Benthic Macroinvertebrates Index Development and Physical Habitat Evaluation for Truckee River, Carson River, &Walker River

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Executive Summary

The objective of this project is two-fold; to develop a benthic macroinvertebrate multi-metric index using existing data to apply to the main stems of the rivers of west central Nevada (the Truckee River, the Carson River, and the Walker River) and to evaluate physical habitat measurements for the main stem of the Truckee River as a potential assessment tool.

A multimetric benthic macroinvertebrate index was developed for the area of interest that integrated data from three river systems and two agencies (Nevada Division of Environmental Protection and Pyramid Lake Paiute Tribe). Data used for the index were collected during low flow periods (late June to early November) to minimize the effects of flow on the calibration of the index. Samples were collected from riffles and were subsampled to 500 organisms, identified to genus level.

The calibrated benthic macroinvertebrate index consists of five metrics each scored 0-100 (100 being closest to reference or optimal) with the final index value calculated as an average of the five metric scores. The metrics are: number of Ephemeroptera, Plecoptera, + Trichoptera (EPT) taxa, number of filterer taxa, number of burrower taxa, percent sprawlers, and percent dominant taxon. Using the newly developed index and the proposed narrative assessments, 7% of samples from all the three rivers rated as Exceptional, 14% as Good, 62% as Fair, and 17% as Poor.

The second goal was to develop a suite of measurements that could be used to easily and effectively assess the physical habitat at various locations on the Truckee River. A number of physical habitat assessment methods were evaluated as applicable to these Nevada rivers. The EMAP protocols were used as a template and then investigated for minimizing the amount of field data needed to ascertain reliable reachwide values.

It was determined that the relative bed stability (RBS) was the single parameter best suited to measuring the physical habitat of the rivers in this study. Modifications of the method were investigated that would get similarly meaningful results with reduced effort in the field. It was found that coarser measurements for bankfull height and thalweg depth could be employed given the homogenous nature of the rivers. The Truckee River, measured with RBS, tends toward stable habitat above Reno and again in the lower river on the Pyramid Lake Paiute Reservation above Nixon.

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1 Introduction

The Clean Water Act (CWA) has as one of its primary goals the maintenance and restoration of biological integrity. This concept of biological integrity refers to the natural assemblage of indigenous organisms that inhabit a particular area that has not been affected by human activities (Karr et al. 1986). The measurable definition of biological integrity is the reference condition (Barbour et al. 1995, 1999), which is characterized using data from minimally-disturbed sites within a region.

Biological integrity *is commonly defined as "the capability of supporting and maintaining a balanced, integrated, adaptive community or organisms having a species composition, diversity and functional organization comparable to that of the natural habitat of the regions"* (Karr and Dudley 1981, Gibson et al. 1996)

States and tribes have been developing and refining bioassessment programs for the last decade to better enable a determination of impaired waters using biological indicators (USEPA 2002). Monitoring and assessment programs are improved for addressing a multitude of management questions when bioassessment is added to the "tool box". Nevada Division of Environmental Protection (NDEP) set about to develop a multi-metric index for benthic macroinvertebrates for the Truckee River, Carson River, and Walker River main stems. In addition NDEP wanted a method to evaluate the physical habitat of the Truckee River that provided meaningful data without overly intensive data collection in the field.

1.1 Study Area

The area of study was limited to west central Nevada on the main stems of the Truckee River, Carson River and Walker River (Figure 1). The headwaters of each of these rivers are in the Sierra-Nevada Mountains of California, and each river flows in a general eastward direction into Nevada. The majority of the study area is in the Northern Basin and Range ecoregion with the headwaters of each river basin in California in the Sierra Nevada ecoregion.

