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Development of Biological Water Quality Targets for Assessment of Total Maximum Daily Load (TMDL) of Sediment in the Squaw Creek Watershed (Placer County, California)

Final Report

April 16, 2002

Contract #9-118-160-0

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Introduction

One approach to defining a TMDL is as an expression of how much pollutant load a waterbody can accommodate without harm or degradation to the integrity of resident stream life. Among the water quality indicators that may be used in developing sediment TMDLs, measures of aquatic invertebrate communities provide direct information on sediment effects to aquatic life uses and a means of evaluating the restoration of biological integrity of stream habitats (USEPA 1999a). Use of quantitative data on the structure of biological communities in evaluating stream habitat quality is known as bioassessment (USEPA 1999b). Bioassessment surveys of baseline conditions can provide an evaluation of the existing status of target watersheds in contrast to reference watersheds that have been selected to reflect the natural spatial and temporal variability expected for similar stream types in minimally disturbed habitats. Differences between reference and target conditions on Squaw Creek (Placer County, California) were used here to evaluate the extent of sediment effects on biological integrity and provide a baseline and goal for monitoring ecological restoration.

Biological structure and integrity of stream environments can be ascertained from a quantitative description of the inhabitant organisms. Aquatic insects and other invertebrates are central to the function of stream ecosystems, consuming organic matter (wood and leaf debris) and algae, and providing food to higher trophic levels (fish and riparian birds). These native organisms also have varying degrees of pollution tolerance and so may be used as indicators of water quality and habitat conditions. Collections of the zoobenthos (bottom-dwelling fauna) may be used to evaluate the relative abundance of different taxa, feeding guilds, pollution indicators, and diversity, in order to develop a quantitative basis for measuring ecological attributes of the stream. Monitoring relative to reference sites (having little or no impact but similar physical setting), and/or over time within subject sites, then permits impact problems or recovery to be quantified (Rosenberg and Resh 1993, Davis and Simon 1995, Karr and Chu 1999). The use of bioassessment data can contribute to developing TMDLs by providing indicators of ecological health of stream habitat as altered by sediment, and setting target values for attaining a restored ecological condition.

Sediment TMDLs are often difficult to assess because transport and deposition of sediment is a natural process of streams. Sedimentation is a natural part of the landscape of watersheds and contributes to the dynamic process of building, shaping, and renewal of stream channels. Sediment can be important to the ecological function of streams in providing habitat and cover for certain kinds of organisms, and as a food resource (organic particles and microbial/algal growth occurring on particle surfaces). It is excessive sediment that can create impairment in the ecological function of streams. The challenge of the TMDL process is to determine at what point excessive sedimentation impairs water quality, and identify indicators that can be used to define and quantify the impairment.

Sediment as a pollutant is particularly harmful to aquatic life uses of stream bottom habitats because fine particles (clay, silt) and sand cause physical disturbance during both transport and deposition. Sediment movement (suspended and bedload) during high flow events scours stream channels and can leave much of the streambed barren of life. During sediment deposition, substrates become covered, embedded, or buried by sediment and life can literally be choked out. Deposition may leave a lasting legacy of lost habitat in streams that may only be recovered slowly by so-called flushing flows (Stalnaker et al. 1994; discharge sufficient to remove fines and sands from the interstices of larger stream bottom substrates). Because of these effects of sediment, benthic organisms such as aquatic invertebrates are a good choice as sensitive indicators for monitoring impairment in stream ecosystems (Waters 1995).

Field Monitoring Study Design and Sampling Strategy

Approach

The monitoring plan was designed to accomplish the following objectives:

1. Describe the existing condition of biological health in Squaw Creek
2. Compare conditions in Squaw Creek to reference watershed streams
3. Examine the relationship between sediment load and biological integrity

The invertebrate communities of reference streams were used here to reflect the potential range of ecological conditions found in stream habitats matched to the Squaw Creek watershed but with minimal or reduced sediment impacts related to land use. Some streams external to the Squaw Creek watershed with moderate to high levels of sediment loading were also sampled to help place sediment effects in a broader context and develop a dose-response relation. Sampling was conducted to frame the natural background spatial and temporal variability of streams nearby and within the Squaw Creek watershed. This was accomplished by sampling a varied size range of reference streams over a 2-year period. In the first year (2000) surveys were conducted during late-season low flows (late August), and in the second year during mid-season moderate flows (early July 2001). This approach allowed the greatest extent of natural differences in stream invertebrate communities to be defined for watersheds that were exposed to minimal land use slope erosion problems compared to the target Squaw Creek watershed, and provided an unbiased standard for evaluating the conditions in Squaw Creek. Quantitative description of biological communities at sites over a range of sediment loading exposures permitted development of a dose-response linkage between sediment stress and biological signals.

The goal of the project is to define biological criteria based on the reference stream sampling that can be used to establish whether and how much the Squaw Creek streams are impaired, and designate a water quality target for attaining recovery of biological integrity. Examination of the biological response over a dose range of sediment may further be used to identify a load level (threshold) at which impairment occurs. This level may be used as a practical guide to identifying a specific TMDL (or in this case annualized or event-related measure of load reduction) needed to attain the reference condition for biological health.

Site Selection

A variety of physical habitat features of streams can affect benthic invertebrate communities (Resh and Rosenberg 1984). In addition to natural erosion and sedimentation, the size, gradient and elevation may contribute to shaping communities as may land use impacts other than the suspected problem source. Site selection for bioassessment was thus guided by the need to account and control for varied environmental background influences.

Six sites were sampled in the target Squaw Creek watershed from the upper to lower portions of the drainage basin. These sites were divided into three stream types based on location and geomorphology: (1) upper watershed tributaries (South and North tributaries at near 6800 ft, representing higher gradient 1st-2nd order streams); (2) low gradient mid-watershed streams (3 sites in the meadows, representing <2% slope 2nd-4th order channel types); and (3) lower watershed streams located near the bottom of drainages (below the terminal valley moraine, just above the Truckee River). Selection of reference watershed streams for each Squaw Creek stream type was based on similarity with regard to:

- stream order (±1)
- channel width (±100-300 cm)
- size/length of upstream watershed (some similar size, others ± 0.25-3X length)
- elevation (mostly within 6,000 – 7,000 ft zone)
- gradient (±2% in most cases)
- aspect (eastern orientation)
- geographic proximity (within 20 mile radius, and tributary to Truckee River)
- geologic and geomorphic setting (metamorphic and granitic rock/soils)

→ what about volcanic/glacial?

Most of the reference sites were selected to represent the low gradient meadow stream type so that a large sample size was available for analysis of conditions in this longest segment of the Squaw Creek drainage. Twenty-eight surveys were conducted over the 2000-2001 period at 22 separate locations (4 Squaw Creek sites and 2 reference sites were sampled in both years to examine temporal variation).

Reference watershed study reaches were also selected based on the sediment load regime predicted from maps generated by the Annual Agricultural NonPoint Source Model (AnnAGNPS, USDA 2000) developed by the Desert Research Institute of the University of Nevada at Reno (DRI 2001). The AnnAGNPS model generates sediment load predictions for different positions within watersheds based on the effects of a high run-off year on the upstream landscape (dependent on slopes, soils, vegetation cover, erodibility, land use, etc). Streams conforming to the general selection criteria above were selected from these maps to form reference streams, and a range of potential sediment exposures.

Listing of stream survey locations and types:

Watershed location / stream type	Squaw Creek Sites	Reference/ or Exposure Sites
Late Season Low-Flow Regime (late August 2000)		
Upper watershed reach	Squaw Ck -South tributary Squaw Ck -North tributary	Pole Creek
Mid-watershed low gradient reach	Squaw Ck meadows –lower Squaw Ck meadows –middle Squaw Ck meadows –upper	Little Truckee R –Perazzo Cold Creek 2017 Sagehen Creek Prosser Creek
Lower watershed reach	Squaw Creek –below moraine	Bear Creek General Creek
Mid-Season Moderate-Flow Regime (early July 2001)		
Upper watershed reach	Squaw Ck -South tributary Squaw Ck -North tributary	Lacey Creek Juniper Creek
Mid-watershed low gradient reach	Squaw Ck meadows –lower Squaw Ck meadows –middle	Little Truckee R. –Coldstream 96 Sagehen Creek 204 Perazzo Creek 103 Independence Creek 104 Martis Creek 276 N. Prosser Creek 193 Alder Creek (load exposure) 726 Trout Creek (load exposure) 987
Lower watershed reach	Not repeated	Bear Creek

T-clistn's sed load model

Sampling Methods

The data gathered consisted of physical habitat surveys and biological sampling of benthic macroinvertebrates, algae and organic matter. Each site was defined as a 150-meter length study reach, located by GPS-UTM coordinates and elevation (near lower end of each site). The longitudinal distribution and length of riffle and pool habitats were first defined then used to determine random locations for sampling of benthic macroinvertebrates from riffle habitat. Slope over the reach was measured with a survey transit and stadia rod, and sinuosity was estimated from straight-line distance over the 150 m channel, or maps of 500-1000 meters of stream length centered on the study reach. Physical habitat was measured over the length of each reach using 15 transects spaced at 10 meter intervals. Water depth, substrate type and current velocity were measured at five equidistant points on each transect along with stream width, bank structure (cover/substrate type and stability rating), riparian canopy cover, and bank angle. Bank structure between water level and bankfull channel level was rated as open, vegetated, or armored (rock or log), and as stable or eroded (evidence of collapse or scour scars). Bank angles were scored as shallow, moderate, or undercut (<30°, 30-90°, and >90°, respectively), and riparian cover was estimated from vegetation reflected on a grid in a concave mirror densiometer (sum of grid points for measurements taken at each stream edge and at mid-stream facing up- and downstream). The type and amount of riparian vegetation along the reach was also estimated by qualitative visual evaluation. The embeddedness of cobble size substrate was estimated as the volume of the rock buried by silt or fine sand for 25 cobbles (encountered during transect surveys or supplemented with random selected cobbles). Discharge was calculated from each transect as the sum of one-fifth the width times depth and current velocity at each of the five transect points, and averaged. Basic water chemistry and related measures consisted of dissolved oxygen, conductivity, alkalinity, pH, temperature, nitrogen, phosphorus, silica, hardness, sulfate, and turbidity. Documentation also included photographs taken at mid-stream looking upstream at 0, 50, and 100 meters, and downstream at 150 meters. Biological sampling consisted of 5 replicate benthic samples taken in riffle zones with a 30-cm wide D-frame kick-net. Each replicate was comprised of a composite of 3 30x30 cm sample areas taken across the riffle transect or over riffle areas of varied depth, substrate and current. This composite of microhabitats provides a more representative sampling and reduces the variability among replicate samples. Samples were processed in the field by washing and removing large organic and rock debris in sample buckets followed by repeated elutriation of the sample to remove invertebrates from remnant sand and gravel debris. Remaining debris was inspected in a shallow white pan to remove any remaining cased caddisflies (e.g., Glossosomatidae), snails or other molluscs. Elutriated and inspected sample fractions were then preserved in ethanol, and a small volume of rose bengal stain added to aid in lab processing. Invertebrate field samples were subsampled in the laboratory using a rotating drum splitter, sorted from subsamples under a magnifying visor and microscope, and identified to the lowest practical taxonomic level possible (usually genus; species when possible based on the availability of taxonomic keys, except for oligochaetes and ostracods). A minimum count of 250 organisms was removed from each replicate for identification (in practice averaging about 300-500). Data analysis yielded information on taxonomic composition by density and relative abundance. Metrics of community structure were calculated to express biological health in terms of diversity, composite community tolerance, number of sensitive taxa (mayfly-stonefly-caddisfly), dominance, and other measures of composition. All stages of sample processing and identification were checked using quality control procedures to assure uniformity, standardization and validation (QAPP; Herbst 2001).

