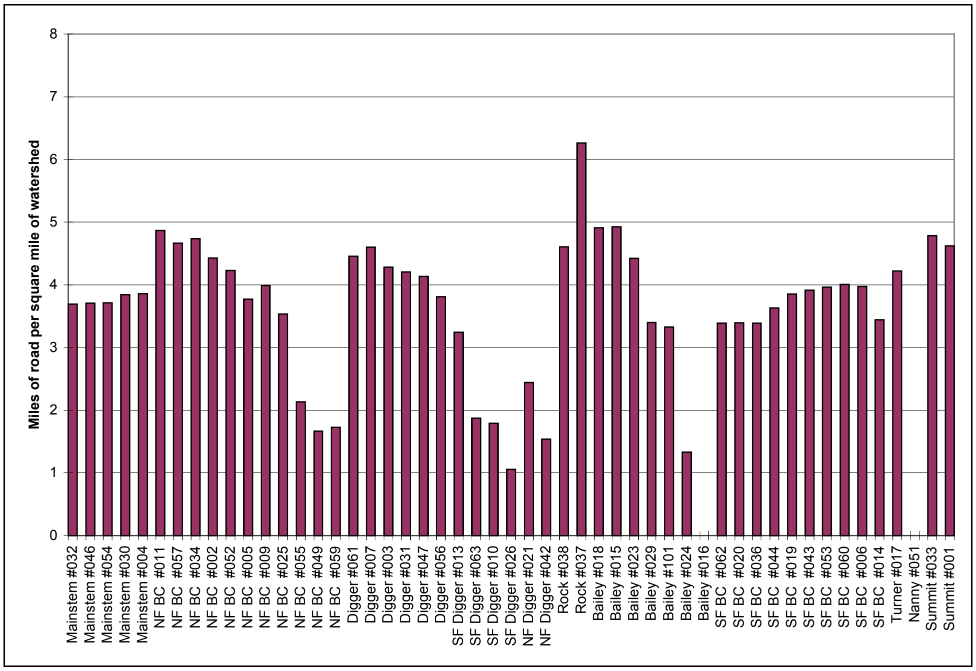

Figure 19. Histogram of road densities within 51 site-specific watersheds within the Battle Creek watershed.

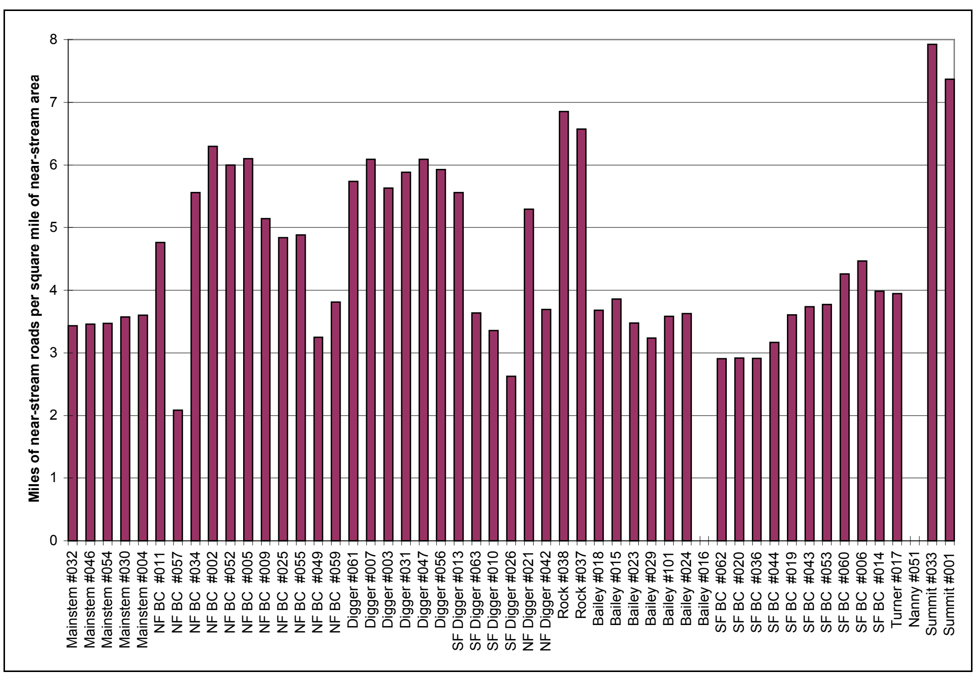

Figure 20. Histogram of near-stream road densities within 51 site-specific watersheds within the Battle Creek watershed.

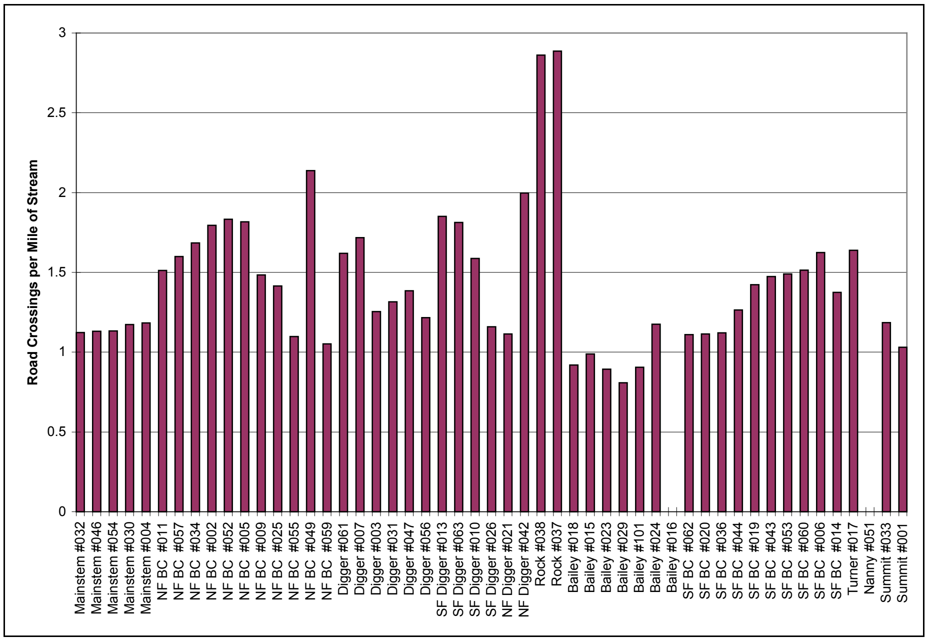

Figure 21. Histogram of road-stream crossing frequency within 51 site-specific watersheds within the Battle Creek watershed.

Rain-on-Snow Area – Approximately 27 percent of the Battle Creek watershed is within the “dominant rain-on-snow zone” from 3,500 to 5,000 feet above sea level. On average, 23 percent (± 18 SEM; range 0 to 84%) of the area within 51 site-specific watersheds lies within the dominant rain-on-snow zone.

Rhyolitic Soils – Approximately 11 percent of the Battle Creek watershed is dominated by rhyolitic soils. Rhyolitic soils are generally located in upper Manzanita and North Fork Bailey Creeks and in the vicinity of Blue Ridge which is drained by Soap, Panther, and South Fork Digger Creeks (Figure 22). These soils occurred within 36 of 51 site-specific watersheds. Rhyolitic soils covered an average of 11 percent (± 11 SEM; range 0 to 34%) of the area within 51 site-specific watersheds.

Table 9. Correlation matrix between three stream condition measurements and ten sediment source factors. Correlations performed using Spearman's rank correlation methods including correction for tied ranks (Zar 1984) and for multiple testing in p-values and 95% confidence intervals (C.I. (r_s); Van Sickle 2003). See Table 1 for the tested hypotheses.

		Road Density	Near-Stream Road Density	Road-Stream Crossing Frequency	Forest Cover	Near-Stream Meadow Area	Rain-on-Snow Area	Rhyolite Soils	Elevation	Watershed Area	Stream Gradient
Fine Sediment	H_0:	Not positively correlated.	Not positively correlated.	Not positively correlated.	Not negatively correlated.	Not positively correlated.	Not positively correlated.	Not positively correlated.	Not correlated.	Not correlated.	Not correlated.
	n	36	36	36	36	36	36	36	36	36	36
	Coefficient (r_s)	0.016	0.043	0.013	-0.116	0.173	0.231	0.300	-0.060	0.182	-0.497
	95% C.I. (r_s)	-0.42 < r < 0.48	-0.40 < r < 0.50	-0.42 < r < 0.48	-0.52 < r < 0.37	-0.28 < r < 0.590	-0.22 < r < 0.63	-0.15 < r < 0.67	-0.51 < r < 0.42	-0.31 < r < 0.60	-0.78 < r < -0.04
	Conclusion	Fail to reject H_0, p>0.05, r > 0.	Fail to reject H_0, p>0.05, r > 0.	Fail to reject H_0, p>0.05, r > 0.	Fail to reject H_0, p>0.05, r < 0.	Fail to reject H_0, p>0.05, r > 0.	Fail to reject H_0, p>0.05, r > 0.	Fail to reject H_0, p>0.05, r > 0.	Fail to reject H_0, p>0.05	Fail to reject H_0, p>0.05	Reject H_0, p < 0.05. Fine sediment is negatively correlated with stream gradient.
Particle Size	H_0:	Not negatively correlated.	Not negatively correlated.	Not negatively correlated.	Not positively correlated.	Not negatively correlated.	Not negatively correlated.	Not negatively correlated.	Not correlated.	Not correlated.	Not correlated.
	n	50	50	50	50	50	50	50	50	50	48
	Coefficient (r_s)	0.088	-0.087	0.104	0.025	0.054	0.169	0.318	-0.284	0.326	0.238
	95% C.I. (r_s)	-0.29 < r < 0.47	-0.44 < r < 0.32	-0.28 < r < 0.48	-0.35 < r < 0.42	-0.32 < r < 0.44	-0.21 < r < 0.53	-0.06 < r < 0.64	-0.61 < r < 0.13	-0.08 < r < 0.64	-0.19 < r < 0.59
	Conclusion	Fail to reject H_0, p>0.05	Fail to reject H_0, p>0.05	Fail to reject H_0, p>0.05	Fail to reject H_0, p>0.05	Fail to reject H_0, p>0.05	Fail to reject H_0, p>0.05	Fail to reject H_0, p>0.05	Fail to reject H_0, p>0.05	Fail to reject H_0, p>0.05	Fail to reject H_0, p>0.05
Residual Pool Depth	H_0:	Not negatively correlated.	Not negatively correlated.	Not negatively correlated.	Not positively correlated.	Not negatively correlated.	Not negatively correlated.	Not negatively correlated.	Not correlated.	Not correlated.	Not correlated.
	n	41	41	41	41	41	41	41	41	41	41
	Coefficient (r_s)	0.401	-0.164	0.041	-0.422	0.463	0.458	0.389	-0.663	0.700	-0.592
	95% C.I. (r_s)	-0.01 < r < 0.71	-0.53 < r < 0.30	-0.37 < r < 0.47	-0.71 < r < 0.02	0.07 < r < 0.75	0.07 < r < 0.75	-0.02 < r < 0.71	-0.85 < r < -0.32	0.38 < r < 0.87	-0.82 < r < -0.21
	Conclusion	Fail to reject H_0, p < 0.05 but 95% confidence interval includes r < 0.	Fail to reject H_0, p `> 0.05, r < 0.	Fail to reject H_0, p > 0.05.	Fail to reject H_0, p < 0.05 but 95% confidence interval includes r > 0.	Fail to reject H_0, p < 0.05 but r > 0. Residual pool depth is positively correlated to near-stream meadow area.	Fail to reject H_0, p < 0.05. Residual pool depth is positively correlated to rain-on-snow area.	Fail to reject H_0, p > 0.05.	Reject H_0, p < 0.05. Residual pool depth is negatively correlated to elevation.	Reject H_0, p < 0.05. Residual pool depth is positively correlated to watershed area.	Reject H_0, p < 0.05. Residual pool depth is negatively correlated to stream gradient.