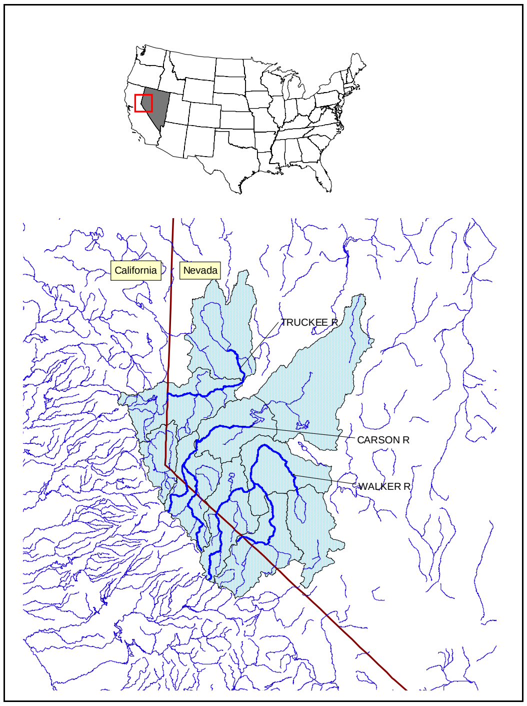

Figure 1. Location of study area.

1.2 Sampling Sites

Many agencies and other entities have collected benthic macroinvertebrate data in the three rivers, because the aquatic health of the rivers in the area is of vital importance to many stakeholders. Data for this study were collected by Nevada Division of Environmental Protection (NDEP) and Pyramid Lake Paiute Tribe (PLPT). There were a total of 377 samples collected by these two agencies from 1981 to 2005 (Figure 2).

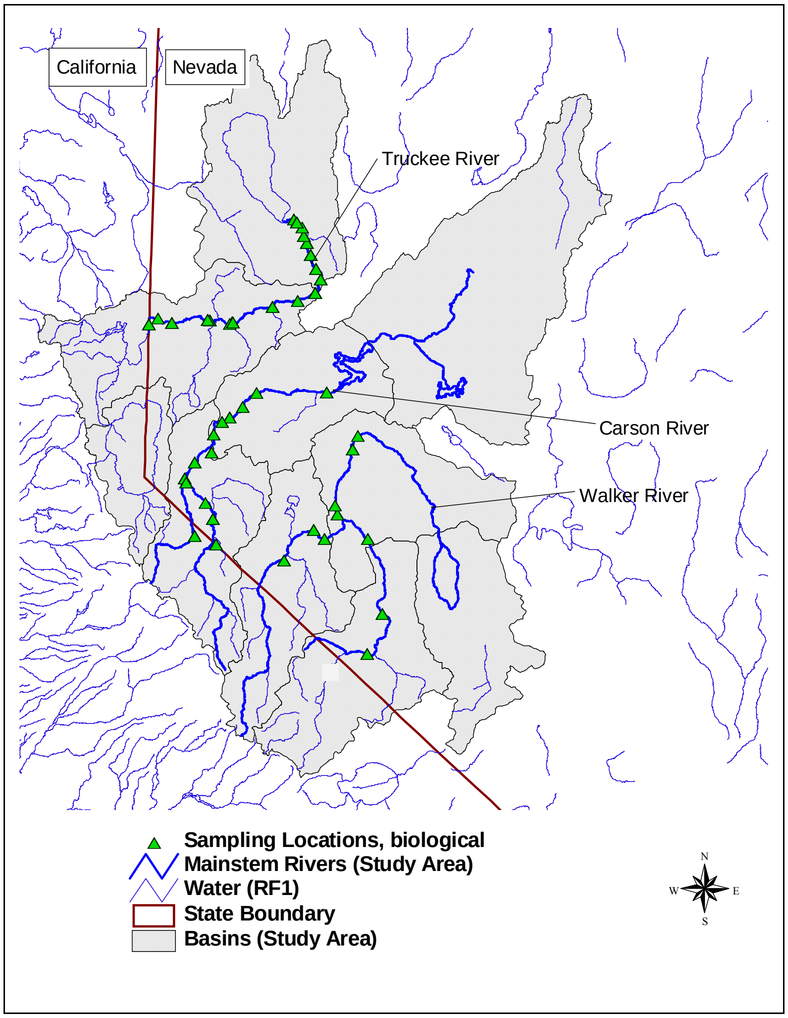

Figure 2. Biological sampling locations in the study area.