The benthic food resources of stream invertebrates were also quantified in sampling of organic matter and algae. Particulate organic matter was sampled using a 250-micron mesh D-frame net, sampling stream bottom riffles as above for invertebrates (3 replicate riffle samples). These samples were poured through a 1-mm screen, with the retained wood and leaf particle debris then weighed as a wet biomass measure of coarse particulate organic matter (CPOM). The fine fraction passing through the screen (particle range 250 microns to 1000 microns) was collected in a 100-micron mesh aquarium net, placed in a sample vial, preserved in formalin, and then dried and ashed in a muffle furnace at the laboratory to quantify ash-free dry mass of fine particulate organic matter (FPOM). Algal periphyton was quantified by scrubbing attached algae off rock surfaces using a wire brush, homogenizing the algae removed using a large syringe, and subsampling the homogenate for (a) chlorophyll-a by filtration through 1-micron pore-size glass fiber filters, and (b) archival of algae for cell counts and taxonomic identifications (preserved in formalin and Lugol's stain). This was performed on three replicate cobble-size rocks from mid-stream riffle habitats. The area of each rock was estimated from measures of length, width, height and circumference, and the chlorophyll-a per area determined by extraction of stored frozen filters in ethanol and reading light absorbance of the extract in a fluorometer relative to a standard curve.

Data Analysis (dose and response variables)

A recent National Research Council review of the scientific basis for use of TMDLs (NRC 2001) recognized that biological criteria or aquatic life uses of streams should be integrated into water quality targets because "biocriteria are a better indicator of designated uses than are chemical criteria." The design developed for the Squaw Creek TMDL anticipated the recommendations of this review in that biological criteria and an empirical dose-response model of the stressor (sediment) were planned from the outset of this study. Appendix I excerpts this review as further justification for the approach used.

The biological response variables used were based on measures that have been commonly applied in bioassessment analyses and have an expected (and documented) response to stress. After correlation analysis with environmental variables, selected metrics were combined into a standardized biological condition score to reduce the measures into a single index of biological integrity (the multimetric approach; Karr and Chu 1999).

Stream habitats with minimal human-related disturbance, heterogeneity in stream bed substrates and food resources, stable banks, mixed riparian cover, and unaltered flow regime typically contain a diverse array of sensitive taxa inhabiting varied microhabitats, using different food resources, and having varied life cycles. Stressors compromise the quality and variety in stream habitats, resulting in the loss of structural and functional diversity, and of organisms intolerant of stress (diversity is lost, composition changes).

<u>List of selected invertebrate community structure metrics and expected response to stress: (based on mean values from replicate samples)</u>

Biological Metric	Metric Definition	Expected Response to Stress
Taxa Diversity (mean of samples)	Total number or richness of taxa found in a sample (reflecting resource variety)	Decrease
EPT Diversity Index (ephemeroptera, plecoptera, and trichoptera)	Number of taxa belonging to mayfly, stonefly, and caddisfly orders, usually regarded as intolerant of pollution	Decrease
%EPT	Percent of the organisms present belonging to one of the EPT orders	Decrease
Biotic Index	Composite measure of community tolerance to pollution (based on tolerance values and relative abundance)	Increase
No. of Sensitive Taxa (0-2)	Number of taxa with tolerance values of 0, 1, or 2 (scale of 10; least to most tolerant)	Decrease
% Tolerant Taxa (7-10)	Percent of organisms with tolerance values of 7-10 (scale of 10)	Increase
%Dominance	Percent of organisms comprising the most abundant taxon (resource imbalance)	Increase
R-50 Dominance (pooled samples) [=diversity at 50% total count, and decreases as dominance increases]	Number of taxa required to reach 50% (half) of the ranked abundance of all organisms – an inverse dominance measure	Decrease

Variables to express the exposure to, or dose of sediment loading were derived both from model predictions (the AnnAGNPS model for the Truckee River watershed), and from empirical on-site measures of sediment-related physical features of the stream environment at each study reach. This complementary approach could also be used to verify whether observed habitat features matched the model predictions.

Predicted sediment loads (tons) were obtained from GIS analysis of the AnnAGNPS model using the UTM coordinates of each study reach as geospatial reference points for calculating the sum of upstream sediment that could reach that point in the watershed. The step-wise procedure used is documented in Appendix II (A. Sutherland, LRWQCB; personal communication).

Reasoning that sediment is transported and deposited from upstream sources over and along stream courses, the model-predicted sediment load was distributed both relative to the upstream channel length (both perennial and intermittent), and the study reach stream width (i.e., tons divided by sum of upstream miles, divided by mean stream width). This "distributed model" (tons/upstream mile/m width) was used to express the potential exposure to sediment loading at each site. In making these calculations, it was further assumed that lakes along the catchment basins serve as sediment traps, so any stream miles above lakes were excluded from the measure of upstream length. For streams surveyed in both years, widths were calculated as the mean of all transects combined. No model estimate of load was available for General Creek, so an approximation was made by using the load for Independence Creek (a similar forested watershed about 50% larger), and reducing this amount by about 10%.

Several measures taken during physical habitat surveys were also used to express the exposure or dose of sediment received at each study reach. Sediment remaining in a stream represents the legacy of past transport and the amount of load deposition onto the habitat of benthic invertebrates. Substrate type measures made along survey transects were used to calculate percent fines, percent fines + sand, and D-50 particle size (particle size at which cumulative distribution reaches 50%; calculated as fraction of size class range attaining the 0.5 proportion). In addition, percent cobble embeddedness is a measure of the extent to which substrate in this size class is buried by fines or sand. Turbidity was also examined as an indicator of sediment transport (though since transport is a transient process, point-sampling of turbidity is unlikely to detect sediment flux).

Once both sets of biological response metrics and sediment dose measures were summarized, a correlation analysis was performed to establish (1) the relation of the distributed sediment load model predictions to in-stream measures of sediment deposition, and (2) the relation of sediment to invertebrate community structure and composition. Each of the biological variables displaying correlations of R>0.5 (negative or positive) with some measure of stream sediment were then combined (after being converted to standard scores) to produce a single biological condition score for each stream. The full range of this score was then divided into to produce a scale for rating impairment thresholds.

Results and TMDL Development

The physical and chemical features of all stream study reaches are summarized in Tables 1a and 1b (low gradient reaches), Table 2 (upper watershed), and Table 3 (lower watershed). Contrast of the Squaw Creek sites with reference sites within each stream type shows that reference conditions frame the target sites with respect to most features except that discharge was lower on Squaw Creek. This was especially true in 2000 when flows were discontinuous over parts of the watershed (subsurface flows over portions of some study reaches). Such spatially intermittent channels come about during low flow periods and often form in reaches with permeable deposits of sediments and gravel (Stanley et al. 1997). Sediment deposition within the channel of Squaw Creek has produced a deep bed of alluvium within which surface water may infiltrate, promoting the occurrence of intermittent flows, especially in the low gradient meadow reaches that form the longest portion of the stream. Sediment deposition and flow variability are interconnected attributes of the Squaw Creek stream channel.

Management of sedimentation requires that there is a reasonable basis for understanding the sources of erosion that need to be controlled to improve water quality. The AGNPS modeling approach explicitly identifies landscape features that contribute to erosion. Examining the relationship between sediment load predictions and the size of watersheds, and in-stream measures of deposition can test the validity of the model. First, load is expected to scale with channel length or discharge (Leopold 1994) in reference watersheds, and Squaw Creek load should be above that expected for its size. Second, increased sediment transport loads should leave behind deposition of smaller particles. These expectations were verified, with Squaw Creek sites showing loads well above the regression-line among all sites surveyed outside the Squaw watershed (Figure 1), and decreased particle size with higher distributed load in low gradient streams (smaller D-50 particle size and greater percent of fines + sand; Figure 2). The clustering of sites along the gradient of distributed sediment loads (Figure 3) also provides a basis for identifying the streams that define the reference condition for each stream type. Low gradient, upper watershed, and lower watershed stream types each have reference sites that possess reduced loadings relative to Squaw Creek. The low gradient stream sites, with the most survey data, show that loads below the bin range of 300-400 tons/mile/m width define the reference stream load level (reference sites listed on upper panel, Figure 3).

Correlations between sediment-related physical variables and metrics of invertebrate community structure are shown as a matrix in Table 4. Data were derived from surveys of 28 streams, 140 benthic samples, and over 80,000 organisms counted. Of the physical variables examined, the distributed sediment load model, along with D-50 particle size and percent fines + sand, showed the best correlations with biological metrics. Turbidity, embeddedness, and %fines alone showed low correlation with metrics, and also did not correspond to the other sediment measures. Invertebrate community metrics that showed the highest correlations with the load, particle size and fines + sand measures of sediment included the biotic index, total taxa diversity, EPT taxa diversity, %EPT, number of sensitive taxa, percent tolerant taxa, and the R-50 measure of dominance and diversity. Selected examples of these dose-response relations are shown in Figures 4 through 6 (for low gradient stream type), Figure 7 (upper watershed stream type), and Figure 8 (lower watershed stream type). This set of physical and biological measures provide the most useful indicators for setting water quality targets and as future monitoring tools for tracking the progress of erosion control measures in habitat restoration.

Inspection of the dose-response graphs for the low gradient stream types suggest the following sediment targets may be associated with improved biological integrity:

- Figure 4: below a distributed sediment load of 400 tons/mile/m stream width
- Figure 5: above a geometric mean D-50 particle size of 40 mm
- Figure 6: below 25% fines + sand cover of the stream bottom

It is apparent that other factors may also ameliorate the negative effects of these levels of sedimentation indicators (since some reference sites also exceed these levels). Flow velocity, the availability of larger substrates, and turbulence (mostly related to gradient and bed roughness) may for example contribute to improved habitat, but the strong response of enhanced measures of the quality of stream life with low sedimentation argues for use of these measures as guidance in the load reductions needed to alleviate sediment stress. Of the low gradient Squaw Creek meadow sites, the lower meadow has the greatest distributed load value at nearly 800 tons/mile/m, suggesting that a load reduction of at least 50% will be required to improve habitat to below the exposure level of 400 tons/mile/m. With reference sites in the load range of 100-300, even greater reduction may be needed to attain this level of habitat quality. Since this load exposure is based on a long-term high-flow year (1996-97 water year), it is the in-stream measures of particle size and fines/sand cover that may be the best short-term indicators of the success of erosion control. If slope erosion is minimized, natural flushing flows may serve to gradually transport sediment out of the channel of Squaw Creek, and improve substrate conditions. A detailed analysis of the annual sediment input-output budgets would be needed to evaluate the conditions that would promote streambed cleansing.