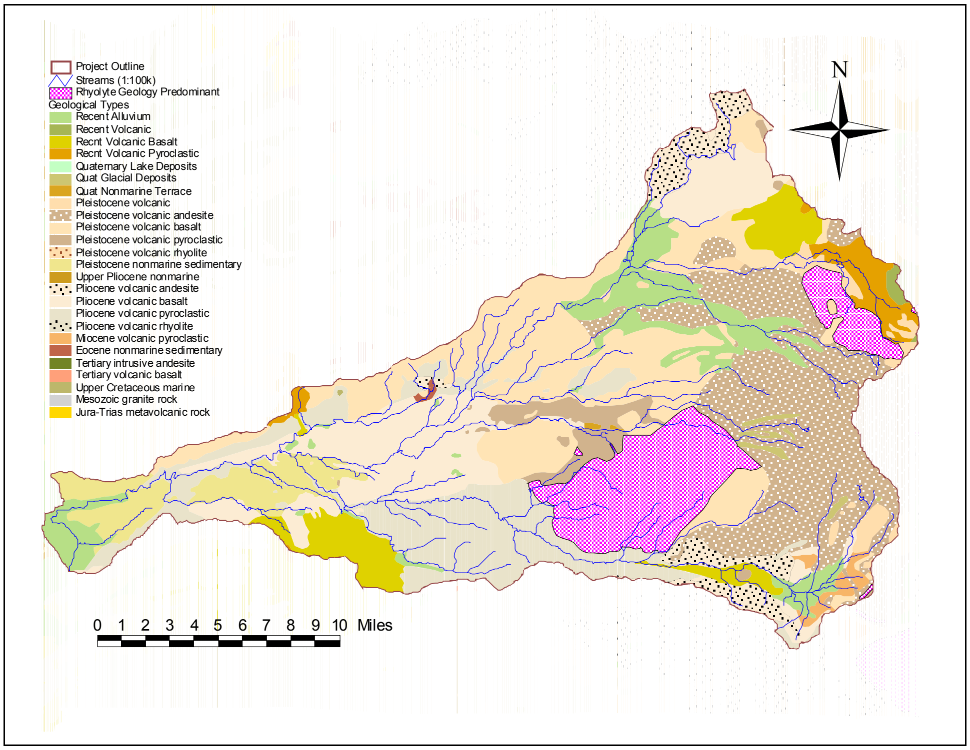

Figure 22. Map depicting geologic types and location of rhyolitic soils (purple) within the Battle Creek watershed.

Response of Stream Conditions to Sediment Source Factors

Fine Sediment

<u>Hypothesis Testing</u> – Fine sediment was significantly, negatively correlated to stream gradient (Table 9; Table 1). No other statistically significant linear correlations were observed between fine sediment and any of the other hypothesized sediment source factors (Table 9). Fine sediment was not significantly correlated to elevation and watershed area. It was not significantly, positively correlated to road density, near-stream road density, road-stream crossing frequency, rain-on-snow area, rhyolite soil and near-stream meadow area. Finally, fine sediment was not significantly, negatively correlated to forest cover. In other words, variability in none of the sediment source factors, with the exception of stream gradient, was statistically related to observed fine sediment in the Battle Creek watershed.

<u>Multivariate Data Exploration</u> – No strong first-order relationships between percent fine sediment and sediment source factors was apparent from examination of scatterplots (Figure 23, focus on top row) although a significant but weak negative correlation (Table 9) and a possible threshold relationship was observed between percent fine sediment and stream gradient (Figure 23, 3rd plot in top row).

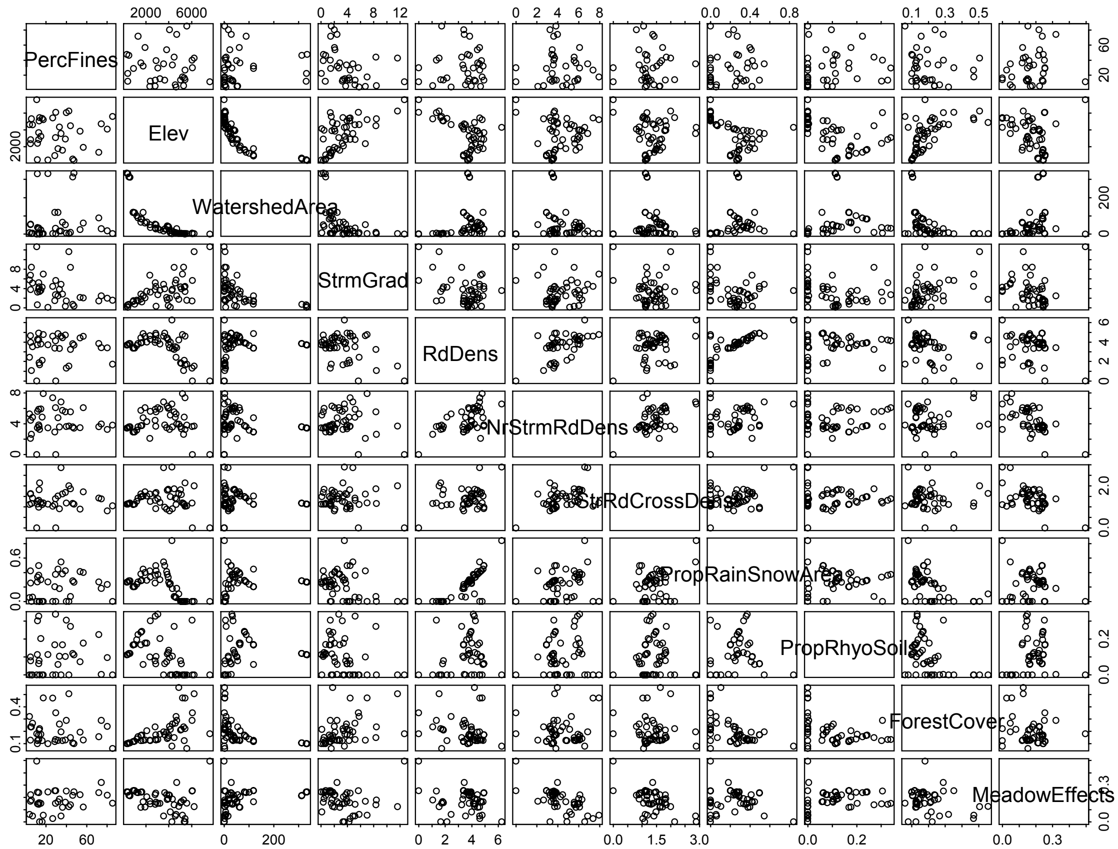

Figure 23. Pairwise scatterplots of percent fine sediment and all potential covariates. The labels along the diagonal define the variable shown on the respective horizontal axes (column) or vertical axes (row).

The lack of linear structure with respect to the responses of interest was also observed in intermediate Pearson product-moment correlations; the maximum product-moment correlation of –0.41 for stream gradient is a weak correlation at best. However, as indicated in Figure 23, the relationship between fine sediment and stream gradient can best be described by non-linear models.

Initial GAM fitting of all data showed that only stream gradient appears to have any detectable relationship to percent fine sediment, with a possibly linearly decreasing structure until a threshold value of around 3 or 4 percent, as predicted by Montgomery and Buffington (1993), where it becomes a constant effect. This effect suggested breaking the data into two parts – those sites with gradients less than 3.5 percent and those with gradients greater than 3.5 percent[14]. Therefore, backwards and forwards stepwise searches were used to fit separate GAMs to the sites with stream gradients less than 3.5 and greater than 3.5 percent.

Stream Gradient less than 3.5 Percent – The six GAMs with the best Aikike Information Criteria (AIC) values all retain stream gradient and drop most other possible sediment source factors and interactions between these factors because these other factors or interactions play no

[14] The value of 3.5 percent was based on visual assessment of the data and was not derived from a change-point model to statistically determine the threshold value.

significant role in explaining variability within percent fine sediment (Table 10). The change in AIC with the addition of the proportion of watershed in rhyolitic soils (PropRhyoSoils) was not significant (analysis of deviance; $p = 0.15$). Hence, the best predictive model explaining the variability in percent fine sediment in channels less than 3.5 percent gradient includes the single covariate of stream gradient; percent fine sediment appears to be approximately quadratically related to stream gradient with a peak in percent fine sediment for stream gradients around 1.9 or 2.0 percent (Figure 24).[15]

Table 10. The best six GAMs for percent fine sediment at stream gradients less than 3.5 percent. 'PercFines~predictor' denotes a linear regression model; 'PercFines ~ s(predictor)' denotes a nonparametric smooth or GAM. Lower AIC values denote better fitting models.

MODEL TERMS	AIC
PercFines ~ s(StrmGrad) + PropRhyoSoils	7571.978
PercFines ~ s(StrmGrad)	7611.369
PercFines ~ s(StrmGrad) + Elev	7743.266
PercFines ~ s(StrmGrad) + PropRainSnowArea	7788.295
PercFines ~ s(StrmGrad) + WatershedArea+ PropRhyoSoils	7893.939
PercFines ~ s(StrmGrad) + WatershedArea	7939.617

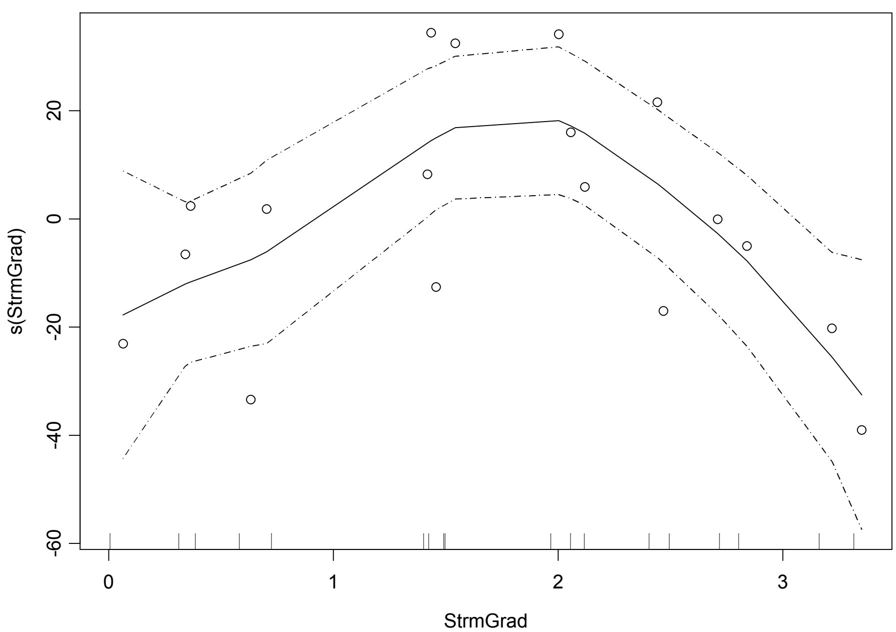

Figure 24. Final GAM model explaining variability within percent fine sediment with the single covariate stream gradient (at stream gradients less than 3.5%). Symbols represent observed data and solid line represents the model fit to that data. Dashed lines are point-wise 95 percent confidence bands for each x value but these confidence bands were not adjusted for multiple testing..

[15] This model was tested and not found to violate any key modeling assumptions: no apparent structure in plots of residuals was found suggesting that the assumption of constant residual variance is supported; likewise, the assumption of normal distribution was supported.

Stream Gradient > 3.5 Percent – All of the retained terms in the six best GAMs were linear, so the stepwise model selection was re-run using linear models (Table 11). Although watershed area and road crossing density were included in the model giving the best fit to percent fine sediment data, the inclusion of these terms were not significant (likelihood ratio test; $p = 0.16$ watershed area, $p = 0.14$ road crossing density).

Table 11. Best six GAMs for percent fine sediment at stream gradients greater than 3.5 percent. 'PercFines~predictor' denotes a linear regression model. Lower AIC values denote better fitting models.

MODEL TERMS	AIC
PercFines ~ 1	3280.387
PercFines ~ WatershedArea	3287.427
PercFines ~ ForestCover	3324.515
PercFines ~ StrRdCrossDens	3423.155
PercFines ~ Elev	3437.603
PercFines ~ StrmGrad	3510.591

The multivariate data exploration of relationships between sediment source factors and fine sediment confirms the conclusions drawn in the formal hypothesis testing reported above and refines our understanding of the relationship between fine sediment and stream gradient in Battle Creek by suggesting that fine sediment is most closely associated with stream gradient at stream gradients less than 3.5 percent and may not be related to sediment source factors in streams greater than 3.5 percent gradient

Particle Size

Hypothesis Testing – No statistically significant linear correlations were observed between particle size and any of the hypothesized sediment source factors (Table 9; Table 1). Particle size was not significantly correlated to elevation, watershed area, or stream gradient. It was not significantly, positively correlated to road density, near-stream road density, road-stream crossing frequency, rain-on-snow area, rhyolite soil and near-stream meadow area. Finally, particle size was not negatively correlated to forest cover. In other words, variability in none of the sediment source factors was statistically related to observed particle size in the Battle Creek watershed.