2 Benthos

Careful sampling and analysis of aquatic systems and their resident biota can characterize biological condition which, in turn, is an indicator of ecological health of the waterbody. Several key ecological attributes are measured to determine the quality of the aquatic resources. Biological surveys establish the attributes or measures, such as taxa richness, number of individuals in particular taxa groups or ecological categories, sensitive or insensitive taxa, observed feeding mechanisms, and the presence or absence of essential habitat elements.

These attributes are termed metrics and represent elements of the structure and function of the bottom-dwelling (benthic) macroinvertebrate assemblage, in this case. Metrics change in a predictable way with increased human influence that alters environmental conditions (Barbour et al. 1996) and include specific measures of diversity, composition, functional feeding group representation, and information on tolerance to pollution. Multimetric indices (MMIs), such as an Index of Biotic Integrity (IBI), incorporate multiple biological community characteristics and measure the overall response of the assemblage to environmental alteration and cumulative stressors (Karr et al. 1986, Barbour et al. 1995). Such a measure of the structure and function of the biota (using a regionally-calibrated multimetric index) is an appropriate indicator of ecological quality, reflecting biological responses to changes in physical habitat quality, the integrity of soil and water chemistry, geophysical process, and land use changes (to the degree that they affect the sampled habitat and water quality).

Multimetric, invertebrate indices of biotic integrity (IBI), also variously called ICI (Invertebrate Condition Index; Ohio EPA 1989), B-IBI (Benthic IBI; Kerans and Karr 1994, Stribling et al. 1998), and SCI (Stream Condition Index; Barbour et al. 1996; Burton and Gerritsen 2003), have been developed for many regions of North America and are generally accepted for biological assessment of aquatic resource quality (e.g., Gibson et al. 1996, Plafkin et al. 1989; Barbour et al. 1999, Southerland and Stribling 1995, Karr 1991). In addition to identifying appropriate biological attributes, the framework for bioassessment consists of characterizing reference conditions upon which comparisons can be made. Reference conditions are typically the “best” conditions where biological communities are the closest to natural for the particular region or area. These reference conditions are taken to be representative of healthy ecosystems.

For this project, biological index development consisted of a series of steps that are iterative but can be generalized as:

- Gathered and organized the data.
- Defined reference selection.
- Partitioned the dataset.
- Calculated biological metrics for all samples.
- Determined metric sensitivity to stressors.
- Combined metrics into index alternatives.
- Selected the most appropriate index.
- Evaluated the performance of the selected index.

2.1 Data Compilation

2.1.1 Field and Laboratory Methods

Each agency collects data according to its own Standard Operating Procedures (SOPs) that meet its own measurement and data quality objectives (MQOs and DQOs). While these methods were similar there were some differences that needed to be resolved before combining the data into a single large dataset for analysis (Table 1). Both agencies sample in riffles with a 500 µm D-frame kick net. To alleviate any real or potential field or laboratory method differences and to ensure data comparability, a common set of parameters had to be developed. Using all samples and methods as reported by each agency would increase the variability (non-random error) and would limit the types of analyses to be performed on the aggregate data. For example, PLPT sorts all samples to completion while NDEP uses a 500 organism subsample. Not accounting for this difference would most likely lead to PLPT samples having much higher numbers of taxa than NDEP samples.

Table 1. Highlights of sampling and processing methods by collecting entity.