In order to reduce the complexity of information contained in the various metrics of invertebrate community structure, standard scores were assigned to each metric for each stream, based on the distribution of all values for each metric (USEPA 1999b), and summed to produce a single biological condition index. The scores assigned to the actual value for each metric comprising the index were as follows:

	Biological Condition Scores Assigned to Metric Value Ranges		
Metric	**5**	**3**	**1**
Biotic Index	< 3.5	3.5 – 4.5	>4.5
Taxa Richness	>50.0	40.0 – 50.0	<40.0
EPT Diversity Index	>20.0	15.0 – 20.0	<15.0
%EPT of Total	>50%	35 – 50%	<35%
No. Sensitive Taxa	>18.0	12.0 – 18.0	<12.0
% Tolerant Taxa	<5%	5-10%	>10%
R-50 Index	>5.0	3.0 – 5.0	<3.0
Biological Condition Score Sum: Rating the loss of biological integrity / water quality			
Reference Score	20-30% impaired	35-50% impaired	>50% impaired
25-35	20-25	15-20	<15

Note that the reference sites, defined *a priori* according to the distributed sediment load model (Figure 3), conform to the threshold set for the biological reference condition (i.e. they score index values of 25 or greater, with the exception of Martis Creek). The other thresholds were set to express different levels of impairment relative to the mid-range of the reference condition (a value of 30).

Biological condition scores for low gradient stream reach types show that impairment of Squaw Creek meadow sites was severe in 2000 when flows were discontinuous, but improved somewhat in 2001 when flows were continuous (Figure 9). Instability in community structure between years in the Squaw meadows stream reaches is another sign of habitat disturbance (community composition measures changed substantially). As a criterion for recovery, the biological condition score should reach a reference value of 25, but recognizing inter-annual variability, this target level should be attained consistently (as a 5-year mean for example) to demonstrate stability in biological health.

Significant impacts to upper and lower watershed Squaw Creek reaches appear to be absent except on the South tributary in 2000 (biological condition scores of Table 5). This may be attributable to load movement through the system in the higher gradient upper watersheds, and upstream sediment capture in low gradient reaches (above the lower watershed Squaw site, below moraine). The South tributary has the highest distributed sediment load (about 2,700 tons/mile/m) and low flow conditions in 2000 may not have been sufficient to transport sediment and maintain high biological quality.

The approach used in this study provides useful guidance for the sediment TMDL because it combined (1) reference site sampling to establish a biological water quality target, (2) dose-response evaluation of impairment thresholds, and (3) determination of sediment exposure both from modeling data and in-stream field measures. With so many potential sources of confounding variation present in field data, the strong relation found between sediment and impaired biological quality attests to the reliability of the results.

Conclusions

using 10 low gradient ref. streams (incl. Martis)

Water quality targets can be defined for Squaw Creek using the reference biological data (25th to 75th percentile of observations), and associated sediment effect levels as follows:

Biotic Index	Taxa Diversity	EPT Taxa	%EPT Taxa	Sensitive Taxa	Tolerant Taxa	R-50 Index	Biological Condition Index
3.09 - 4.22	47.2 - 52.6	20.8 - 24.9	36 - 46%	16.8 - 19.9	0.4 - 1.7%	2.6 - 5.9	≥ 25

Distributed Load (tons/mile/m)	D-50 Size (mm)	%F+S Cover
< 400	> 40	< 25

Low gradient meadow reaches of Squaw Creek should be the focus of further monitoring of recovery indicators because these reaches represent cumulative effects, and are the most impaired stream habitats. Additional monitoring of reference watersheds under other flow conditions will also make target values more robust and applicable to a wider range of conditions.

The sediment load reductions necessary to (a) reduce impairment below an apparent threshold at 400 tons/mile/m is about 50%, and (b) achieve target values corresponding to loadings and biological condition of reference sites is about 75%. Inspection of the AnnAGNPS model terms, and the historic flow regime may provide insight to what control strategies could produce load reductions in this range (e.g. vegetation cover), or remove accumulated sediment (flushing flow level, below erosion thresholds).

As a final note, the data showed that Trout Creek at Bennett Flat had among the highest levels of sediment impairment of aquatic life uses. The sources and control of erosion in this small watershed should be considered in future water quality planning.

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Table 1a. Physical Habitat of Low Gradient Stream Types (2000)

Stream Site Day-month Year	Little Truckee upper Perazzo mdw 31 VIII 2000	Sagehen Ck below field stn 1 IX 2000	Cold Creek upper gravel pit 1 X 2000	Prosser Ck below confluence 31 VIII 2000	Squaw Ck lower mdw 28 VIII 2000	Squaw Ck middle mdw 29 VIII 2000	Squaw Ck upper mdw 29 VIII 2000
stream order	4	2	2	3	3	3	3
upstream length (miles)	33.16	19.18	14.66	38.85	9.14	8.94	8.81
Mean width (cm)	**522.3**	**381.9**	**523**	**743.7**	**254.4**	**301.7**	**492.2**
SD width	168.3	108.6	228	167.8	110.9	101.7	206.7
Mean depth (cm)	**10.8**	**20.6**	**23**	**16.9**	**20.6**	**22.7**	**18.6**
SD depth	6.3	17.6	19.3	9.1	15.5	16.2	15.6
Mean velocity (cm/s)	**2.9**	**49.9**	**7.8**	**13.1**	**0**	**0**	**0**
SD velocity	7	50.6	17.1	14.5	0	0	0
Max depth (cm)	34	77	88	40	68	75	79
% Riparian cover	14.1	32.4	18	20.9	12.2	5	3.4
Sinuosity	1.42	1.28	1.1	1.04	1.1	1.2	1.97
Elevation (ft)	6525	6280	6140	6000	6180	6180	6180
Slope %	0.7	1.4	0.5	0.7	0.2	0.1	0.2
GPS N	43 73750	43 68936	43 53689	43 62919	43 43245	43 433185	43 42814
GPS E	10 725859	10 738354	10 736865	10 738934	10 740475	10 740287	10 740091
Embeddedness:							
Mean embedded. %	24	7.6	21.2	12.2	0.8	3.25	7.6
Riparian Index:							
Herbaceous (0-5)	3	5	2	1	5	5	5
Woody (0-15)	6	9	7	7	1	1	2
Bank cover:							
% stable	96.7	96.7	73.3	96.3	76.7	80	83.3
% eroded	3.3	3.3	26.7	3.3	23.3	20	16.7
% open	0	3.3	0	26.7	43.3	60	56.7
% Vg	63.3	73.3	43.3	10	33.3	13.3	20
% Vb	0	0	0	0	0	0	3.3
% Vt	6.7	3.3	0	30	0	0	0
% Armored	30	20	56.7	33.3	23.3	26.7	20
Bank angle:							
% shallow	26.7	23.3	23.3	63.3	43.3	46.7	50
% moderate	56.7	33.3	46.7	30	46.7	46.7	50
% undercut	16.7	43.3	30	6.7	10	6.7	0
% riffle	34	44	29.3	36	20	34.7	30
% pool	18	31.3	50	14.7	34	40.7	38
% dry	0	0	0	0	19.3	7.3	3.3
Water chemistry:							
Temperature (degC)	19.1	9.3	11.2	18.9	24	17.8	17.2
pH	7.14	7.77	6.56	7.78	6.85	6.77	6.46
Conductivity (uS)	81.2	172.7	67.2	130.2	174.4	156.9	162.1
D.O. (ppm)	9.2	10	9	8.5	9.5	8.8	6.2
Alkalinity	30	90	42	70	60	42	42
Turbidity (NTU)	0.64	0.48	1.32	0.48	1.42	5.64	1.26
Total N (mg/L)	0	0	0	0	0	0	0
TKN (mg/L)	0.84	1.1	1.3	1.3	1.3	1.2	1
Total P (mg/L)	0	0	0	0	0	0	0
SO4 (mg/L)	2	0	0	1.9	17	22	31
Hardness (mg/L)	28.4	66.3	23.5	51.5	64.4	49	59.8
SiO2 (mg/L)	16	24	19	17	4.3	4.5	7.4
Substrate/cover:							
% fines	0	1.3	4	0	8	9.3	13.3
% sand	1.3	0	4	14.7	21.3	30.7	32
% gravel	37.3	42.7	58.7	18.7	40	41.3	44
% cobble	48	50.7	33.3	16	30.7	14.7	10.7
% boulder	13.3	5.3	0	50.7	0	4	0
D-50 particle size (mm)	**109**	**87**	**47**	**335**	**35**	**18**	**9.6**
Discharge Q (cfs):							
Mean non-zero Q	**0.47**	**9.65**	**1.33**	**5.72**	**0.00**	**0.00**	**0.00**
SD non-zero Q	0.38	4.63	0.78	3.64	0.00	0.00	0.00
Mean FPOM (g/m^2)	**0.47**	**2.54**	**1.54**	**0.78**	**1.46**	**1.29**	**4.95**
SD FPOM	0.21	0.81	1.50	0.65	0.54	0.70	3.15
Mean CPOM (g/m^2)	**16**	**86.7**	**1159.3**	**24**	**16.7**	**21.3**	**10.7**
SD CPOM	14.4	34.5	1923.2	14.4	15.1	9	3.1
Mean Chl a (ug/cm^2)	**0.973**	**1.655**	**1.358**	**2.664**	**0.656**	**0.694**	**0.407**
SD Chla	0.521	0.957	1.327	0.305	0.373	0.336	0.188

→ SG. very low

see habitat

Table 1b. Physical Habitat of Low Gradient Stream Types (2001)