Multivariate Data Exploration – Potential linear effects between particle size (D_{50}) and watershed area and stream gradient are apparent from visual examination of scatterplots (Figure 25, 2nd and 3rd plots). Plots of near-stream road density and road crossing density suggest a simple shift for sites with values of 0 versus those greater than 0 but this relationship was not significant ($p > 0.10$) possibly because it is based only on two sites with values of 0. An initial GAM fit to D_{50} as a function of all the predictors showed a possible stream gradient threshold near 6 percent. Subsequent GAMs were not fit to subsets of the data based on this apparent threshold because 1) this apparent threshold is not supported by literature (e.g., Montgomery and Buffington 1993) and 2) this apparent threshold was driven by only two steep sites.

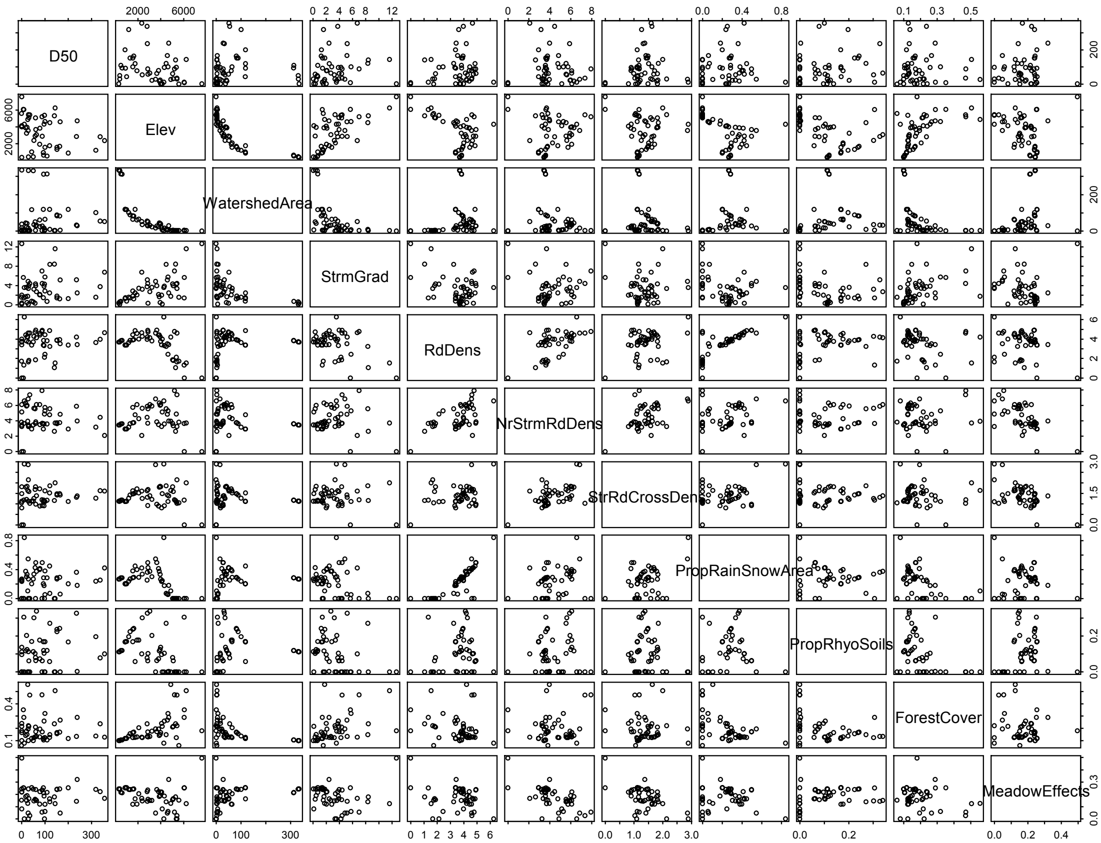

Figure 25. Pairwise scatterplots of median particle size (D_{50}) and all potential covariates. The labels along the diagonal define the variable shown on the respective horizontal axes (column) or vertical axes (row).

The six GAMs with the best AIC values all retain a nonparametric smoothed function of watershed area, stream gradient, road density, near-stream road density, proportion of watershed in rain-on-snow zone, and either road crossing density or a nonparametric smoothed function of road crossing density, or a subset of these sediment source factors (near-stream meadow area is also included in the case of the model in row 6, Table 12). Other possible sediment source factors and/or interactions between these factors are not included because they play no significant role in explaining variability within D_{50}.

Of these six models, it is important to note that models in rows 1, 3, 4, and 5 of Table 12 are all subsets of the model in row 2. A comparison of the “full” model in row 2 of Table 12 with each “reduced” model (that includes dropping each of the terms one at a time) indicates that the contribution of each term to the full model is significant in terms of model development (Table 13). Hence, the model with the best predictive capability for explaining the observed variability in D_{50}, is the full model in row 2 of Table 12 and as depicted in Figure 25.[16]

[16] This model was tested and not found to violate any key modeling assumptions: no apparent structure in plots of residuals was found suggesting that the assumption of constant residual variance is supported; likewise, the assumption of normal distribution was supported.

The strength of this model to predict the effects of these six sediment source factors on D_{50} should not be overestimated for several reasons, including: 1)the model is based on relatively many (six) predictor covariates and relatively few (49) observations of D_{50}, 2) possible spatial correlations among the observed data were not factored into this model, 3) possible collinearity may exists as indicated by the fact that "observed" relationships (e.g., positive relationship between road density and particle size) were of opposite sign from hypothesized relationships. Specifically, the value of coefficients (and error associated with this model could be affected by these limitations. The predictive capability of this model would need to be validated with additional data before this model is used for purposes other than exploration of this observed data set.

The multivariate data exploration of relationships between sediment source factors and particle size does not necessarily conflict with the conclusions drawn in the formal hypothesis testing reported above. For example, model exploration confirmed that road-stream crossings, proportion of watershed in rhyolite soils, forest cover, and near-stream meadow areas play no meaningful role in predicting variability in observed particle size data. While this exploration shows that the best predictive model includes watershed area, stream gradient, road density, near stream road density, and the proportion of the watershed in rain-on-snow areas, statistical limitations with this model, as described above, preclude concluding that statistically significant relationships exist between any of the hypothesized sediment source factors and particle size.

Table 12. The best six GAM models for particle size (D_{50}). ' D50~predictor' denotes a linear regression model; ' D50 ~ 1' denotes a constant model; 'D50~s(predictor)' denotes a nonparametric smooth or GAM term. Lower AIC values denote better fitting models.

Row	Model Terms	AIC
1	D50 ~ s(WatershedArea) + StrmGrad + RdDens + NrStrmRdDens + PropRainSnowArea + StrRdCrossDens	324545.9
2	D50 ~ s(WatershedArea) + StrmGrad + RdDens + NrStrmRdDens + PropRainSnowArea + s(StrRdCrossDens)	328994.5
3	D50 ~ s(WatershedArea) + StrmGrad + RdDens + NrStrmRdDens + s(StrRdCrossDens)	329767.6
4	D50 ~ s(WatershedArea) + StrmGrad + RdDens + NrStrmRdDens + PropRainSnowArea	329847
5	D50 ~ s(WatershedArea) + StrmGrad + NrStrmRdDens + s(StrRdCrossDens) + PropRainSnowArea	331134.9
6	D50 ~ s(WatershedArea) + StrmGrad + RdDens + NrStrmRdDens + StrRdCrossDens + PropRainSnowArea + MeadowEffects	331853.7

Table 13. Likelihood ratio test p-values from comparing the 'full' model (D50 ~ s(WatershedArea) + StrmGrad + RdDens + NrStrmRdDens + s(StrRdCrossDens) + PropRainSnowArea) to each 'reduced' model formed by removing the listed term. Note that all other terms remain in the model.

Dropped Term	P-value		Dropped Term	P-value
s(WatershedArea)	0.0001		NrStrmRdDens	0.0008
StrmGrad	0.0005		s(StrRdCrossDens)	0.007
RdDens	0.023		PropRainSnowArea	0.029

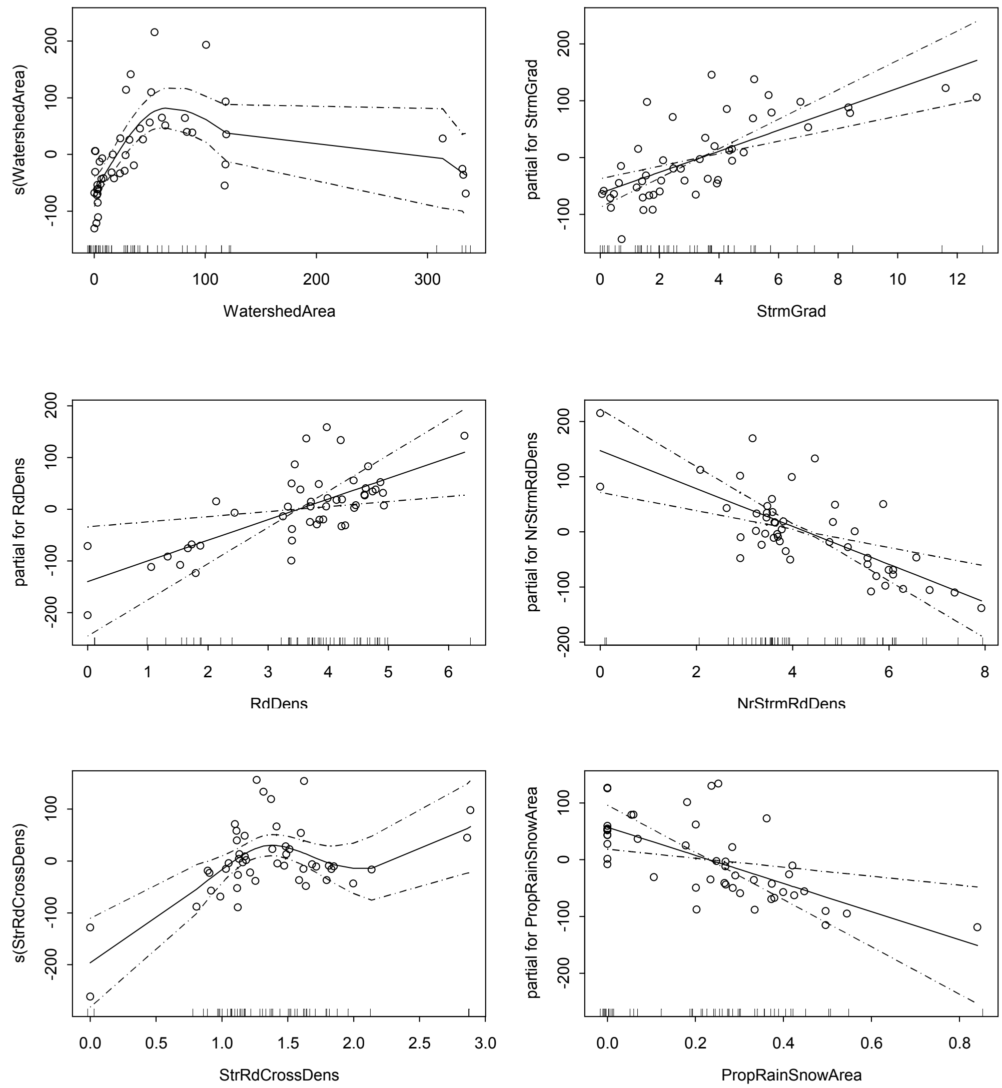

Figure 26. Final GAM model explaining variability within D_{50} with a smoothed function of watershed area, stream gradient, road density, near-stream road density, proportion of watershed in rain-on-snow zone, and a nonparametric smoothed function of road crossing density. Symbols represent observed data and solid line represents the model fit to that data. Dashed lines are point-wise 95 percent confidence bands for each x value but these confidence bands were not adjusted for multiple testing.