Stream	Perazzo Ck	Independence Ck	Trout Ck	Martis Ck	Alder Ck	N. Prosser Ck	Sagehen Ck	Little Truckee	Squaw Ck	Squaw Ck
Site	meadow	below rd	Bennett flat	above confluence	meadow	below USFS	below field stn	below Coldstream	lower mdw	middle mdw
Day-month	12 VII	13 VII	11 VII	10 VII	11 VII	11 VII	12 VII	13 VII	9 VII	9 VII
Year	2001	2001	2001	2001	2001	2001	2001	2001	2001	2001
stream order	3	2	1	2	1	2	2	4	3	3
upstream length (miles)	16.16	16.25	2.35	13.47	4.33	20.41	19.18	28.44	9.14	8.94
Mean width (cm)	**527.7**	**497.3**	**108.8**	**225.6**	**159**	**602**	**360**	**679.7**	**321.8**	**465.7**
SD width	150.4	108.9	13.6	87.8	47.5	201.6	154.9	172.9	110.2	198.3
Mean depth (cm)	**19.5**	**16.3**	**15**	**20.5**	**14.3**	**22.1**	**19.7**	**22.7**	**21.3**	**27.3**
SD depth	18.5	9.5	10.7	13.7	14.3	14.9	15.9	18.8	15.2	19.2
Mean velocity (cm/s)	**5.2**	**18.1**	**11.4**	**13.5**	**11.1**	**8.3**	**12.9**	**7.6**	**2.7**	**27.7**
SD velocity	9.8	16.3	14	14.1	14.8	14.1	16.2	14.2	8.7	24
Max depth (cm)	77	50	41	54	51	64	72	96	62	85
% Riparian cover	4.2	34.3	49.1	30.4	45.6	21.8	27.8	13.3	7.1	3.7
Sinuosity	1.21	1.1	1.97	1.46	1.43	1.19	1.28	1.49	1.1	1.2
Elevation (ft)	6550	6420	6180	5840	6220	6180	6280	6460	6180	6180
Slope %	0.3	2.1	0.5	0.6	1.2	0.6	1.4	0.7	0.2	0.1
GPS N	43 72780	43 74222	43 58647	43 53677	43 61255	43 63239	43 68932	43 74930	43 43248	43 43375
GPS E	10 725190	10 0733749	10 740431	10 0746938	10 0738728	10 0736638	10 738372	10 0728193	10 0740476	10 740340
Embeddedness:										
Mean embedded. %	2.2	0	33	4.58	24.2	47.2	15.4	4.4	15.2	24.2
Riparian index:										
Herbaceous (0-5)	3	3	5	5	5	4	4	3	5	2
Woody (0-15)	2	8	2	8	6	5	6	2	1	1
Bank cover:										
% stable	26.7	96.7	96.7	76.7	90	86.7	96.7	83.3	20	26.7
% eroded	73.3	3.3	3.3	23.3	10	13.3	3.3	16.7	80	73.3
% open	50	3.3	0	20	3.3	33.3	13.3	0	43.3	50
% Vg	40	53.3	100	60	80	23.3	50	53.3	56.7	50
% Vb	0	6.7	0	6.7	0	3.3	10	0	0	0
% Vt	0	26.7	0	13.3	6.7	30	6.7	0	0	0
% Armored	10	10	0	0	10	16.7	20	46.7	0	0
Bank angle:										
% shallow	43.3	13.3	3.3	20	3.3	43.3	13.3	40	33.3	43.3
% moderate	50	36.7	80	50	76.7	43.3	40	40	46.7	36.7
% undercut	6.7	50	16.7	30	20	13.3	46.7	16.7	20	20
% riffle	22.7	68.7	26	40.7	44	39.3	37.3	30.7	10	7.3
% pool	66.7	17.3	14	40	24.7	29.3	40	41.3	90	54.7
% dry	0	0	0	0	0	0	0	0	0	0
Water chemistry:										
Temperature (degC)	15.3	12	12.9	14.3	13.2	21.2	18	18.7	22.8	21.7
pH	6.29	6.78	7.28	7.39	7.54	7.13	7.55	6.71	6.55	6.59
Conductivity (uS)	77.7	54.2	196	158.6	140.8	102.6	173.1	82.4	160.7	166.9
D.O. (ppm)	8.4	9	8.4	9.8	8.4	7.9	8	8	7.9	7.4
Alkalinity	56	36	88	94	73	62	104	68	64	51
Turbidity (NTU)	0.58	0.71	3.32	1.16	2.08	0.55	0.45	8.48	0.76	0.4
Total N (mg/L)	0.019	0.012	0.005	0.006	0.013	0.003	0.016	0.004	0.002	0.003
TKN (mg/L)	0.073	0.088	0.246	0.108	0.207	0.128	0.102	0.121	0.097	0.091
Total P (mg/L)	0.006	0.008	0.043	0.031	0.016	0.014	0.022	0.017	0.012	0.007
SO4 (mg/L)	4.2	0.15	1.1	0.43	0.37	1.7	0.12	1.6	21	22
Hardness (mg/L)	27.3	20.6	65	56.3	49.3	32	71.7	34.7	52.3	55.2
SiO2 (mg/L)	7.3	6.5	11	14	13	10	15	10	4.5	4.3
Substrate/cover:										
% fines	4	1.3	47.3	18.7	6.7	2.7	6.7	1.3	16	13.3
% sand	5.3	4	14.7	10.7	0	33.3	1.3	4	10.7	36
% gravel	56	24	34.7	48	62.7	12	25.3	25.3	72	44
% cobble	34.7	57.3	4	22.7	30.7	34.7	56	69.3	1.3	6.7
% boulder	0	13.3	0	0	0	17.3	10.7	0	0	0
D-50 particle size (mm)	**48**	**132**	**1.4**	**30**	**46**	**76**	**120**	**117**	**23**	**4**
Discharge Q (cfs):										
Mean non-zero Q	**1.02**	**5.08**	**0.65**	**1.62**	**0.42**	**3.30**	**2.80**	**2.95**	**0.17**	**0.23**
SD non-zero Q	0.75	2.50	0.22	0.64	0.15	2.40	1.10	2.09	0.14	0.27
Mean FPOM (g/m^2)	**1.09**	**1.93**	**1.98**	**2.16**	**4.55**	**1.03**	**2.38**	**2.16**	**0.36**	**0.39**
SD FPOM	1.30	0.29	1.05	0.44	0.71	0.38	1.12	1.25	0.30	0.20
Mean CPOM (g/m^2)	**325.3**	**241.3**	**82.7**	**121.3**	**84**	**50**	**340**	**40**	**6.7**	**11.3**
SD CPOM	545.1	159.2	67.9	38.4	44	38.9	455.7	10	1.2	9
Mean Chl a (ug/cm^2)	**0.560**	**0.394**	**0.844**	**0.412**	**1.214**	**0.306**	**0.518**	**0.438**	**0.099**	**0.342**
SD Chla	0.516	0.178	0.468	0.173	0.779	0.109	0.171	0.166	0.053	0.314

Table 2. Physical Habitat of Upper Watershed Stream Types (2000-01)

Stream **Site** **Day-month** **Year**	Pole Ck tributary reference 31 VIII 2000	Lacey Ck confined section 12 VII 2001	Juniper Ck above rd xing 10 VII 2001	Squaw S. Trib. below headwall 29 VIII 2000	Squaw S. Trib. below headwall 9 VII 2001	Squaw N. Trib. below Silverado 28 VIII 2000	Squaw N. Trib. below Silverado 9 VII 2001
stream **order**	2	2	2	2	2	2	2
upstream **length** (miles)	2.4	10.38	14.26	1.65	1.65	3.12	3.12
Mean **width** (cm)	**193.6**	**319**	**189.7**	**168.1**	**176.2**	**151.7**	**252.7**
SD width	54.4	111.8	72.2	96.6	80.2	84.8	110.6
Mean **depth** (cm)	**10.3**	**15.2**	**8.7**	**7.3**	**11.4**	**11.2**	**16.3**
SD depth	6.3	12.6	4.6	7.4	10.2	11.8	10.5
Mean **velocity** (cm/s)	**4.8**	**5.2**	**9.7**	**4.4**	**5.6**	**0**	**3.5**
SD velocity	7.3	10.2	12.6	6	9.3	0	9.6
Max depth (cm)	29	71	20	43	55	53	59
% Riparian cover	54.5	34.1	20.7	52.4	46.1	77.3	65.3
Sinuosity	1.14	1.01	1.2	1.17	1.17	1.15	1.15
Elevation (ft)	6780	6830	6260	6820	6820	6780	6780
Slope %	5.5	1.8	2.9	7.6	7.6	3.2	3.2
GPS N	43 46250	43 71424	43 60128	43 41298	43 41334	43 42995	43 43030
GPS E	*10 738800*	*10 0721405*	*10 753618*	*10 737668*	*10 0737726*	*10 737361*	*10 737366*
Embeddedness:							
Mean embedded. %	33.4	10	38.8	27.4	20.4	2.4	32.8
Riparian Index:							
Herbaceous (0-5)	1	3	5	1	1	1	1
Woody (0-15)	8	7	7	8	6	11	11
Bank cover:							
% stable	93.3	100	83.3	100	96.7	100	96.7
% eroded	6.7	0	16.7	0	3.3	0	3.3
% open	6.7	3.3	6.7	0	3.3	3.5	3.3
% Vg	6.7	26.7	56.7	0	0	0	3.3
% Vb	0	0	0	0	0	0	0
% Vt	33.3	10	3.3	10	10	50	36.7
% Armored	53.3	60	33.3	90	86.7	46.5	56.7
Bank angle:							
% shallow	20	16.7	20	20	3.3	3.5	10
% moderate	80	73.3	46.7	73.3	90	93	73.3
% undercut	0	10	33.3	6.7	6.7	3.5	16.7
% riffle	58	17.3	58.7	33.3	46.7	17	22.7
% pool	16.7	35.3	26	22.7	24	26	38
% dry	0	0	0	0	0	0	0
Water chemistry:							
Temperature (degC)	10.2	15.2	17.4	13	12.3	11.6	12.2
pH	6.96	7.74	7.72	7.18	6.94	6.86	6.43
Conductivity (uS)	147.4	42.4	156.4	136	17.8	65.9	52.3
D.O. (ppm)	10	8.6	6.8	8.8	8.8	8.8	8.6
Alkalinity	70	25	70	65	64	30	25
Turbidity (NTU)	0.42	0.21	2.81	0.39	0.24	0.23	0.24
Total N (mg/L)	0	0.002	0.003	0.063	0.044	0.056	0.012
TKN (mg/L)	0.7	0.072	0.112	0.84	0.081	0.98	0.058
Total P (mg/L)	0	0.006	0.025	0	0.007	0	0.004
SO4 (mg/L)	9	0.61	3.9	4	3.6	2	1.1
Hardness (mg/L)	58.1	16.1	51.8	56.9	37.8	23.6	15.5
SiO2 (mg/L)	13	7.8	12	5.7	3	5.4	3.2
Substrate/cover:							
% fines	0	0	0	0	1.3	0	0
% sand	5.3	12	1.3	5.3	12	13.3	13.3
% gravel	30.7	22.7	45.3	32	22.7	33.3	18.7
% cobble	52	29.3	44	28	30.7	25.3	32
% boulder	12	36	9.3	34.7	33.3	28	36
D-50 particle size (mm)	**116**	**162**	**79**	**149**	**149**	**90**	**169**
Discharge Q (cfs):							
Mean non-zero Q	**0.35**	**0.75**	**0.49**	**0.12**	**0.26**	**0.00**	**0.37**
SD non-zero Q	0.15	0.38	0.28	0.07	0.16	0.00	0.12
Mean **FPOM** (g/m^2)	**1.07**	**0.70**	**3.53**	**0.63**	**0.91**	**1.36**	**1.27**
SD FPOM	0.44	0.03	1.86	0.19	0.20	0.51	0.66
Mean **CPOM** (g/m^2)	**75.3**	**80**	**64.7**	**45.3**	**100.7**	**228**	**129.3**
SD CPOM	85.5	73.7	28.9	29.5	112.3	98.2	107
Mean **Chl a** (ug/cm^2)	**0.543**	**0.133**	**0.535**	**2.377**	**0.246**	**0.915**	**0.678**
SD Chla	0.278	0.039	0.335	2.090	0.102	0.164	0.559

Table 3. Physical Habitat of Lower Watershed Stream Types (2000-01)

Stream	Bear Ck	Bear Ck	General Ck	Squaw Ck
Site	lower	lower	below loop rd	below moraine
Day-month	30 VIII	10 VII	30 VIII	28 VIII
Year	2000	2001	2000	2000
stream **order**	2	2	3	3
upstream **length** (miles)	3.84	3.84	9.27	9.86
Mean **width** (cm)	**271.3**	**314.3**	**439**	**270.9**
SD width	82.7	117.9	206	178.4
Mean **depth** (cm)	**12.8**	**13.2**	**23.6**	**8.7**
SD depth	9.3	9.6	18.4	5.7
Mean **velocity** (cm/s)	**12.2**	**8**	**3.2**	**4**
SD velocity	14.5	13.2	7.2	8.2
Max depth (cm)	21	45	64	28
% Riparian cover	49.1	33.4	55.3	38.9
Sinuosity	1.15	1.15	1.75	1.03
Elevation (ft)	6180	6180	6420	6160
Slope %	4.3	4.3	1.1	1.7
GPS N	43 41599	43 41641	43 25388	43 43493
GPS E	10 741900	10 0741854	10 747161	10 741141
Embeddedness:				
Mean embedded. %	8.8	19.6	32.4	26.6
Riparian index:				
Herbaceous (0-5)	1	1	3	3
Woody (0-15)	6	6	10	9
Bank cover:				
% stable	100	100	93.3	100
% eroded	0	0	6.7	0
% open	0	10	3.3	20
% Vg	6.7	0	23.3	0
% Vb	0	13.3	0	0
% Vt	13.3	0	20	16.7
% Armored	80	76.7	53.3	63.3
Bank angle:				
% shallow	46.7	20	23.3	33.3
% moderate	36.7	73.3	63.3	63.3
% undercut	16.7	6.7	13.3	3.3
% riffle	46.7	48	15.3	21.3
% pool	18.7	16.7	50.7	78.7
% dry	0	0	0	0
Water chemistry:				
Temperature (degC)	14.3	19.8	9	13.8
pH	7.45	7.5	5.8	7.05
Conductivity (uS)	113.1	112.8	48.4	264
D.O. (ppm)	8.2	8	8.5	8.5
Alkalinity	60	80	35	42
Turbidity (NTU)	0.55	2.1	0.49	0.61
Total N (mg/L)	0	0.01	0	0.069
TKN (mg/L)	0.98	0.091	1.1	1.5
Total P (mg/L)	0	0.013	0.	0
SO4 (mg/L)	1.2	2.9	0.5	82
Hardness (mg/L)	3.3	37.4	16.1	115.5
SiO2 (mg/L)	14	7.8	11	0
Substrate/cover:				
% fines	0	0	0	0
% sand	0	4	30.7	46.7
% gravel	22.7	20	30.7	30.7
% cobble	40	38.7	18.7	13.3
% boulder	37.3	37.3	20	9.3
D-50 particle size (mm)	**191**	**195**	**42**	**9.7**
Discharge Q (cfs):				
Mean non-zero Q	**1.31**	**1.29**	**0.39**	**0.03**
SD non-zero Q	0.67	0.97	0.22	0.02
Mean **FPOM** (g/m^2)	**2.31**	**0.79**	**0.56**	**0.30**
SD FPOM	0.34	0.37	0.16	0.10
Mean **CPOM** (g/m^2)	**73.3**	**43.33**	**94.7**	**53.3**
SD CPOM	10.1	25.2	125.9	37.8
Mean **Chl** <u>a</u> (ug/cm^2)	**0.714**	**0.109**	**1.904**	**1.259**
SD Chla	0.258	0.052	1.112	1.614

Table 4. Correlation Matrix for Sediment Dose and Biological Response Variables (R-values)

	Load	*D-50*	*%Embed.*	*Turbidity*	*%F+S*	*%F*
Load	1.000					
D-50	***-0.596***	1.000				
%Embed.	0.190	-0.100	1.000			
Turbidity	0.120	-0.108	-0.202	1.000		
%F+S	***0.675***	***-0.502***	0.304	0.081	1.000	
%F	***0.730***	***-0.509***	0.258	0.116	***0.757***	1.000
Total Richness	***-0.506***	0.428	0.088	-0.144	***-0.650***	-0.428
Biotic Index (mod.HBI)	***0.642***	***-0.608***	-0.353	0.387	***0.586***	0.472
Mean Richness	***-0.545***	0.454	0.071	-0.181	***-0.680***	-0.407
EPT Diversity	***-0.619***	***0.566***	0.317	-0.289	***-0.660***	-0.472
Density (#/m^2)	-0.206	-0.025	0.118	-0.184	-0.339	0.006
%Dominance	0.368	-0.436	0.083	-0.129	0.176	0.369
%Chironomidae	0.066	-0.280	-0.474	0.350	-0.017	-0.115
Chironomidae richness	-0.265	0.185	-0.304	0.215	-0.436	-0.302
EPT/Chironomidae	-0.251	0.352	0.416	-0.325	-0.237	-0.174
%EPT total	***-0.510***	***0.560***	0.359	-0.308	-0.356	-0.431
%EPT (w/o B,H)	-0.307	0.456	0.293	-0.222	-0.210	-0.344
No. Sensitive (0-2)	***-0.597***	***0.514***	0.310	-0.292	***-0.651***	-0.389
% Tolerant (7-10)	***0.632***	-0.422	-0.139	0.373	***0.649***	***0.541***
R-50 Dominance Index	-0.322	***0.541***	-0.094	0.067	-0.289	-0.407

Correlations with a value of greater than 0.5 (negative or positive) are highlighted in bold italics for relationships among sediment variables (above line) and between sediment dose measure and biological response measure (below line).

Load refers to distributed model of predicted sediment load, D-50 is the geometric mean particle size, % embed. is the percent embeddedness of cobble substrates, turbidity is suspended particles, %F+S refers to percent fines and sand cover on the stream bottom.

Note that figures do not show error bars for the means plotted. For an indication of the error term in the metrics, the coefficient of variation (below) can be used. Metrics in left column have some of the best correlations with physical habitat variables and also the lowest values for coefficient of variation.

Coefficient of Variation for Biological Metrics (all 28 stream surveys)

Metric	Mean %CV	Metric	Mean %CV
Biotic Index	9.2	Density	38.0
Taxa Richness	10.8	%Dominance	28.3
EPT Taxa Diversity	12.6	%Chironomidae	29.1
%EPT Taxa	20.0	Chironomid Richness	17.2
No.sensitive taxa (tv 0-2)	15.8	EPT/Chiro. ratio	33.9
		%EPT(w/o *Baetis,Hydropsyche*)	23.0
		%Tolerant taxa (tv 7-10)	76.2

Table 5. Listing of Biological Condition Scores for all stream reaches and component metric scores.

BIOLOGICAL CONDITION SCORES

Lower Watershed Stream Reach Type		Year	HBI	Mean R	EPT	%EPT	No. 0-2	% 7-10	R-50	Index Sum
General Ck	below loop rd	2000	5	3	5	5	5	5	3	**31**
Bear Ck	lower	2000	5	5	5	5	5	5	3	**33**
Bear Ck	lower	2001	3	5	5	3	5	5	3	**29**
Squaw Ck	below moraine	2000	5	3	3	5	3	5	5	**29**
Upper Watershed Stream Reach Type										
Lacey Ck	confined section	2001	5	3	5	3	5	5	5	**31**
Juniper Ck	above rd xing	2001	3	5	5	1	5	5	3	**27**
Pole Ck	tributary reference	2000	5	3	5	5	5	5	3	**31**
Squaw N. Trib.	below Silverado	2000	5	3	5	5	5	5	3	**31**
Squaw N. Trib.	below Silverado	2001	5	3	5	5	5	5	5	**33**
Squaw S. Trib.	below headwall	2000	3	1	3	5	3	5	1	**21**
Squaw S. Trib.	below headwall	2001	5	3	3	3	5	5	5	**29**
Low Gradient Stream Reach Type										
Trout Ck	Bennett Flat	2001	1	1	1	3	1	1	3	**11**
Squaw Ck	middle mdw	2001	3	3	3	3	3	5	3	**23**
Squaw Ck	upper mdw	2000	1	1	1	1	1	1	3	**9**
Squaw Ck	middle mdw	2000	1	1	1	1	1	1	3	**9**
Squaw Ck	lower mdw	2001	1	3	3	1	3	5	1	**17**
Martis Ck	above confluence	2001	3	3	3	3	3	5	1	**21**
Squaw Ck	lower mdw	2000	1	1	1	3	1	1	3	**11**
Alder Ck	meadow	2001	1	5	5	1	5	3	5	**25**
Cold Creek	upper gravel pit	2000	3	3	5	5	5	5	3	**29**
Perazzo Ck	meadow	2001	3	3	3	3	3	5	5	**25**
N. Prosser Ck	below USFS boundary	2001	5	3	5	5	5	5	5	**33**
Sagehen Ck	below field stn	2000	5	5	5	5	5	5	5	**35**
Little Truckee	upper Perazzo mdw	2000	5	3	5	5	5	5	1	**29**
Little Truckee	below Coldstream	2001	3	5	5	1	3	3	5	**25**
Sagehen Ck	below field stn	2001	3	5	5	1	5	5	5	**29**
Independence Ck	below rd	2001	3	5	5	3	5	5	5	**31**
Prosser Ck	below confluence	2000	5	3	5	5	5	5	5	**33**

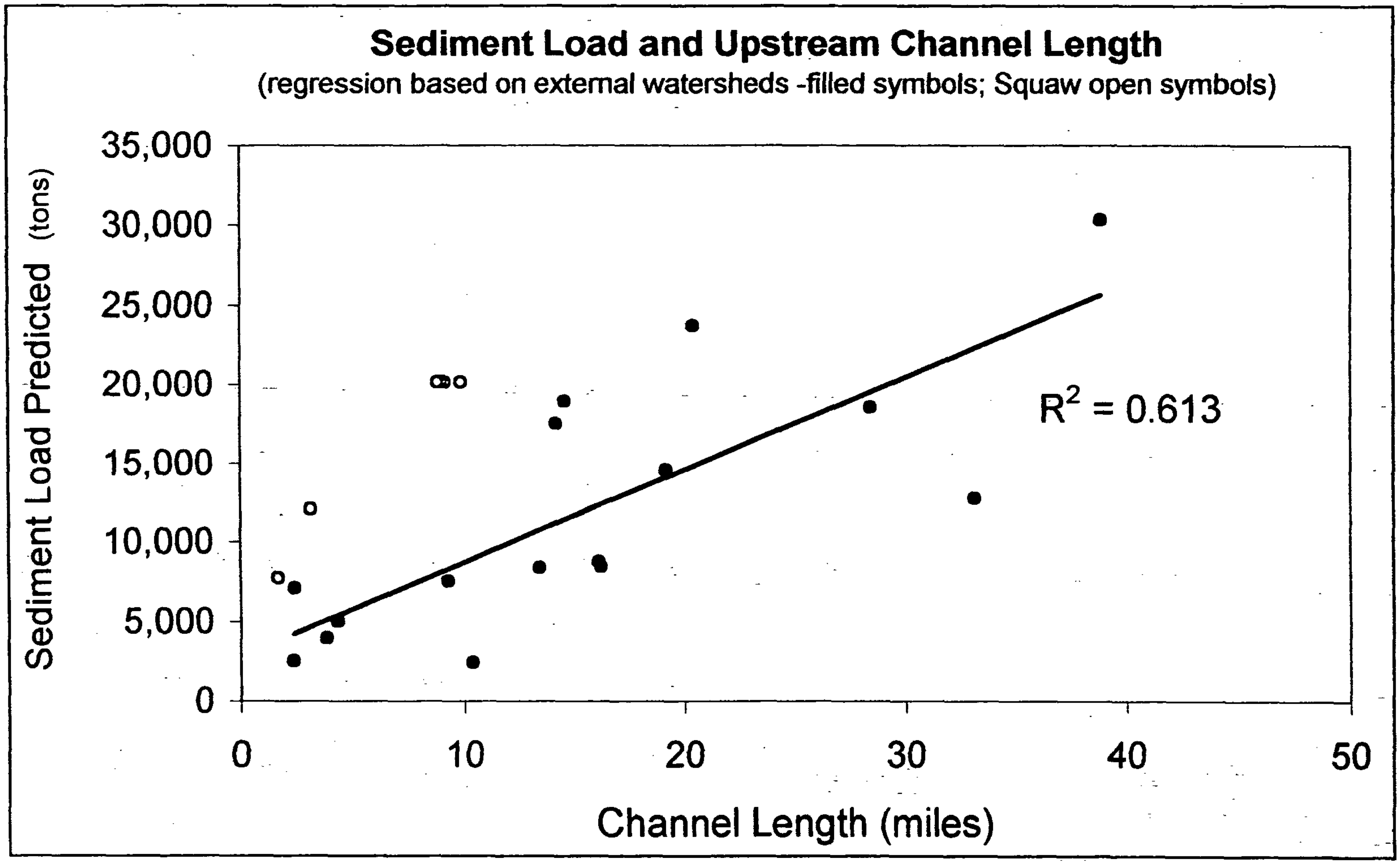


Figure 1. Relationship between maximum sediment load potential (based on a high flow year) for each stream site **and the total upstream miles of the watershed** above the stream site (perennial and intermittent channels). Regression based on watersheds external to or outside of (filled symbols) the Squaw watershed (open symbols). This provides a conservative approximation of the sediment loading to be expected based on the size of the watershed, and shows Squaw sediment load exceeds that expected for the watershed size.