Residual Pool Depth

Hypothesis Testing – Residual pool depth was significantly correlated with elevation (negatively), watershed area (positively), stream gradient (negatively), and the proportion of the watershed in rain-on-snow area (negatively; Table 9; Table 1). No statistically significant linear correlations were observed between particle size and any of the other hypothesized sediment source factors (Table 9). Particle size was not significantly, positively correlated to road density, near-stream road density, road-stream crossing frequency, rhyolitic soils, forest cover, and near-stream meadow area.

Multivariate Data Exploration – No strong first-order relationships between residual pool depth and sediment source factors were apparent from examination of scatterplots (Figure 27, focus on top row), although possible relationships were apparent between residual pool depth and elevation and near-stream meadow area. (Figure 27, 1st and 10th plots in top row). An initial stepwise search of GAMs showed no signs of any nonlinear associations among the dependent and independent variables. Subsequent stepwise selection of only GAMs with linear terms, allowing for two way interactions.

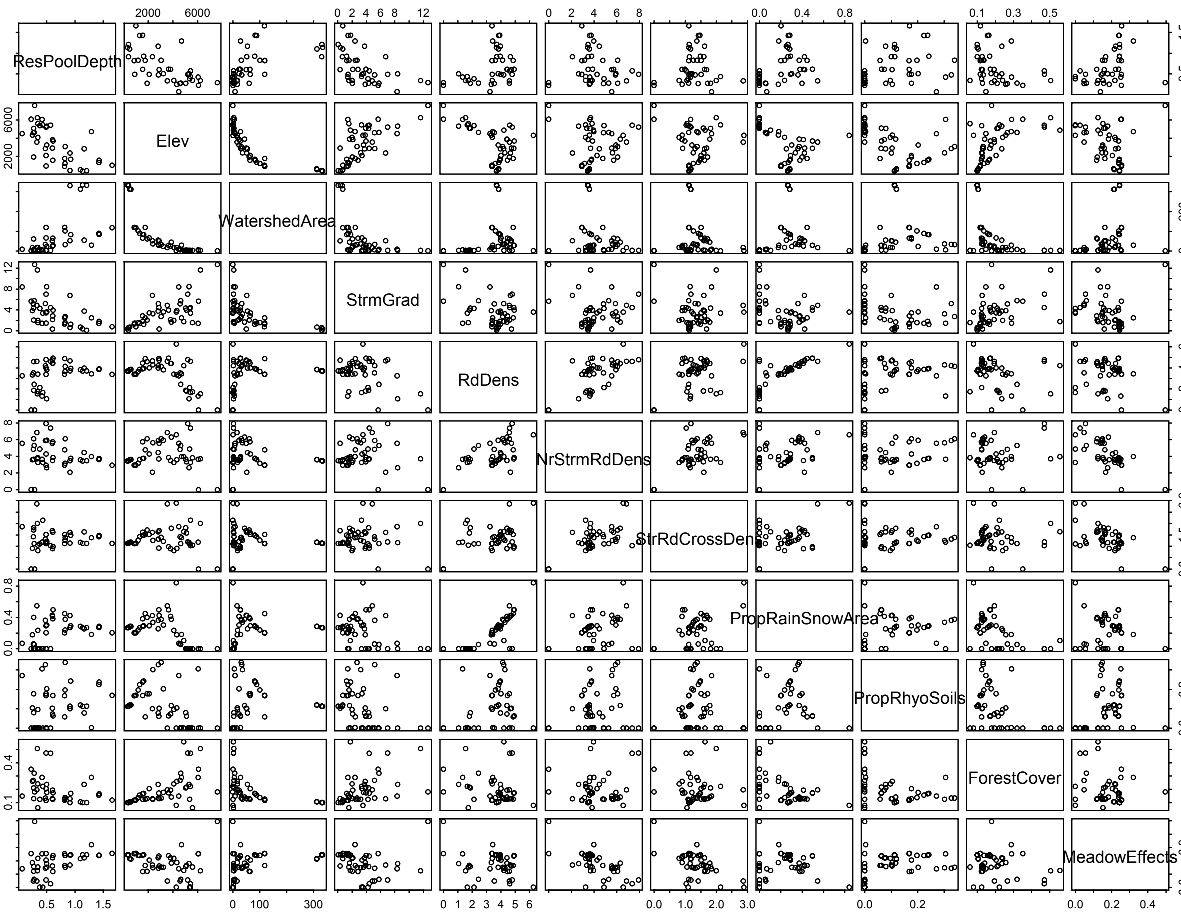

Figure 27. Pairwise scatterplots of residual pool depth and all potential covariates. The labels along the diagonal define the variable shown on the respective horizontal axes (column) or vertical axes (row).

The four GAMs with best AIC values drop most possible sediment source factors and interactions between these factors because these other factors or interactions play no significant role in explaining variability within residual pool depth (Table 14). The three GAMs with the best AIC values build on a constant-effect model including just the intercept term by sequentially adding the effects of elevation, near-stream meadow area, and an interaction term between elevation and near-stream meadow area. However, very high correlation between model coefficients was observed. Conditional t-tests on the coefficients suggested that elevation is no longer significant and was dropped from the final model to reduce concerns about multicollinearity. The final GAM model includes the intercept, and the effects of near-stream meadow area and an interaction term between elevation and near-stream meadow area (Table 14).

High collinearity was observed between several variables while testing GAMs, including elevation, watershed area, stream gradient, rain-on-snow area, and near-stream meadow area. This high collinearity is responsible for the apparent discrepancy between the several positive conclusions drawn from formal pair-wise hypothesis testing compared to the relative simplicity of the best predictive model that only include near-stream meadow area with an elevation interaction term. These five variables covary, meaning that they exhibit similar distributions and explain similar patterns in the variability of residual pool depth, and it follows from this collinearity that significant correlations between any one of these five variables are reflected by significant correlations among the others.[17] Another effect of the high collinearity is that meadow effects, instead of elevation, might have been dropped from the final GAM model with equal or very similar statistical significance. In this case, the order in which the stepwise removal of model terms was carried out had a strong influence on the outcome of the final model because of the high collinearity.

The multivariate data exploration of relationships between sediment source factors and residual pool depth also confirmed several other conclusions drawn in the formal hypothesis testing reported above. For example, model exploration confirmed that road density, near-stream road density, road-stream crossings, proportion of watershed in rhyolite soils, and forest cover play no meaningful role in predicting variability in observed residual pool depth data.

Table 14. The best five linear models for Residual Pool Depth. The best model does not include "Elev" because of considerations of collinearity that are explained in the text.

MODEL TERMS	AIC
Intercept + MeadowEffect+Elev*MeadowEffect	n.a.
Intercept + Elev + MeadowEffect + Elev*MeadowEffect	3.878669
Intercept + Elev + MeadowEffect	3.980384
Intercept + Elev	4.109558
Intercept	6.388749

[17] One exception is the correlation of meadow effects with residual pool depth. While there was a significant relationship between near-stream meadow effects and residual pool depth, it was of the opposite sign as hypothesized. Therefore, we failed to reject the null hypothesis and concluded that it this variable was not negatively correlated with residual pool depth, but the strength of the correlation was large enough that it was included within the best predictor model.

DISCUSSION

Comments on Methodology

General AREMP Protocols and EMDS Modeling – AREMP field protocols were relatively easy to implement with the exception of channel morphology classification as described below in more detail. The application of the linguistic modeling nomenclature used in the EMDS model can be difficult to employ and understand, especially for those used to standard statistics or for those who overlook the limitations of using standardized reference criteria in data interpretation. However, we continue to believe that the linguistic modeling at the core of the EMDS model provides a more candid presentation of stream condition data than standard statistical techniques largely because of the explicit acknowledgement of uncertainty within linguistic modeling and the ability to easily examine the relationships used for interpretation. Ecologists can generally recognize very favorable or very unfavorable conditions but are often more uncertain when interpreting intermediate conditions; the linguistic modeling used in EMDS acknowledges the uncertainty inherent in intermediate conditions. Standard statistical tests, such as correlations, GAMs, linear regression, and analysis of variance, can produce definitive conclusions with comforting estimates of precision and power; however, linguistic modeling in the EMDS builds in the measure of uncertainty inherent in ambiguous, conflicting, or missing data that can be overlooked in the presentation of purely statistical results.

We believe that the application of AREMP protocols in the Battle Creek watershed in 2001 and 2002 has produced a robust and statistically valid baseline against which future changes in conditions can be compared through monitoring. A particularly important component of this study was the application of randomized site selection to insure that the entire watershed was adequately sampled. The protocols presented in Gallo et al. (2001) are being strengthened and coordinated through regional collaborative approaches and will likely grow in acceptance as stream condition monitoring tools. For example, the Pacific Northwest Aquatic Monitoring Partnership, comprised of representatives of federal, tribal, Washington, Oregon, and California agencies, is coordinating various aspects of watershed condition monitoring, fish population monitoring, effectiveness monitoring, and management of resulting data. Continued implementation of these or similar protocols in Battle Creek will ensure that trends in changing stream conditions here will be comparable with changes in other watersheds located in Northern California, Oregon, USFS lands throughout the Pacific Northwest, and Columbia River subbasins. Programs in these other areas are all moving toward application of protocols similar to those used in this assessment (Lanigan 2004; Hillman 2004).

The USFS is now in the process of updating the empirical relationships that they use within the AREMP EMDS model to more closely reflect regional variation (Gallo pers. comm.). However, we continued to use the 2001 version of the EMDS tool to stay within to the initial scope of work and budget. The data collected in this study are robust and can easily be re-analyzed by future researchers with future versions of EMDS or other tools.

Fine Sediment and Particle Size Measurements – The Gallo (2001) methods for measuring fine sediment were easy to implement and facilitated comparison with large regional data sets collected by the USFS but are generally considered less conservative than other methodologies such as core sampling with McNeil core samplers (Bunte and Abt 2001). It is possible that the lack of significant relationships between fine sediment and sediment source factors was due to an inherent variability in this fine sediment methodology that a more conservative method would not share. However, the use of McNeil core samplers would not be appropriate at many sites within Battle Creek where stream bed particle sizes are much too large for effective coring.

Fine sediment measurements using the Gallo (2001) methods appeared to be affected by processes active during the low flow period in addition to sediment delivery processes that are primarily active at higher flows. Such low-flow processes included fine sediment deposition resulting from the interception of suspended sediment by algae and the decomposition of the algae itself (particularly at many low elevation sites in late-summer or fall), fine sediment deposition related to chemical flocculents (at mineral-rich Site #016), and possibly the settling of air-borne dust and pollen (at sites with particularly low water velocities). Our hypotheses linking fine sediment measurements with sediment source factors relied on the presumption that source factors and instream conditions would be linked by integrative, high-flow, sediment delivery processes. Therefore, if low-flow, site-specific processes cause a large signal in observed fine-sediment, then perhaps the mechanism underlying our hypotheses indeed do occur but are masked by more local influences.

<u>Channel Geomorphology</u> – The portion of the AREMP EMDS model intended to evaluate stream channel geomorphology which used a Rosgen-type classification system was found to be deficient and was not used in this analysis. The primary deficiencies in this portion of the EMDS model involved 1) an incomplete application of Rosgen's Level I and II classification system and 2) conceptual flaws pertaining to the meaning of the model's evaluation comparison.

The AREMP EMDS model evaluated the field-based classifications through comparisons with map-based classifications. Rosgen's Level I and II classification system depends on knowledge of four stream channel parameters including entrenchment, width/depth ratio, sinuosity, and slope. Our field-based classifications of channel type included all four of these parameters. However, the map-based component classified channel types by using only two of the four parameters required by Rosgen (i.e., gradient and sinuosity) and by using a simplified classification scheme (Table 15) which did not closely match Rosgen's categories. Although we were successful in modifying this simplified scheme to more closely match Rosgen's categories (Table 16) the general approach was still unable to uniquely identify Rosgen channel classes because two of the four required parameters were not included in the EMDS approach nor were they measurable from maps.

The conceptual problems with the approach of this EMDS model node involved improper analysis of the departure of a site's stream geomorphology from its potential condition. At its core, the overall EMDS model approach was to compare each observed metric with reference criteria to determine whether observed values depart from a range of reference criteria that are believed to be either fully favorable or fully unfavorable. The channel geomorphology node of the EMDS model used map-based classifications to determine the reference criteria ranges that were used to compare with field-based observations. This approach was based on the assumption that there is a one-to-one correspondence between stream classification performed at 1:100,000 or 1:24,000 scale and stream classification performed on the ground. However, this assumption is not valid because such a correspondence does not exist.

Instead, to properly assess departures in stream condition from a reaches' potential condition Rosgen (1996) requires either the measurement of additional parameters or the measurement of the same parameters at different times. Rosgen's additional Level III parameters were not measured in this study because they were not a part of the Gallo (2001) protocols. Future monitoring will be necessary to track trends in channel geomorphology and to assess departures from potential.

Table 15. Classification systems used by the 2001 version of the AREMP EMDS model to assign "Rosgen" stream classes to sample sites using only slope and sinuosity determined from maps (Eldred pers. comm.; Don Evans pers. comm.). See text for discussion of flaws in this approach.

		Slope (s)				
		s<1%	1%<s<2%	2%<s<4%	4%<s<10%	10%<s<100%
Sinuosity (S)	S<1.01	C	B/C	B	A	A
	1.01<S<1.1	C	B/C	B	A	A
	1.1<S<1.2	C	C	C/E	A	B
	1.2<S<1.4	C	E	C/E	B	0
	1.4<S<999	E	0	0	0	0

Table 16. A classification system based on the 2001 version of the AREMP EMDS model (Table 15) but modified to more closely match Rosgen's (1996) primary delineative criteria. This system recognizes that unique assignments cannot be made without entrenchment and width/depth information.

		Slope (s)				
		s<1%	1%<s<2%	2%<s<4%	4%<s<10%	10%<s<100%
Sinuosity (S)	S<1.01	D	D	D	A	A
	1.01<S<1.1	D	D	D	A	A
	1.1<S<1.2	B/F/G	B/F/G	B/F/G	A	A
	1.2<S<1.4	C/B/F/G	C/B/F/G	C/B/F/G	B	B
	1.4<S<999	E	E	E	B	B

Forest Cover and Timber Harvest – As noted in the Methodology Section, sufficient data to characterize historical timber harvest in Battle Creek did not exist in a format useful for direct comparison with stream condition data. As a surrogate, we developed the metric "forest cover" because variability in the potential amount of sediment delivery has been related to variation in vegetation density and canopy cover in watersheds affected by timber harvest (e.g., Jones and Grant 1996; Reeves et al. 1993). Keithley's (1999) analysis suggested that vegetation data obtained through remote sensing methods may be used as a proxy for canopy cover.

Better surrogates for timber harvest may have become available since we conducted this analysis. Levien et al. (2002) performed a change-scene analysis of vegetation in northeast California from which additional surrogates of recent timber harvest activities might be derived. However, we did not become aware of this document and the accompanying GIS data until December 2003 which was too late to include in this analysis. Future investigators may wish to use this, or more contemporary, change-scene analyses to develop timber harvest surrogates for comparison with stream channel conditions. Levien et al. (2002) state that the timber harvest accounts for the majority of vegetation canopy cover change in Shasta county which offers additional support for our use of forest cover as a proxy for previous timber harvest.

Stream Conditions

Fine Sediment and Particle Size – Fine sediment levels observed in this study were compared to three other data sets: 1) observations by USFS personnel within 60 stream reaches within the Battle Creek watershed on Lassen National Forest property in 1997 through 2000 (Lassen National Forest 2001); 2) observations by USFS personnel at 25 "reference sites" within areas that have been unmanaged (i.e., are relatively free from roads or timber harvesting though not necessarily free from disturbance, particularly disturbance from fires) throughout USFS Region 5 (Lassen National Forest 2001; Region 5 includes California); and 3) observations by USFS personnel at 77 "non-reference sites" within areas that have been managed and may be influenced to some degree by roads or timber harvest disturbance throughout USFS Region 5 (Lassen National Forest 2001).[18] Fine sediment data were broken into categories based on the gradient of the stream reach in which they were collected. Following Lassen National Forest (2001), these categories included "transport" reaches which were greater than 4 percent gradient and "response" reaches which were less than 4 percent gradient.[19]

No significant difference in mean fine sediment levels was observed in transport reaches among the four data sets but mean fine sediment levels were significantly different in response reaches (Table 17).[20] Multiple comparisons between the four data sets indicated that fine sediment levels in Battle Creek (observed in the present study) were significantly greater than levels observed at USFS Region 5 reference sites. However, the statistical tests used (Tukey's and Newman-Keuls) were not powerful enough to unambiguously discern differences between USFS's Battle Creek data or Region 5 non-reference data with the other two data sets (Zar 1984).

The lack of a statistically significant difference between our Battle Creek sites, USFS Battle Creek sites, and Region 5 non-reference sites in transport and response reaches implies that 1) our results confirm Lassen National Forest results in Battle Creek and 2) fine sediment conditions in Battle Creek are not significantly different than conditions in other managed watersheds within the USFS Region 5 data set.

[18] USFS data used in these comparisons were obtained from Ken Roby, Lassen National Forest. Fine sediment was measured by USFS using the same methods as our study. However, site/reach selection methods differed between the present study and those conducted by Lassen National Forest and Region 5.

[19] The use of 4% gradient by Lassen National Forest (2001) as the break between "transport" and "response" differs from the 3% break identified by Montgomery and Buffington (1993) in their definition of these reach types. However, the underlying physics suggesting that fine sediment in steep reaches is less likely to respond to "persistent, moderate perturbations" remain the same. This break point is close to the 3.5% break observed in the GAM analysis of our data.

[20] Lassen National Forest (2001) concluded that fine sediment in Battle Creek tributaries was more similar to USFS Region 5 reference sites than to non-reference sites, giving the impression that conditions in Battle Creek were relatively undisturbed. However, their comparison was graphical, not statistical, and was made in transport reaches only which are not as likely to respond to perturbations in fines sediment as are response reaches (Montgomery and Buffington 1993).

Table 17. Fine sediment levels from the present study and three other data sets, and results of ANOVA and multiple comparison tests.

Transport Reaches	USFS Region 5 Reference Sites[21]	USFS Lassen Nat'l Forest Sites (1997-2000)	USFS Region 5 Non-Reference	Battle Creek (2001-2002, present study)
Sample Size	7	49	33	18
Mean Fine Sediment Level (%)	8	13	14	16

Conclusion: No significant difference in mean fine sediment levels was observed in transport reaches (ANOVA, $p = 0.62$)

Response Reaches	USFS Region 5 Reference Sites[21]	USFS Lassen Nat'l Forest Sites (1997-2000)	USFS Region 5 Non-Reference	Battle Creek (2001-2002, present study)
Sample Size	18	11	44	16
Mean Fine Sediment Level (%)	22	28	34	47

Conclusion: Mean fine sediment levels were significantly different in response reaches among the four data sets (ANOVA, $p = 0.02$).
Fine sediment levels in Battle Creek (2001-2002, present study) are significantly higher than USFS Region 5 Reference Sites but potential differences between other means were not discernable.
Means that are not significantly different are underlined with dark bars (Tukey's test and/or Newman-Keuls test).

It is notable that levels of fine sediment at USFS Region 5 "reference" sites (average = 22%) are higher than AREMP EMDS "fully favorable" fine sediment levels (11%) and "fully unfavorable" levels (17%). Fine sediment levels at USFS Region 5 reference sites are unfavorable for salmonid production, on average, according to AREMP evaluation criteria.[22] However, if USFS Region 5 reference sites properly reflect relatively undisturbed California streams, conditions in the Battle Creek watersheds are much closer to an "unmanaged" benchmark than they appear in Figure 5 and Figure 6. As discussed below in the section on Trend Monitoring, and as recognized by Armentrout et al. (1998), conclusions drawn from these reference criteria are less important than temporal trends in observed data that will become apparent through monitoring.

[21] Lassen National Forest (2001; their Table 4) inadvertently mis-reported values for USFS Region 5 reference sites (Roby pers. comm.).
[22] While Region 5 "reference sites" have been unmanaged for timber production and are relatively free from roads or timber harvesting, they are not necessarily free from disturbance, particularly disturbance from fires (Murphy et al pers. comm.), and one cannot assume that stream conditions at these sites are fully favorable for salmonid production (Gallo pers. comm.). Development of more regionally-specific EMDS reference criteria might modify conclusions drawn about fine sediment levels (Murphy et al. pers. comm.) though we believe that the EMDS reference criteria we used are likely sufficient because salmonid tolerance to fine sediment (the basis for AREMP's decision for establishing these fine sediment level criteria) likely does not vary greatly among regions.

Particle size measurements also indicated that a large percentage of measured sediment particles were fine sediment although we were unaware of any definitive reference criteria and could draw no firm conclusion from this observation. Comparing these data with data collected only in riffles would be misleading. Rosgen (1996) illustrates particle size distributions for selected reaches sampled in all habitat types; however, these were poor references to use because of the tautological requirement of using observed particle size to determine which reach type should be used as a reference against which to compare observed particle sizes. In other words, Rosgen (1996) does not provide a standard reference against which our particle size data could be compared. Rosgen (1996) does state that bimodal particle size distributions in some stream types, a phenomena that was observed in at least 25 sites (for example, see particle frequency histograms for sites #009, #016, #019 in Appendix B), may indicate stream channel instability but, again, no definitive conclusions could be drawn from this observation because bimodal particle size distributions are common in other stream types and because of the lack of scientifically derived standards applicable to this technique.

Pools – Pool frequencies observed in this study were generally similar to or greater than that found by TRPA (1998), who counted deep (> 1m) and shallow (<1 m) pools during extensive surveys of portions of Battle Creek in 1988 (Table 18). During the 2001 to 2002 sample period, as compared to 1988:

- a much greater proportion of habitat occurred as deep and shallow pools in mainstem Battle Creek between the stream mouth and Coleman Powerhouse;
- a greater proportion of habitat occurred as deep and shallow pools in mainstem Battle Creek between Coleman Powerhouse and Baldwin Creek;
- a similar proportion of habitat occurred as deep and shallow pools in North Fork Battle Creek between Digger Creek and North Battle Feeder Dam and between Bailey Creek and an "accretion point" downstream of site #034;
- a greater proportion of habitat occurred as deep and shallow pools in North Fork Battle Creek between the "accretion point" and Keswick Diversion;
- a similar proportion of habitat occurred as deep and shallow pools in North Fork Battle Creek between Al Smith Diversion and North Battle Creek Reservoir;
- a similar proportion of habitat occurred as deep and shallow pools in South Fork Battle Creek between Confluence of Forks and Coleman Dam, and between Inskip Dam and Soap Creek; and
- a greater proportion of deep pool habitat, but less shallow pool habitat, occurred in South Fork Battle Creek between Coleman Dam and Inskip Dam (Table 18).

However, differences in methodologies between the two studies[23] suggest that pool frequencies were underestimated in 1988 as compared to the present study, particularly in reaches between

[23] TRPA (1998) identified pools using somewhat different definitions of what constitutes a pool compared to the present study. For example, some plunge pools, which were counted in our tally of "all pools", were lumped into "pocket water" by TRPA (1998) and not counted as pools. Portions of pool habitat that we measured (i.e. long pool tails) may not have been counted by TRPA (1998) who included a water velocity component to their pool definition. Instream flows during the present study were higher than in 1988 in the mainstem upstream of Coleman Powerhouse, in North Fork Battle Creek downstream of Eagle Canyon Dam, and in South Fork Battle Creek downstream from Coleman Dam, because of increased flow releases from these two dams. Finally, Gallo et al. (2001) compared pool frequency estimates from "intensive surveys" (as in the present study) and "extensive surveys" (as in 1988) and found that "pool frequency was overestimated in the intensive surveys [as compared to extensive surveys] and that . . . the [statistical] difference between the two surveys was probably due to inclusion of

Eagle Canyon Dam and Coleman Powerhouse, and in South Fork Battle Creek downstream of Coleman Dam, though the extent of this underestimation cannot be determined.

No dramatic change in pool depth classification was observed between the 1988 and present studies (Table 18). In general, TRPA (1998; see their report for additional reaches not sampled in this study) also found relatively greater frequencies of "deep" pools at lower elevations than at high elevations though the 1988 studies generally did not include tributary streams or some high elevation stream reaches. Again, methodological differences between the two studies confound more rigorous comparisons[24].

It is logical that pool frequency (i.e., the number of pools per unit length of stream) would be higher in smaller streams where pools are shorter than in larger streams where pools are longer. Such a general relationship where pool spacing is a function of bankfull width has been described by Leopold et al. (1964) and Rosgen (1996) and has been empirically demonstrated by Bilby and Ward (1991) to be a logarithmic relationship.