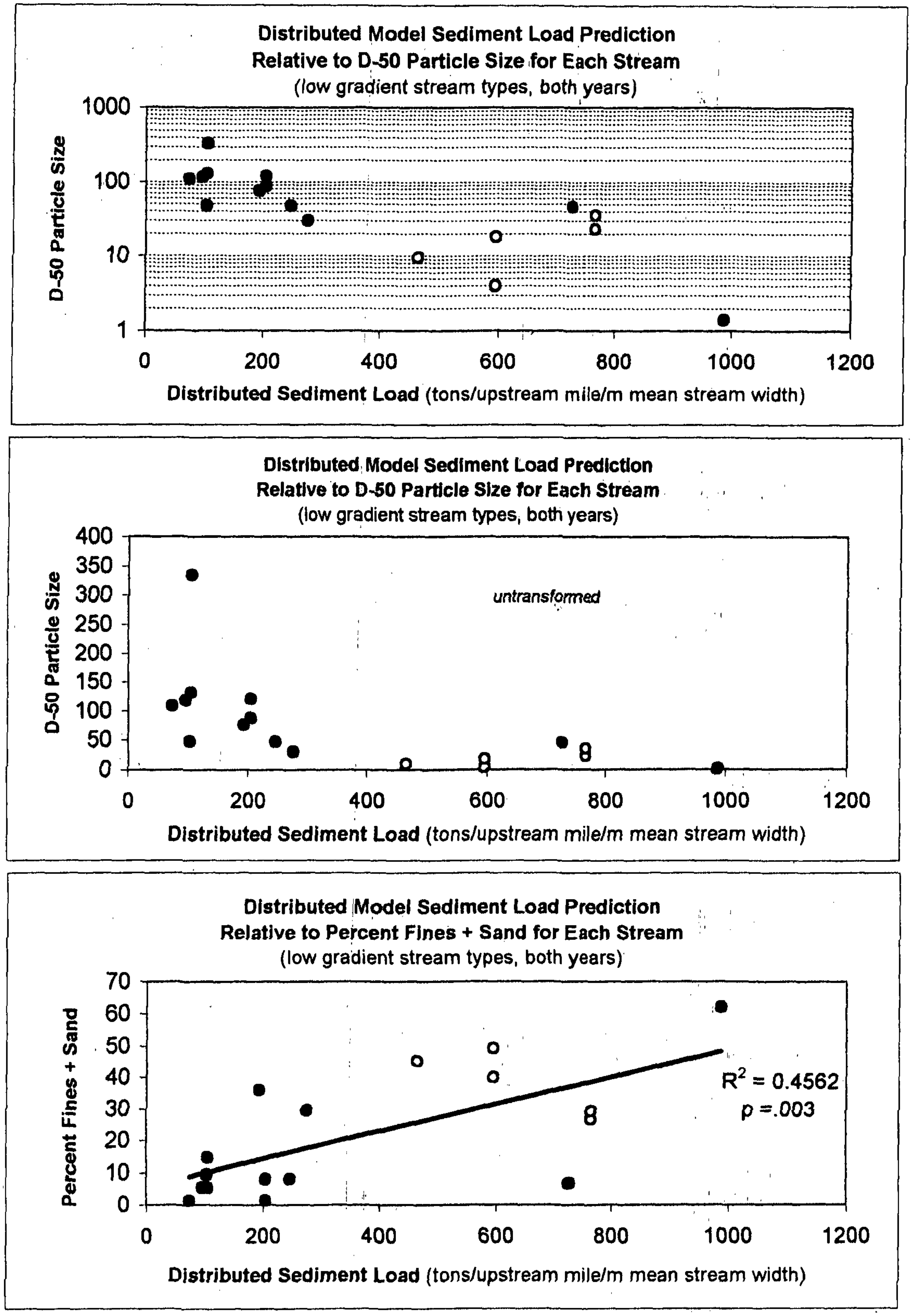


Figure 2. Relationship between sediment load model prediction (distributed over total upstream miles and mean channel width) **and measured sediment particle size and deposition** at each stream site (2000 and 2001 sampling). Upper panel is the log-transformed geometric mean particle size, and middle panel is the untransformed plot of the same data. Lower panel is the percent fines and sand. Data comes from low gradient (<2%) stream types from both years of sampling and open symbols are Squaw meadows sites. Some sites are repeated (both years) but were assigned the same sediment load (based on maximum load potential for a high flow year at each site). Observed conditions match the predicted sediment exposure.

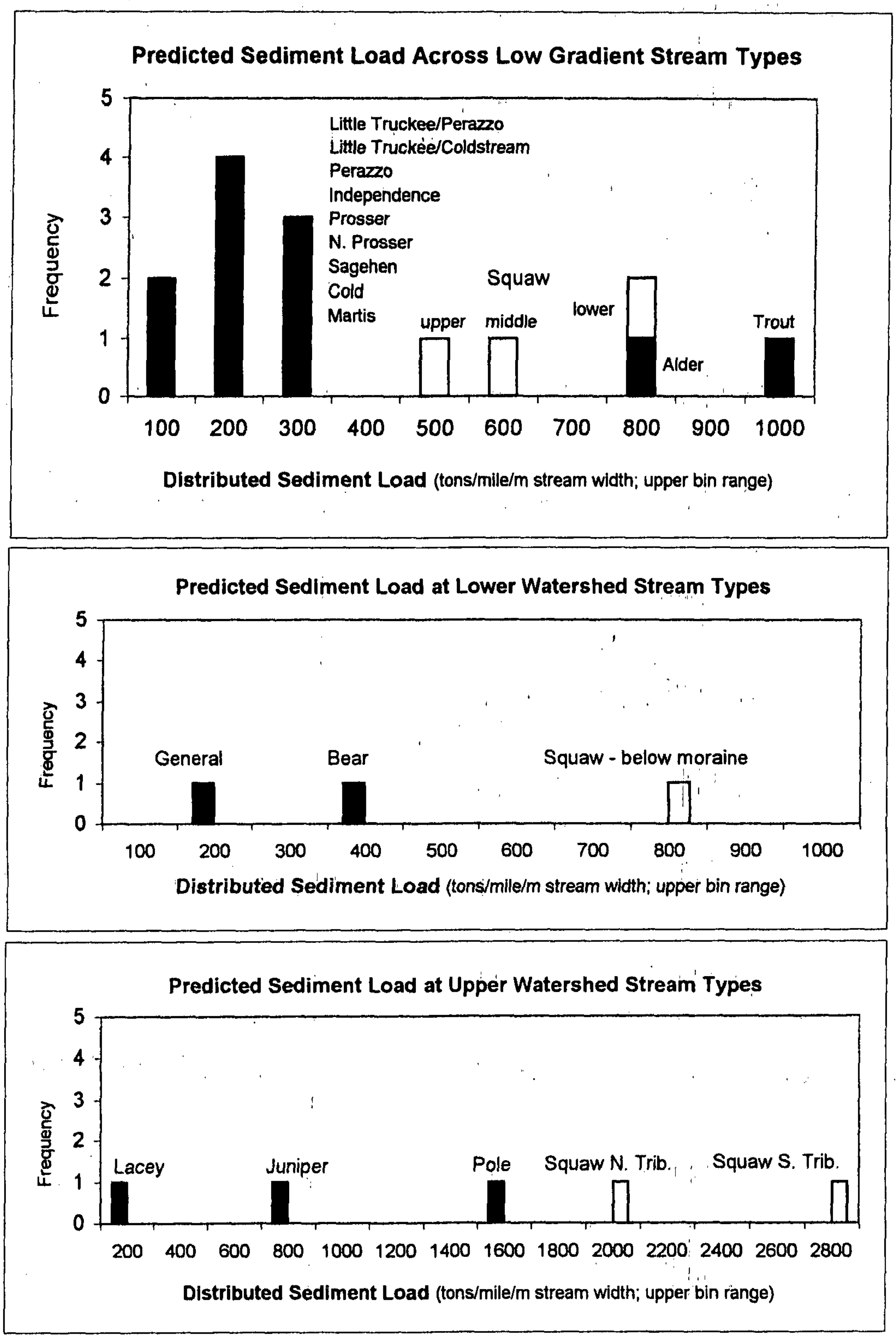
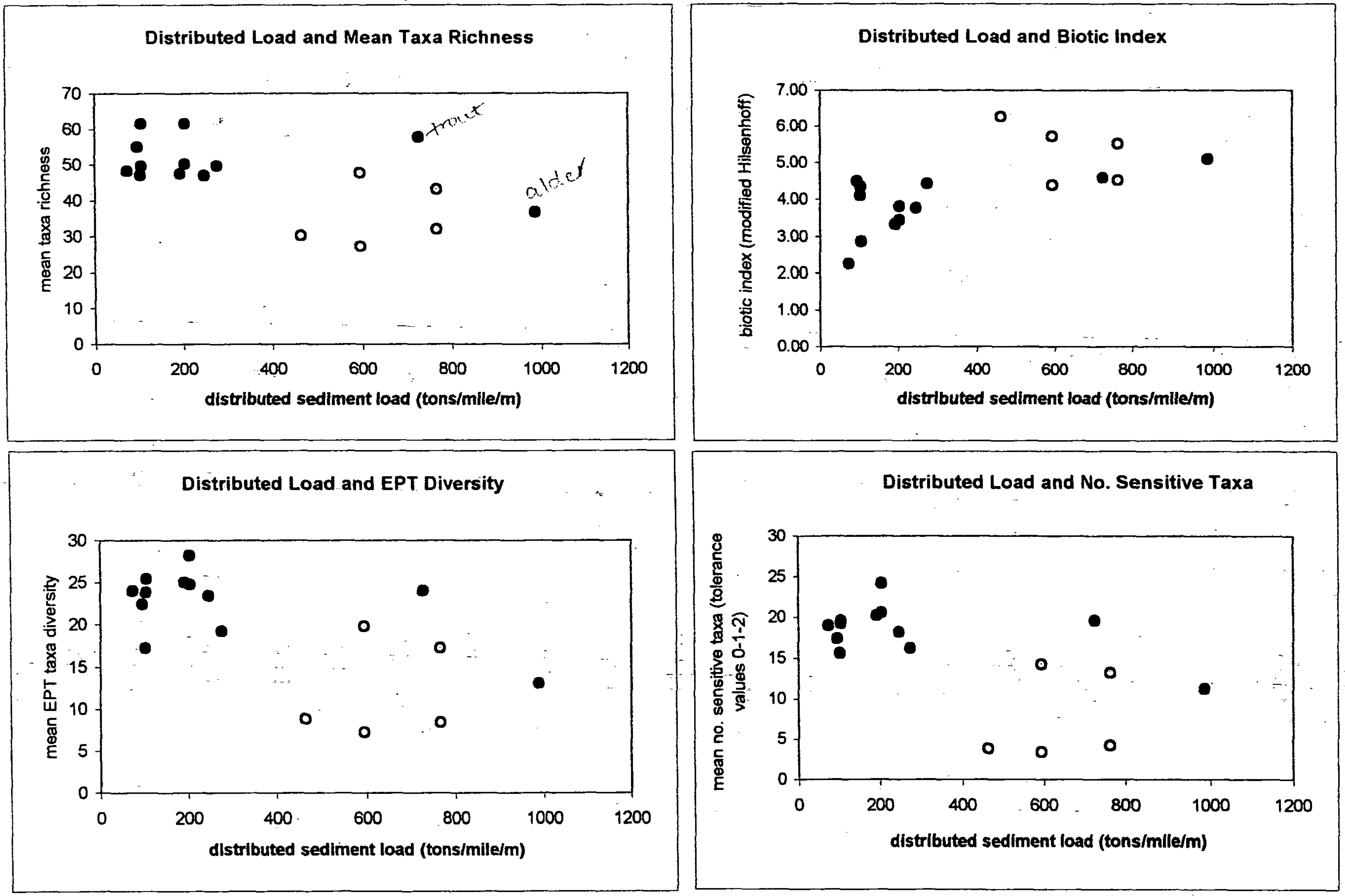


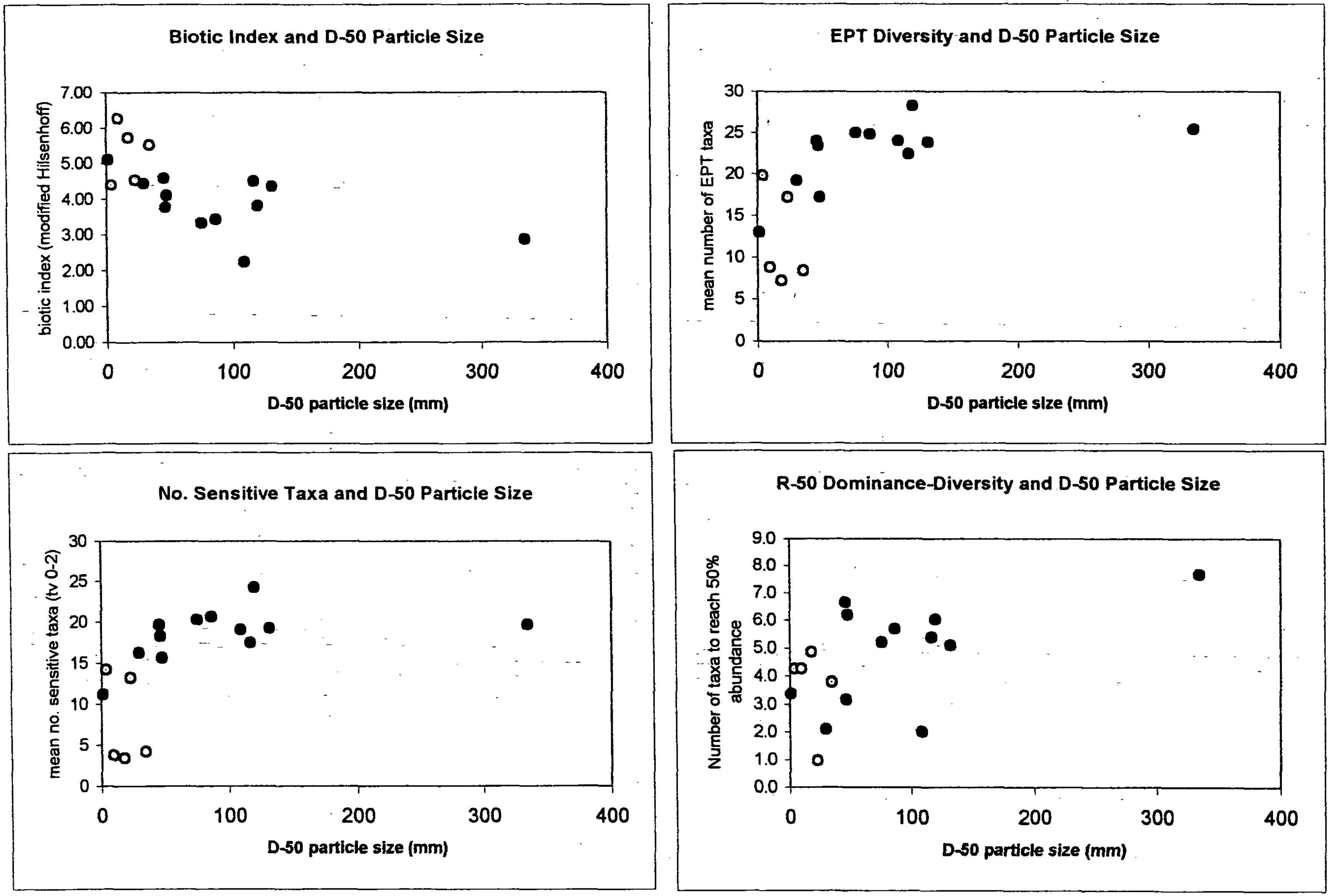
Figure 3. Distributed sediment load predicted for each stream type. Upper panel shows low gradient type (<2% slope); middle panel the lower watershed types (downstream in drainage); and lower panel the upper watershed stream types. Note that most of the Squaw sites (open bars) have higher predicted sediment loads than the external watershed sites (filled bars). Those external watershed sites falling to the left of the Squaw sites are defined as **reference watersheds** for contrast to each Squaw Creek watershed stream type. Alder and Trout Creek will serve to examine response to a range of potential sediment exposure for low gradient streams.

Figure 4. Relationships between distributed sediment load model and selected biological metrics among low gradient stream types.



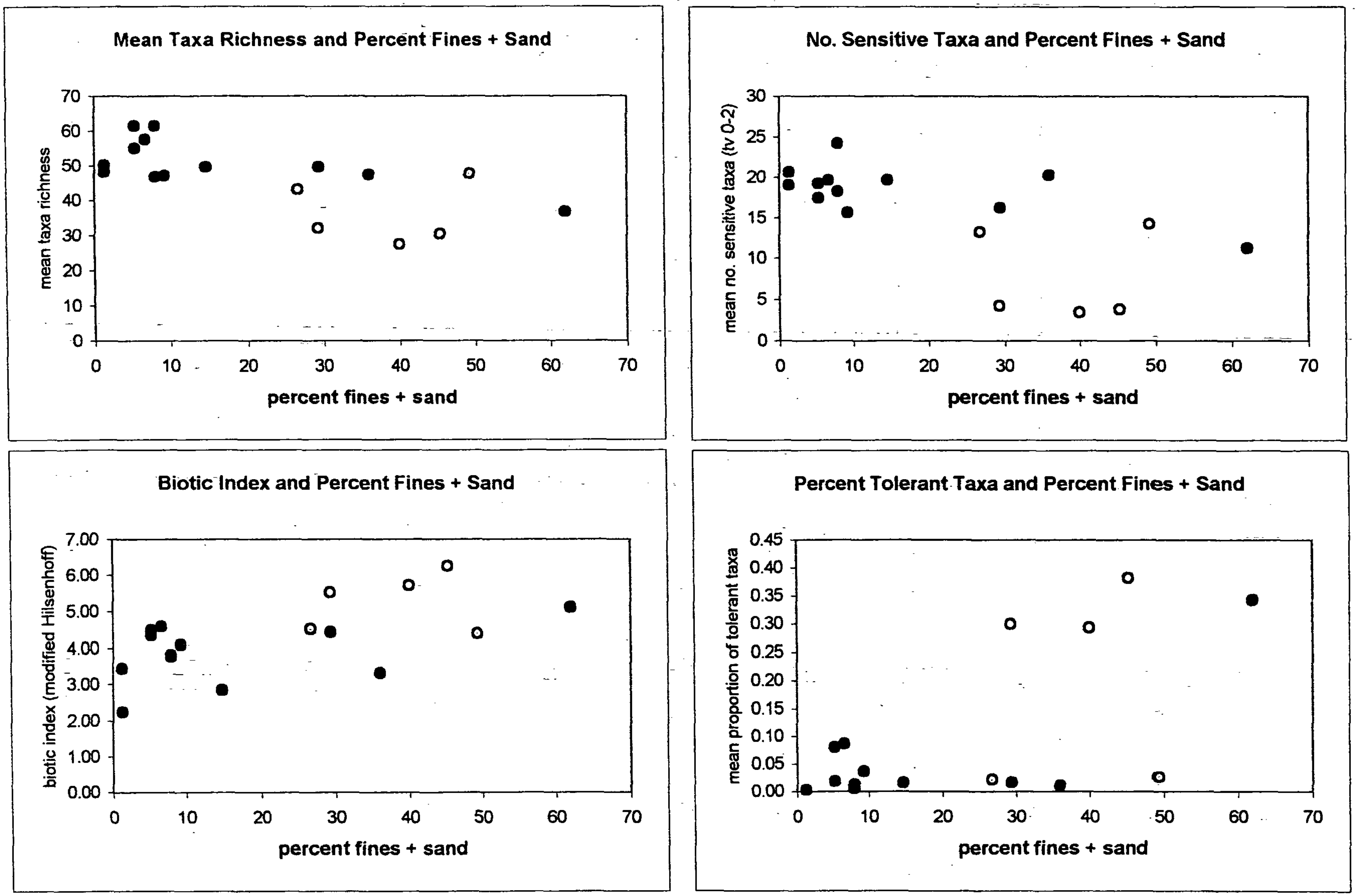
Open symbols -Squaw watershed 2000, Grey symbols -Squaw in 2001, and Filled symbols are external watersheds (2000-01)

Figure 5. Relationships between D-50 particle size and selected biological metrics among low gradient stream types.