However, in Battle Creek this expected relationship is not strongly apparent as demonstrated by the weak relationship between pool frequency and bankfull width and by the unexpected lack of linear trends in heteroscedasticity described in Footnote 11. Furthermore, pool frequencies are not logarithmically related to bankfull width in Battle Creek as expected. If there was a strong relationship between pool frequency and bankfull width, one would expect the linear trend line would have a steep slope. If the relationship between pool frequency and bankfull width were logarithmic, one would expect that pool frequency data would demonstrate a curvilinear relationship similar to the relationships depicted by the fully favorable or fully unfavorable curves (Figure 10). The lack of a logarithmic relationship in Battle Creek data is especially apparent in smaller streams which would, based on theory and empirical studies, have many more pools per unit stream length than larger streams (Figure 10). Results from the EMDS model further support this finding; pool frequency is fully favorable in larger stream reaches but pools are lacking in all stream reaches less than 16.5 meters wide.

Pool frequencies can be depressed when pools are filled by excessive bedload or transported fine sediment (Montgomery and Buffington 1993; Rosgen 1996). However, the field protocol used to define pools in the present study, which did not include a depth component, was sufficiently strong to identify as pools even those habitat units filled with fine sediment. For a habitat unit to deviate enough from the "pool" criteria to be considered, say, as a "run" or "riffle", its morphology would necessarily be controlled by larger bedload material than fine sediment. Therefore, if lower pool frequencies observed in this study are the result of pool infilling, then it is likely that they have been filled with relatively larger bed material and not fine

small or shallow pools in the intensive survey that were less likely to be split out during the coarser extensive survey." All four of these differences in methodologies would have the effect of underestimating pools in 1988 compared to the present study.

Though sample site selection in this study was not biased by pool frequencies or other geomorphic variables, we still surveyed habitat based on samples and not a complete census, and as such, we are not able to determine the relative bias of sample-based mean habitat values compared to actual habitat values typical of all habitat in a given reach.

[24] TRPA (1998) likely measured "total pool depth" and not "residual pool depth" as we did, though that is not clear from their methods. Changes in pool depths from 1988 to the present could not be determined because 1988 pool depths were classified (as < or > 3 feet deep) but were not recorded.

sediment. Sources for this larger bed material would likely have come from bank erosion, gullying, or mass wasting, rather than overland sediment transport.

The unexpected lack of pools in small streams within Battle Creek could indicate the relative location and timing of sediment input if the observed low pool frequencies were caused by pool infilling by bedload and fine sediment. If significant input of sediment in the upper watershed has recently occurred, then the observed pattern (Figure 11) of low pool frequencies at higher elevations (small bankfull widths) and favorable pool frequencies at lower elevations (large bankfull widths) would be expected, especially if a very recent input of sediment occurred (e.g., during the 1997 flood) because sediment waves may take long time periods to pass through watersheds after disturbance; [25] such a sediment wave in Battle Creek may not have yet reached the lower watershed.

Evidence for such a wave of bedload was directly observed in an approximately 1,100 meter long reach extending from Site #057 (in the middle reaches of North Fork at about 2,300' elev.) downstream to near the confluence with Bailey Creek. Within this reach, perhaps one to two feet of aggraded gravel to cobble sized material (the D_{50} at Site #057 was 356 mm) spanned the width of the stream channel and buried the trunks of mature alders closest to the stream. The wetted stream channel and bankfull channel was higher than it would have been at the time of alder colonization because of general aggradation of the stream channel: many mature alders were within the wetted width and the recent bankfull width indicators were found bank-side of mature alders in many places. We estimated that this sediment aggradation was no older than three to five years because many mature alders were still alive while the dead trees had not been dead for long. Channel avulsions at Site #057 were also considered to be indicators of an unstable stream channel at this site. Observed stream channel instability at Sites #053 (1,194 feet elev.) and #044 (1,654 feet elev.) in South Fork Battle Creek may be indirect evidence of a wave of bedload movement in South Fork Battle Creek; direct evidence of such a wave was not looked for or noted at these sites.

Although TRPA (1998) did not sample many high-elevation, small streams, they did sample the relatively high-elevation North Fork Battle Creek, between Al Smith Diversion and North Battle Creek Reservoir, where they also found relatively low pool frequencies in 1988. This could suggest that "recent" inputs of sediment, that affect the broad relationship between pool frequencies and bankfull width described in the present study, may have occurred prior to the 1997 flood and affected TRPA's observations too. It is more difficult, under this hypothesis of increased sediment input depressing pool frequencies in small streams, to explain why pool frequencies in the lower watershed increased between 1988 and 2001-2002, unless TRPA's observations were made when an older sediment wave was passing out of the lower watershed. Future periodic sampling of pool frequencies as part of a trend monitoring program may allow us to 1) discern whether low pool frequencies in smaller streams are indeed a result of recent sediment input or are a persistent feature of Battle Creek, and 2) describe the rates and scales at which watershed-wide sediment transport dynamics occur in Battle Creek.

[25] For example, disturbance associated with logging in Big Beef Creek, Washington, generated an aggradational wave that took 20 to 40 years to pass through the watershed (Madej 1979, 1982 as cited in Montgomery and Buffington 1993).

The statistically significant relationships between residual pool depth and elevation, watershed area, and stream gradient was expected (Leopold et al. 1964). The statistically significant positive relationship between residual pool depth and rain-on-snow area makes sense when considering that larger channel-forming flows at sites with a greater proportion of rain-on-snow area are likely to scour deeper pools, particularly if these rain-on-snow areas are not contributing excess sediment (as was shown by the lack of a relationships between rain-on-snow area and fine sediment levels or median particle size). The positive association between residual pool depth and near-stream meadow area (i.e., pools with greater residual depths are more likely to be found in watersheds with a greater proportion of riparian areas in small trees, shrubs or grass) is counter intuitive and difficult to explain. We hypothesized that riparian areas without trees, presumably where grazing practices were most likely to occur and to affect stream channels, are more likely to contribute sediment to streams thereby reducing residual pool depths. One possible explanation for the observed relationship of deeper pools in site-specific watersheds with greater near-stream meadow areas is that most of the sites with high near-stream meadow areas were located in sparsely-treed, low elevation portions of the watershed (e.g., the mainstem Battle Creek, lower North Fork Battle Creek and lower South Fork Battle Creek) where pools were deeper and where near-stream areas are topographically protected from livestock grazing. Steep canyon walls typically exclude cattle from these areas. On the other hand, grazing does seem to occur throughout even the higher-elevation, forested areas of the watershed where we tended to find shallow pools. The link between near-stream meadow area and elevation was particularly clear in our observation of collinearity between elevation and near-stream meadow area – both variables were so tightly covariant that they exhibited similar power in explaining variability in residual pool depth.

Aquatic Macroinvertebrates – Sediment-related aquatic macroinvertebrate indices were somewhat conflicting but were generally higher than low scoring sediment-related physical stream condition metrics. The generally favorable macroinvertebrate indices relative to physical metrics at the watershed scale may indicate that macroinvertebrate communities are not currently affected by chronic sources of fine sediment and have recovered more quickly from the storm event of January 1997 than have fine sediment levels and other stream condition indices.

Sediment sensitive taxa richness (SSTR), a count of the number of taxa that are sensitive to inputs of fine sediment,[26] was favorable (average truth value of 0.64 including missing data at 7 of 50 sites) suggesting that fine sediment loading is not a major influence on the macroinvertebrate community. The lack of a relationship between high fine sediment levels and favorable SSTR scores was illustrated by the absence of a strong statistically significant correlation between these two variables ($p = 0.07$, $r^2 = 0.11$). Another sediment-related macroinvertebrate metric, percent sediment tolerant taxa (PSTT), was less definitive (average truth value of 0.10 including missing data at 7 of 50 sites) but was also not found to be significantly correlated to fine sediment ($p = 0.32$, $r^2 = 0.32$).

[26] Zero or a low number of sediment sensitive taxa suggests that sediment loading is influencing the macroinvertebrate community.

Table 18. Comparison of deep (> 1 m deep) and shallow (< 1 m deep) pool habitat frequencies observed in the present study and in a study conducted in 1988 by TRPA (1998).

Reach	Portion of Reach Sampled	Sample Period	Sampled Habitat Length	No. All Pools	Length of Deep Pools (m)	Deep Pool Frequency (% of Sampled Habitat)	Length of Shallow Pools (m)	Shallow Pool Frequency (% of Sampled Habitat)
Mainstem – Mouth to Coleman Powerhouse	Whole reach	1988	9,803	na	2,058	21	454	5
	Three sites (#032, #046, #054)	2001-2002	1,506	7	600	70	252	30
Mainstem – Coleman Powerhouse to Baldwin Creek	Whole reach	1988	12,678	na	3,132	25	1,454	11
	One site (#030)	2001-2002	484	3	169	35	94	19
North Fork – Digger Creek to North Battle Feeder Dam	Whole reach	1988	6,856	na	730	11	1,637	24
	One site (#011)	2001-2002	230	6[27]	33[27]	14	36[27]	16
North Fork – Bailey Creek to Accretion Point (d.s. site #034)	Whole reach	1988	2,968	na	280	9	543	18
	One site (#057)	2001-2002	201	6[28]	34[28]	17	25[28]	13
North Fork – Accretion Point (d.s. site #034) to Keswick Diversion	Whole reach	1988	5,539	na	238	4	1,248	23
	One site (#034)	2001-2002	153	5	34	22	63	41
North Fork -- Al Smith Diversion to North Battle Creek Reservoir	Whole reach	1988	19,766	na	308	2	4,956	25
	Four sites (#009, #025, #055, #049)[29]	2001-2002	616	19	0	0	155	25
South Fork – Confluence of Forks to Coleman Dam	Whole reach	1988	4,091	na	433	11	1,383	34
	Two Sites (#062, #020)	2001-2002	555	5	45	8	153	28
South Fork – Coleman Dam to Inskip Dam	Whole reach	1988	8,724	na	1,430	16	2,011	23
	Three sites (#036, #044, #019)	2001-2002	910	12	366	40	138	15
South Fork – Inskip Dam to Soap Creek	Whole reach	1988	5,921	na	1,226	21	772	13
	Two sites (#043, #053)	2001-2002	513	7	139	27	64	12

[27] Only scour pools were counted at this site though other pool types were observed. This site is included in this table for comparison because it was the only site sampled in this study in a large portion of North Fork Battle Creek.
[28] Depth and length data from one pool that was observed in this reach was inadvertently not collected. Pool frequencies reported in this table are based on the 5 pools that were surveyed.
[29] Three other sites were sampled within this reach but were not included in this analysis because only scour pools were counted at these sites.

Conflicts between the four metrics may indicate limiting factors other than fine sediment. For example, three sites with unfavorable SSTR scores in the lower South Fork Battle Creek had favorable PSTT scores and several sites with low ODEQ-BI and/or low B-IBI had favorable SSTR or PSTT scores. Both examples could be caused by generally reduced macroinvertebrate community diversity related to other water quality problems besides fine sediment.

The lack of statistically significant correlations between fine sediment and either SSTR or PSTT is odd and suggests that perhaps fine sediment levels in scour pool tails (where we sampled fine sediment) may not be closely related to fine sediment levels in riffles (where we sampled macroinvertebrates).

Sediment Source Factors

Roads – There was little direct evidence that road-related factors (road density, near-stream road density, and road-stream crossing frequency) played a significant role in explaining the variability of three key stream condition indices at the watershed scale. None of the three road-related metrics were found to be significantly correlated to either of the three stream condition indices: fine sediment, median particle size, or residual pool depth. Also, the three road-related factors were not included within predictive models developed for fine sediment or residual pool depth.

The three road-related metrics were included within the model that best predicted median particle size. This model illustrated that sites with lower road densities, with greater near-stream road densities, and lower frequencies of road-stream crossings, tended to have lower median particle sizes. However, relationships implied by this model cannot be considered statistically significant in a formal sense because we had a relatively low sample size compared to the relatively high number of possible candidate sediment source factors considered within the GAM analysis, and because observed collinearity may have resulted in "observed" relationships that conflict with results expected from assumptions of the underlying physical process. For example, the results of this GAM can be considered exploratory, at best, because it is difficult to explain without additional investigation why sites with lower road densities would tend to have lower median particle sizes.