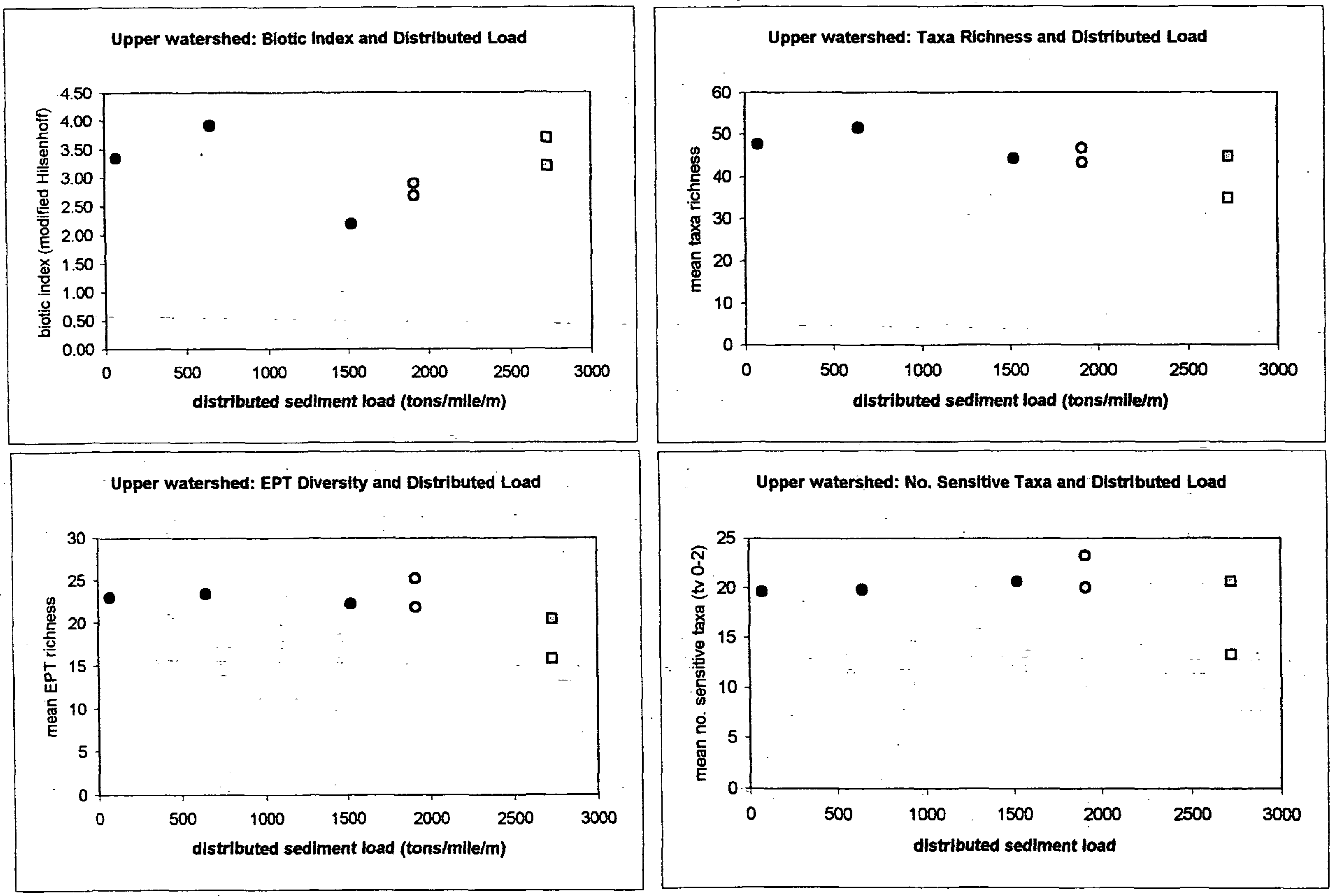
Open symbols -Squaw watershed 2000, Grey symbols -Squaw in 2001, and Filled symbols are external watersheds (2000-01)

Figure 6. Relationships between percent fines + sand and selected biological metrics among low gradient stream types.



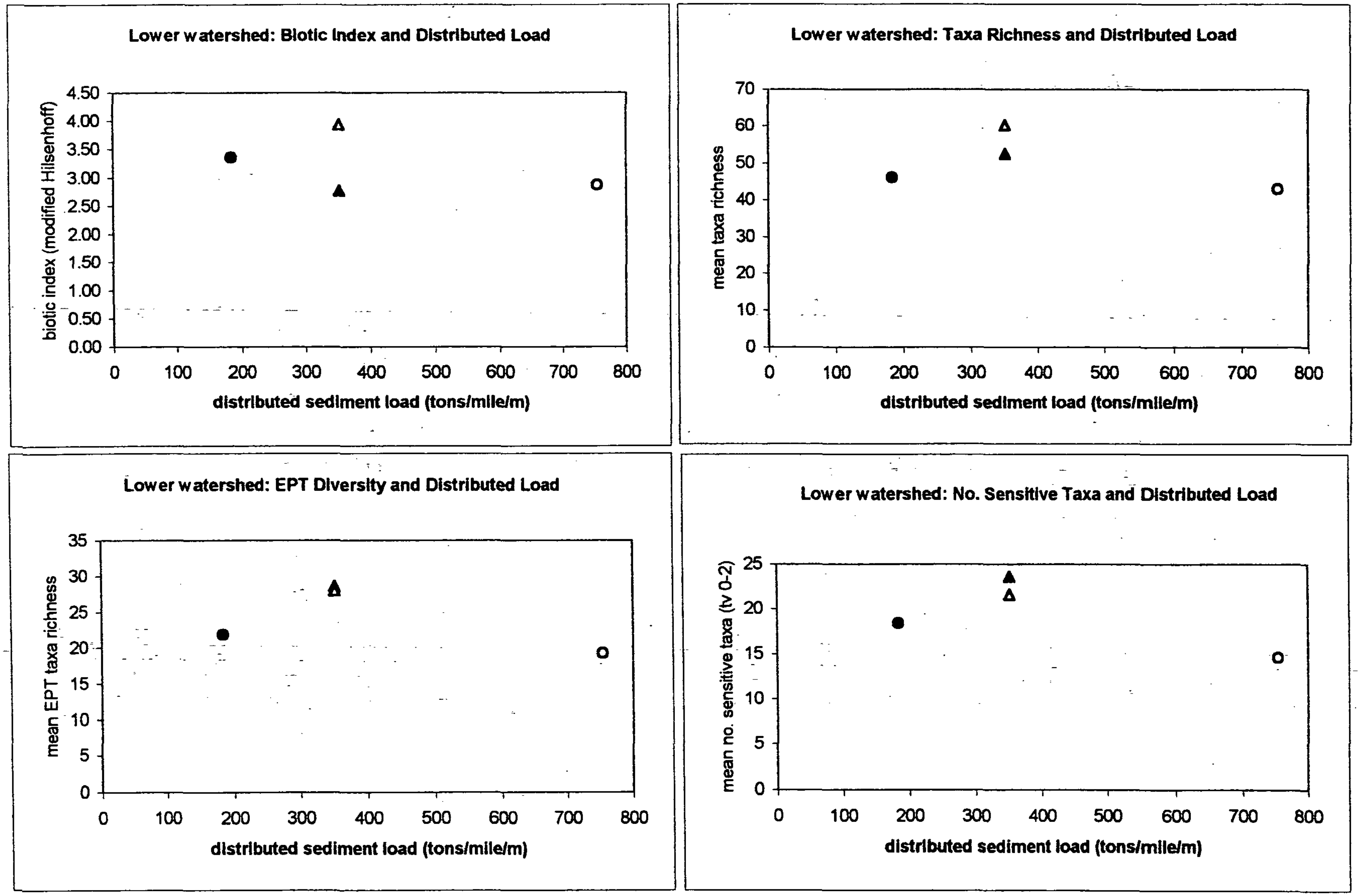
Open symbols -Squaw watershed 2000, Grey symbols -Squaw in 2001, and Filled symbols are external watersheds (2000-01)

Figure 7. Relationships between distributed sediment load model and selected biological metrics among upper watershed stream types.



Open circle -Squaw N. tributary (2000, grey 2001); open square -Squaw S. tributary (2000, grey 2001); filled circles are external reference sites.

Figure 8. Relationships between distributed sediment load model and selected biological metrics for lower watershed stream types.



Open symbol - Squaw, below moraine site; filled symbol - General Creek; triangles are Bear Creek (filled 2000, gey 2001)

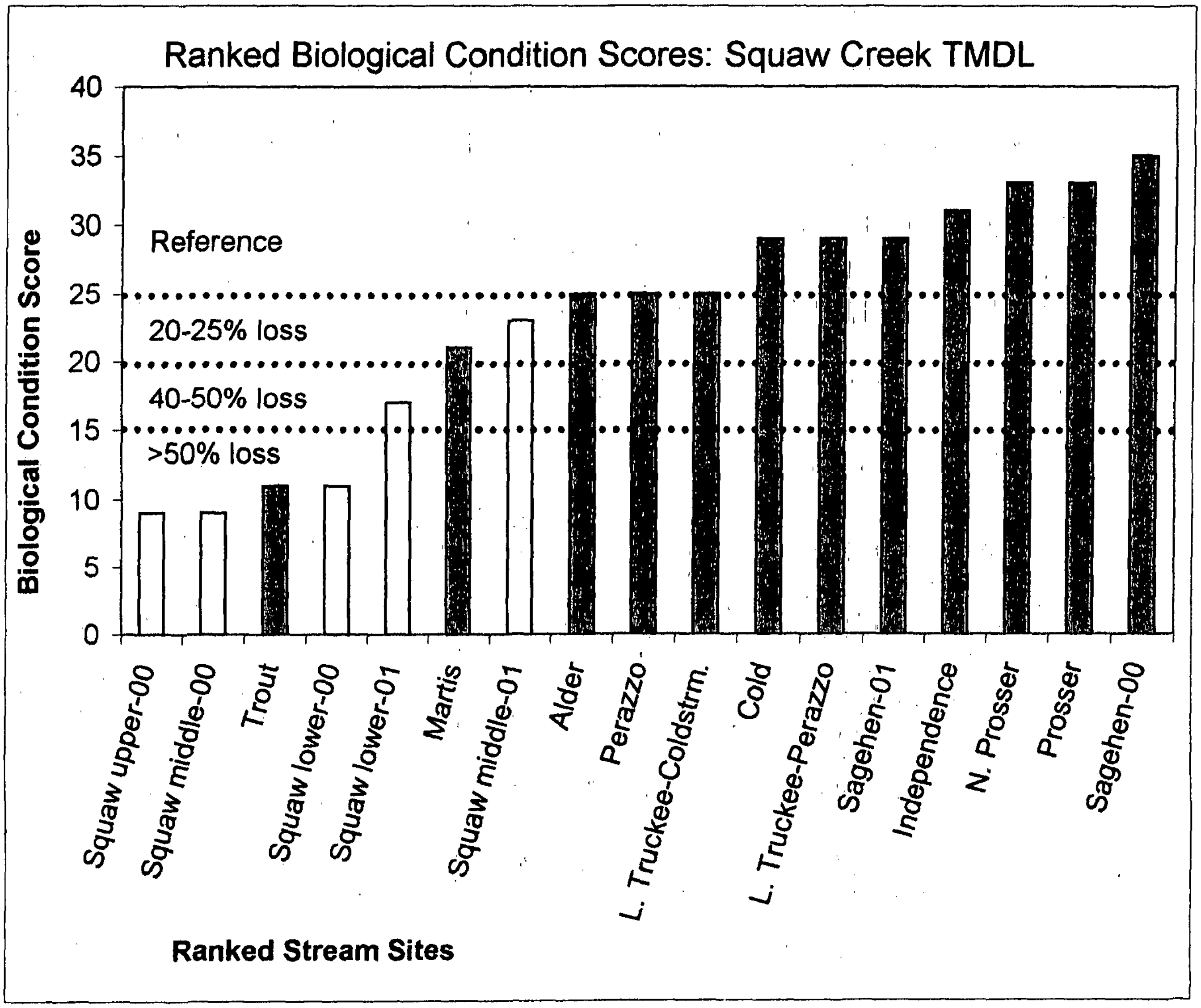


Figure 9. Rank-order distribution of biological condition scores for low gradient stream types. Values are index scores for rating biological integrity and indicate levels of loss or impairment relative to reference conditions.