The significant difference in fine sediment levels within response reaches between our Battle Creek sites and USFS Region 5 reference sites (reported above in the Discussion Section on fine sediment), which are relatively free of roads or timber harvesting, could imply that roads and timber harvesting in Battle Creek may be responsible for observed high fine sediment levels. However, the lack of any statistically significant correlation between the amount of road impacts with instream fine sediment levels and uncertainty regarding differences in land use between USFS Region 5 reference sites and Battle Creek mean that we cannot definitively conclude that road-related sediment sources affect Battle Creek at the watershed scale.

Other unexamined factors, such as topography, fire disturbance, and time since the last major flood, may also play a role in differences between our data and USFS Region 5 reference sites. We cannot rule out timber harvest as the source of the difference in fine sediment between our data set and the USFS Region 5 reference sites because our "forest cover" index, though unrelated to observed fine sediment levels, may not sufficiently capture the variability in timber harvest effects to preclude such a relationship. Also, sediment production varies among road segments and can depend on road age, use and maintenance patterns, surface type and dimensions, proximity to streams, road and watershed slope, construction type, level of outsloping, location on hill slopes, and other characteristics (McCammon et al. 1993, USDA-FS 1999). The scope of this study did not allow us to perform a complete road analysis (e.g., USDA-FS 1999). Similarly, scope constraints did not allow us to sample enough sites to allow for the inclusion of additional variables such as these road characteristics in our modeling – for each additional variable included within the statistical models that we tested, we would have had to sample an additional 10 or more sample sites in the field to insure adequate statistical power.

The lack of evidence for direct relationships between road-related sediment sources and stream conditions in Battle Creek at the watershed scale does not mean that site-specific sources of sediment, like individual road crossings or stretches of poorly constructed roads, do not contribute sediment to the stream – merely that the extensive evidence collected in this study does not clearly suggest that any of these road-related factors, either singly or in combination with others factors, are significant sediment sources at the watershed scale.

Perhaps it should not be surprising that road-related sediment sources do not appear to have a direct relationship on stream conditions in Battle Creek at the watershed scale. The density of roads in the Battle Creek watershed is generally lower than those levels shown to have measurable impacts to streams in other studies. Cederholm et al. (1980) found that sediment levels remain near natural levels where less than 2.5 percent of a basin's area is roaded (a road equivalent to about 4.8 mi/mi^2). Only 4 of 51 site-specific watersheds in our analysis had road densities greater than 4.8 mi/mi^2. McGurk and Fong (1995) found the diversity of aquatic insects is not significantly affected by ERA disturbances of less than 5 percent of the near-stream area (equivalent to about 5.8 mi/mi^2 of near-stream roads). Only 11 of 51 site-specific watersheds in our analysis had near-stream road densities greater than 5.8 mi/mi^2.

Forest Cover and Near-Stream Meadow Area – There was little evidence that the two vegetation cover metrics (forest cover and near-stream meadow areas) played a significant role in explaining the variability of three key stream condition indices at the watershed scale. Forest cover was not found to be significantly correlated to either of the three stream condition indices, fine sediment, median particle size, or residual pool depth, and near-stream meadow area only correlated to residual pool depth but not fine sediment or particle size. The selection of predictive models using GAMs produced similar results where the only instance that one of these two vegetation cover metrics was included in a predictive model was when near-stream meadow area was found to be positively correlated to residual pool depth.

Our findings do not rule out grazing or timber harvest as significant sediment sources because the metrics we used (forest cover and near-stream meadow area) may not adequately capture the physical driving variables associated with these land uses at the watershed scale. While we believe that our metrics were the best estimators of these land uses available for use within the scope of this study, future researchers may develop better tools which are more closely linked to the underlying physical processes believed to connect grazing and timber harvest with stream channel conditions.

Also, as in the discussion of road-related factors, the lack of evidence for direct relationships between forest cover or near-stream meadow areas and stream conditions in Battle Creek at the watershed scale does not mean that site-specific sources of sediment related to grazing or timber harvest do not contribute sediment to the stream – merely that the extensive evidence collected in this study does not clearly suggest that either of these road-related factors, either singly or in combination with others factors, are significant sediment sources at the watershed scale.

One other unlikely possibility for the lack of strong signals in the correlation and GAM analysis, particularly from forest cover,[30] could be that timber harvest in Battle Creek has exceeded some upper threshold level above which fine sediment levels are high but no longer vary proportionally with forest cover. Differing levels of timber harvest may be one explanation for observed differences in fine sediment levels at our Battle Creek sites and USFS Region 5 reference sites. Also, the amount of forest cover (i.e., trees larger than 20 inches in diameter) in the Battle Creek watershed was rarely more than 30 percent of site-specific watershed areas despite the fact that much of the watershed is within the Sierran mixed conifer plant community where large amounts of forest might be expected. However, McGurk and Fong (1995) looked for, and failed to find, such an upper-limit threshold in their study of ERA. While we did not calculate ERA values for our study sites, Napper (2001) reported ERA values for nine subwatersheds of Battle Creek ranging between 1.1 and 7.5, well within the range examined by McGurk and Fong (1995). Therefore, it is unlikely that such an upper threshold has been exceeded in Battle Creek.

<u>Rain-on-Snow Area and the January 1997 Storm</u> – The proportion of watershed area in the rain-on-snow zone was found to be significantly related to residual pool depth but not fine sediment or particle size. The positive relationship between rain-on-snow area and residual pool depth, however, was opposite from the anticipated relationship if rain-on-snow was a significant sediment source. This statistically significant relationship makes sense when considering that larger channel-forming flows at sites with a greater proportion of rain-on-snow area are likely to scour deeper pools. If there were significant sediment sources within the rain-on-snow zone that could be exacerbated by rain-on-snow events, like roads or timber harvests, then this observed relationship might be confusing. However, these other sediment source factors do not appear to play a strong role at the watershed scale and rain-on-snow area does not appear related to more direct evidence of sediment delivery including fine sediment levels or median particle size.

Several studies have documented a link between timber harvest and hydrological impacts associated with rain-on-snow events (Jones and Grant 1996; Heeswijk et al. 1995; Harr 1981, 1986; Berris and Harr 1987). Our analysis using GAMs was able to identify any strong interactions between forest cover and rain-on-snow area that might have occurred if the combination of forest cover and rain-on-snow area had been strong predictors of stream conditions. The lack of predictive interactions between these two variables suggests that links between timber harvest, hydrological impacts, and stream conditions in Battle Creek either function differently than has been described elsewhere or are not important in Battle Creek

[30] Assuming, once again, that this metric is functionally related to the hypothesized effects of timber harvest on stream channel conditions.

because one or more components of the physical process are above or below some critical threshold that would trigger significant correlations.

Of course, methodological errors, like our definition of the rain-on-snow zone, may not adequately reflect the underlying physical process and could have contributed to the lack of observed relationships. The elevation band from 3,600 to 5,000 feet was defined as the dominant rain-on-snow zone by Armentrout et al. (1998) but channel instability resulting from the January 1997 rain-on-snow event suggests that significant sediment inputs from such storms occurs at higher elevations, perhaps from 4,000 feet to the top of the watershed (Figure 14). This may partially explain the lack of statistically significant relationships between rain-on-snow and fine sediment and particle size, and the unanticipated relationship between rain-on-snow and residual pool depth, in our analysis. Perhaps stream channels downstream of the dominant rain-on-snow zone are stable at a size capable of handling "normal" rain-on-snow storms and therefore did not show signs of severe bank erosion or channel avulsions. Storms which occur at higher elevations than usual may be the cause of unusual patterns of channel instability at higher elevation sites such as that noted in our work and could also explain high levels of fine sediment at most sites throughout the watershed.

The variability in the stream condition data suggests that another process with a larger signal may be obscuring the signals generated from the sediment source factors that we had hypothesized would explain most of the variability. Visual evidence apparent in the field, evidence collected by other researchers, and evidence from data collected in this study suggests that a large rain-on-snow storm event in January 1997 may have produced such an overwhelming signal. This evidence included:

- shallow pool depths and low pool frequencies in smaller, higher-elevation channels;
- bank erosion at higher elevations;
- stream channel instability and channel avulsions possibly due to excessive sediment input in higher-elevation channels;
- generally high fine sediment levels at sites throughout the watershed;
- a wave of transported bedload in middle reaches of North Fork Battle Creek and possibly also in South Fork Battle Creek; and
- Lassen National Forest (2001) found that the majority of sediment sources they observed, in their study of higher elevation reaches of the watershed, were related to natural bank failures and landslides attributed to the January 1997 storm. This flood damage occurred widely among several of the major sub-basins in the headwaters of the Battle Creek watershed.

<u>Rhyolitic Soils</u> – The localized nature of rhyolitic soils within the Battle Creek watershed (comprising over 30 percent of 4 site-specific watersheds and absent from 15 site-specific watersheds) should have produced a stronger signal in our analysis if it was a significant sediment source factor. The complete lack of a signal between rhyolitic soils and stream conditions at the watershed scale, and observations by Armentrout et al. (1998) and Lassen National Forest (2001) that rhyolitic soils are significant sediment sources, suggests that rhyolitic soils may have strong effects at the more localized site-specific scale.

Mass Wasting – Landslides and mass wasting are other typical sources of sediment that were not specifically studied in this analysis because of our previous belief that they were not common in the Battle Creek watershed. Indeed, evidence of mass wasting was not widely observed at our sample sites or during our travels. Specific instances of mass-wasting were noted in a few cases. Active, potentially catastrophic, mass wasting was noted at Site # 031 in Digger Creek and was found to be caused by deficiencies in the conveyance system of Boole Ditch, a private irrigation canal. Stream side trails at Site #023 in lower Bailey Creek were also causing mass wasting and delivery of sediment directly to the stream. Landslides at sites in South Fork Battle Creek have been noted by the USFS (Lassen National Forest 2001) but were not observed in this study. Topographic aspects of Battle Creek, including large flat areas in the North Fork Battle Creek watershed and steep bedrock canyons near middle and lower elevation stream areas, may moderate the influences of potential sediment factors which can cause mass wasting, like roads, though steep areas in rhyolitic soils may be locally important sediment sources.

CONCLUSIONS

Watershed Conditions

The extensive data set collected and analyzed in this study provides a strong foundation on which to build an understanding of conditions within the Battle Creek watershed. While conditions varied by site, average site conditions were moderately favorable for salmonid production when considering one or more of the stream condition indices: substrate (fine sediment and median particle size), pool frequency, wood frequency, and four biological metrics.

The data collected as part of this study also provides a strong foundation upon which to build a watershed monitoring program, in part to assist in measuring the effectiveness of restoration actions either at the site-specific scale or at the watershed/reach scale as anticipated by the Battle Creek Salmon and Steelhead Restoration Project.

We believe that a storm event in January 1997 was the primary sediment source factor affecting aspects of stream condition such as fine sediment levels, particle size, pool frequency, pool depth, and geomorphic channel conditions like bank erosion and channel avulsions. While we were unable to rule out roads or other land use as possible sediment sources, there was little direct evidence that road factors (density, near-stream density, road-stream crossing frequency) or other land-use factors (forest cover and near-stream meadow area) played a significant role in explaining the variability of three key stream condition indices at the watershed scale. We believe that this lack of evidence is due, in part, to the overwhelmingly strong signal from the January 1997 storm. This lack of obvious land-use-related sediment sources at the watershed scale does not mean that site-specific sources of sediment, say, individual road crossings or particular areas of timber harvest, do not contribute sediment to the stream – merely that the extensive evidence collected in this study does not clearly suggest that any of these land-use activities, either singly or in combination with others factors including situational variables like elevation, rain-on-snow area, or the presence of rhyolite soils, are significant sediment sources at the watershed scale.

Restoration actions taken to reduce sediment delivery to Battle Creek and its tributaries may be able to improve conditions for salmonid production because conditions for salmonid production are not completely favorable at all or most sites. However, other techniques to identify significant sediment sources at scales smaller than the watershed scale will need to be employed. Formal roads analyses, which takes into account variations in road construction and maintenance, might be useful to identify site-specific road problems. Also, identification of sediment sources during the course of other investigations may also be useful although the significance of these sources may be difficult to discern or even define. More specific timber harvest data, perhaps the change scene detection data in Levien et al. (2002), may reduce variability inherent in our forest cover metric which might have obscured possibly significant relationships between this land use and sediment delivery to streams.

While watershed-scale conditions were less than fully favorable for salmonid production, the strongest identifiable sediment source was a storm event with watershed-wide impacts that occurred only a few years before the field data were collected. It is typical for watersheds to be periodically disturbed by such storms and it is typical that they recover as sediment moves through the system and as geomorphic conditions stabilize. It may take as many as 20 to 40 years for evidence of this storm event to pass from the watershed (Madej 1979, 1982 as cited in Montgomery and Buffington 1993). Fisheries restoration efforts within Battle Creek need to account for the time-spans involved in this recovery process when forecasting rates of population recovery and when considering adaptive management actions. Because populations of anadromous salmonids in Battle Creek are currently very low, it is possible that freshwater habitat conditions will recover at about the same rate as the fish populations and would not act as a factor limiting population recovery.

As the signal from this storm is ameliorated, other sediment source factors, including those analyzed in this study, may become discernable and appear significant, and may possibly even delay the watershed's recovery from this storm. Continued monitoring of stream conditions within Battle Creek will 1) provide us with a regionally-significant learning opportunity to quantify a watershed's recovery from such a large storm as that which occurred in January 1997, 2) determine if other sediment sources besides the 1997 storm are significant, and 3) take steps to reduce sediment delivery if other significant sediment sources are found.

In addition to the broader points made above, the following are key findings from this study:

- Fine sediment levels were high – higher, in most cases, than levels which are favorable for salmonid production, higher than unmanaged California streams, and higher than USFS standards – but were similar to other managed watersheds on USFS lands in California.
- Pool frequencies and depths were lower at middle and high elevation sites than predicted though pool frequencies had increased or remained the same since 1988. Approximately 150 pools with depths greater than 1 meter would be suitable as spring Chinook salmon adult holding habitat although very few of these pools are greater than 2 meters deep.
- Large woody debris levels were favorable for salmonid production at most sites and were unfavorable at about 15 percent of the sampled sites..
- No strong geographic signals were evident in geomorphic channel data to suggest that any one sub-basin of the Battle Creek watershed should be prioritized for sediment reduction. However, significant sediment inputs, particularly eroding stream banks and landslides caused by the January 1997 storm event, were generally at higher elevations above 4,000 feet.
- There was little direct evidence that road-related factors (road density, near-stream road density, and road-stream crossing frequency) played a significant role in explaining the variability of three key stream condition indices at the watershed scale.
- There was little evidence that the two vegetation cover metrics (forest cover and near-stream meadow areas) played a significant role in explaining the variability of three key stream condition indices at the watershed scale although we cannot rule out the possibility that these factors affect sediment delivery in the Battle Creek watershed.

- Rain-on-snow areas, as defined by our index, were not found to be significant sediment sources at the watershed scale. However, a rain-on-snow storm in January 1997 disturbed stream reaches at high elevations, perhaps higher than what was accounted for in our rain-on-snow index. We believe this storm event was the primary sediment source factor affecting aspects of stream condition in the Battle Creek watershed.
- Erosive rhyolite soils were not found to significantly influence sediment delivery at the watershed scale although they may have local effects that could be mitigated through restoration.
- Sediment-related aquatic macroinvertebrate indices were somewhat conflicting but were generally higher than low scoring sediment-related physical stream condition metrics. The generally favorable macroinvertebrate indices relative to physical metrics at the watershed scale may indicate that macroinvertebrate communities are not currently affected by chronic sources of fine sediment and have recovered more quickly from the storm event of January 1997 than have fine sediment levels and other physical variables.

Trend Monitoring

This study provides a robust and statistically valid baseline against which future changes in conditions can be compared through monitoring. Trends and processes cannot be verified from a single sample in time. Continued, periodic, and statistically valid monitoring will be necessary to make several important conclusions, regarding:

- Trends in watershed condition. As the signal from the 1997 storm is ameliorated, other sediment source factors, including those analyzed in this study, may become discernable and appear significant, and may possibly even delay the watershed's recovery from this storm. Trend monitoring of stream conditions within Battle Creek will 1) allow us to quantify the watershed's recovery, 2) determine if other sediment sources besides the 1997 storm are significant, and 3) take steps to reduce sediment delivery if other significant sediment sources are found.
- The effectiveness of restoration efforts including the effectiveness of sediment source treatments and the effectiveness of ecological restoration programs where organisms like fish are used as measures of success. Because fish can be influenced by stream channel conditions as well as specific ecological restoration actions, knowledge of changes in stream channel conditions will be critical to correctly tease out the effectiveness of these types of actions. Ecological processes affected by future projects will need to be identified to augment the use of data from this study in gaging project effectiveness;
- The stability of observed stream reaches. Stream reach stability can only be assessed through observation of changes over time;
- Determination of the key processes and pathways of sediment delivery (e.g., pool infilling and the movement of sediment waves) within the Battle Creek watershed;

- Comparison of changes in Battle Creek with changes in other regional watersheds. This is particularly important to regional restoration programs, such as the California Bay-Delta Authority's Ecosystem Restoration Program, which is funding restoration work throughout the Bay-Delta watershed but has few statistically valid tools for comparing the relative results of their various investments.

The Battle Creek Watershed Conservancy has been awarded funding to prepare a comprehensive monitoring program to monitor stream channel conditions in Battle Creek. This program will be developed in 2005 and 2006 in collaboration with interested landowners, agencies, watershed residents, and other interested parties including the Greater Battle Creek Watershed Working Group. This monitoring plan will be founded on data collected and reported as part of this study and will likely follow the lead of regional collaborative approaches being crafted by groups like the Pacific Northwest Aquatic Monitoring Partnership. Another benefit of the assessment approach used in this study is that statistical guidance on trends analysis has already been developed (Stevens 2002; Diaz-Ramos et al. 1996), and will be incorporated into future monitoring programs.

Prioritized Criteria for Treatment of Sediment Sources

None of the potential sediment sources that we set out to prioritize were found to be significant sediment sources at the watershed scale, perhaps because they were relatively minor compared to what we believe were the overwhelming effects of a storm that occurred in January 1997. This lack of obvious land-use-related sediment sources at the watershed scale does not mean that site-specific sources of sediment are not significant at smaller scales than were examined in this study. Other techniques to identify significant sediment sources at scales smaller than the watershed scale will need to be employed. However, the significance to the watershed of these smaller-scale sources may be difficult to discern or even define. Despite the lack of evidence of significant sediment sources at the watershed scale, other research suggests that smaller-scale sediment sources related to our hypothesized sediment source factors can be prioritized for treatment. The following paragraphs list criteria that need to be considered when prioritizing sediment sources:

- Specific sites that do not meet the characteristics described herein may be demonstrated by future research to be sources of sediment delivery to the stream network. These sites should receive consideration for treatment even if they conflict with the general guidelines in this section.

- Areas of known mass wasting or potential mass wasting. Though generally few, Lassen National Forest (2001) has identified some areas of landslides or potential mass wasting and ranked these as high priority areas. We identified only one area with potentially catastrophic mass wasting potential; this active slide affected Digger Creek on the north side of Digger Butte and was related to deficiencies in the Boole Ditch conveyance system. We did not compare this potential landslide with those identified by Lassen National Forest (2001)

- High elevation sites, generally above 4,000 feet, and sites where sediment sources or hydrologic effects could exacerbate or impede the recovery from previous flood damage.

Low elevation sites, generally below 3,000 feet were generally stable and would be low priority unless site-specific conditions suggest that they should be considered.

- Near-stream roads and places where road-influenced sediment delivery is shown to affect the stream. For example, turnouts, landings, and areas near road-stream crossings.

- Areas where timber harvest is shown to contribute sediment.

- Sites where rhyolitic soils predominate should be prioritized if other factors included herein are equal.

- Areas upstream of known reservoirs and lakes would be lower priority than areas downstream of reservoirs and lakes although fine sediment transport may occur through the generally small reservoirs in the Battle Creek watershed.

- Other considerations for sediment treatment that were not analyzed in this study may enter into site-specific prioritization including, but not limited to, protection of endangered or at-risk species, landowner permission, available funding, and relative magnitude of treatment size or sediment source size.

Ongoing Sediment Source Treatments

Site-specific sediment source treatment efforts are underway in the Battle Creek watershed and are being conducted, at least, by SPI, USFS, and the Battle Creek Watershed Conservancy. Appendix A documents efforts conducted by SPI in 2001 and 2002 to reduce sediment delivery to streams. The Lassen National Forest has removed roads and otherwise reduced sediment sources within the Battle Creek watershed in the past. The Lassen National Forest and the Battle Creek Watershed are working together to further reduce sediment sources and will be implementing several actions beginning in 2004 and 2005. Significant sediment sources on Lassen National Forest property will be treated by decommissioning up to 18 miles of roads, relocating approximately 2 miles of roads, outsloping 12 miles of roads, improving up to 13 road crossings of streams, decommissioning 10 acres of skid trails, and restoring 16 acres of aspen riparian vegetation stands. Road-stream crossing treatments will include decommissioning, conversion to fords, replacement of culverts with open arches or bridges, and/or culvert modifications. The Battle Creek Watershed Conservancy has been, and continues, to seek funding to prevent catastrophic mass wasting on the north side of Digger Butte and continues to work with local landowners to identify and treat site-specific sediment sources on private lands.

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APPENDIX A: BATTLE CREEK WATERSHED IMPROVEMENT PROJECTS BY SIERRA PACIFIC INDUSTRIES FROM 2001 TO 2003

Sierra Pacific Industries (SPI) has undertaken many projects over the last two years designed to reduce potential sediment sources within the Battle Creek watershed. The following is a brief description provided by SPI of these activities and the expenses incurred to demonstrate compliance with this project's funding requirement of matching contributions:

1. Many road crossings of watercourses and road segments near watercourses have been rocked. This reduces the potential for sediment to move off of the road surface and into the nearby watercourse. The cost for this was $13,000.

2. Road maintenance is done on an annual basis. Roads and drainage structure are assessed each year for damage and functionality. Maintenance is directed as needed. In addition, many roads are improved as they are used for harvesting operations. This improvement generally involves adding drainage structures such as culverts and rolling dips intended to disburse water off of the road surface before it can damage the road and transport sediment into watercourses. The cost for this was $32,900.

3. Abandonment of roads that are located in sensitive areas near watercourses is assessed prior to harvesting operations. Roads with a high potential to add sediment to watercourses are abandoned by blocking access, waterbarring and at times removing culverts. Approximately 6.5 miles of road were abandoned over the last two years at a cost of $4,500.

4. Many of our roads are protected from public vehicle traffic during the winter period by locked gates. By limiting public access during the winter period we are protecting our roads from rutting and damage to drainage structures when the roads are wet. This road damage could result in sediment increases to watercourses nearby and causes additional maintenance costs. Approximately 46,600 acres within the watershed is gated. Over the last two years we have added 9 gates at a cost of $27,000.

5. Landings on soil with a high potential to erode were straw or slash mulched to reduce the potential for soil movement. The cost for this was $900.

6. The protection of watersheds from catastrophic fire through fuels reduction and improving forest health potentially reduces the severe erosion associated with burned over land. Biomass chipping operations that remove excess understory vegetation also is removing ladder fuels that would allow a ground fire to burn up into the crown of the larger trees. A crown fire is much more damaging to the trees and allows the fire to move much faster and cover a larger area. The trees remaining after a biomass chipping operation are optimally spaced so that they are not competing for moisture or sunlight thus improving the forest health. Approximately 1,750 acres have been treated in this manner over the last two years. This has resulted in an out of pocket expense of $70,000 after reimbursement for the value of the chips.

7. Near future projects include fencing of two springs to exclude cattle thereby reducing bank erosion. Another project involves planning community wide defensible fuel profile zones (DFPZ) in conjunction with the California Department of Forestry, the United States Forest Service and other private landowners. The purpose of the DFPZs is to reduce the number of acres that would be burned by high intensity, stand replacing fires. The DFPZ is a strip of land strategically located to facilitate fire-fighting activities. The fuels along this strip will be reduced so that the potential for crown fire is minimized and the area provides a safer location for firefighters to accomplish their goal.

The total expense for the completed projects is $148,300.

APPENDIX B

Appendix B of this report contains photos, field data, and graphics for each of 51 sites sampled as part of this watershed assessment. You may download this file at www.battle-creek.net. Look for the file named <BCWA_Report_AppendixB.pdf>.