	NDEP	**PLPT**
Sampling Gear	d-frame kicknet	Modified kicknet
Mesh Size (µm)	500	500
Habitat Sampled	Riffle	Riffle
Field Effort	9 combined	1-4 (kept separate)
Laboratory Subsampling	500 organisms	Total pick
Organism Identifications (non-midges)	Genus	Genus
Organism Identifications (midges)	Genus species	Genus

Therefore, to address comparability, the PLPT sample replicates were combined into a single sample. Sampling effort increases richness metrics (e.g., Barbour and Gerritsen 1996). All samples were subsampled via computer to 500 organisms, ± 20% (400 – 600). Samples with less than 400 organisms were not used for this study. Any sample over the maximum number of organisms (600) was electronically randomly subsampled to within the target range.

Another difference in the laboratory processing of samples was the level of effort of taxonomic identification between NDEP and PLPT (Table 1). To obtain consistent taxonomy across all data being analyzed, genus level identifications were used to provide the most consistent detail. For this exercise we assumed that all identifications were performed by a qualified taxonomist and proper QC procedures were followed.

For metric calculations it is important to have complete ecological information on all taxa. This includes the phylogenetic hierarchy and autecology information (tolerance values, functional feeding groups, and habits). After combining the data from both entities the master taxa list was checked for spelling errors and synonyms. Information on taxa not available from either entity was researched in the National Wadeable Streams Assessment (WSA) taxa list (USEPA 2006), Integrated Taxonomic Information System (ITIS) (www.itis.gov), the revised Rapid Bioassessment Protocols (RBPs) (Barbour et al. 1999), and other literature.

Flow was evaluated as a potential covariate influencing the benthic data. Data were gathered from all USGS gaging stations in the study area (Figure 3). Monthly mean data from each gage on each River for the time period 1980 to 2005 were examined (Figure 4).

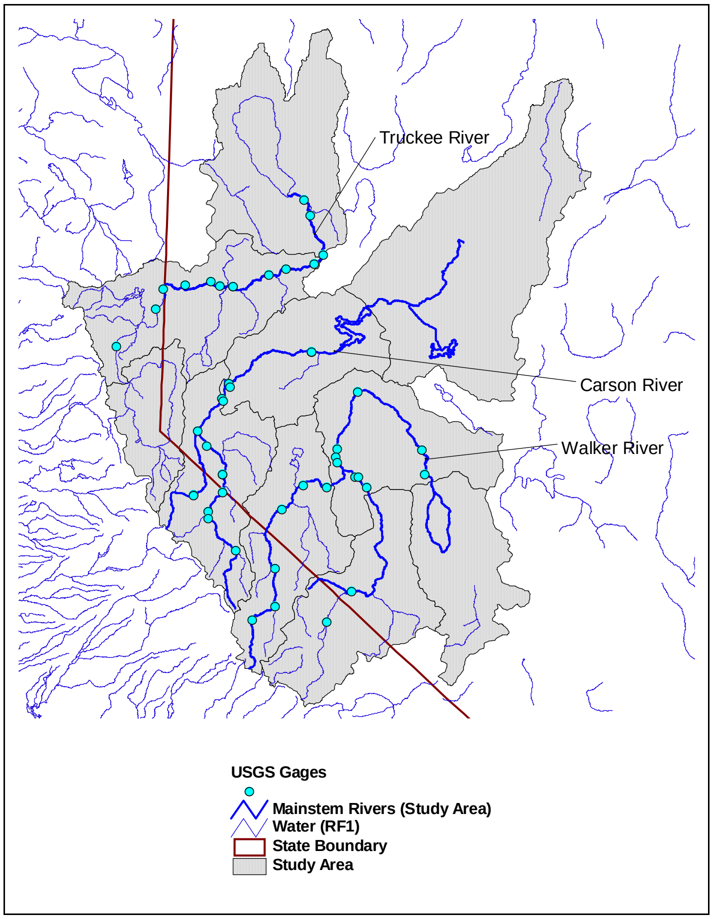

Figure 3. Locations of USGS gages in the Truckee, Carson, and Walker River basins.

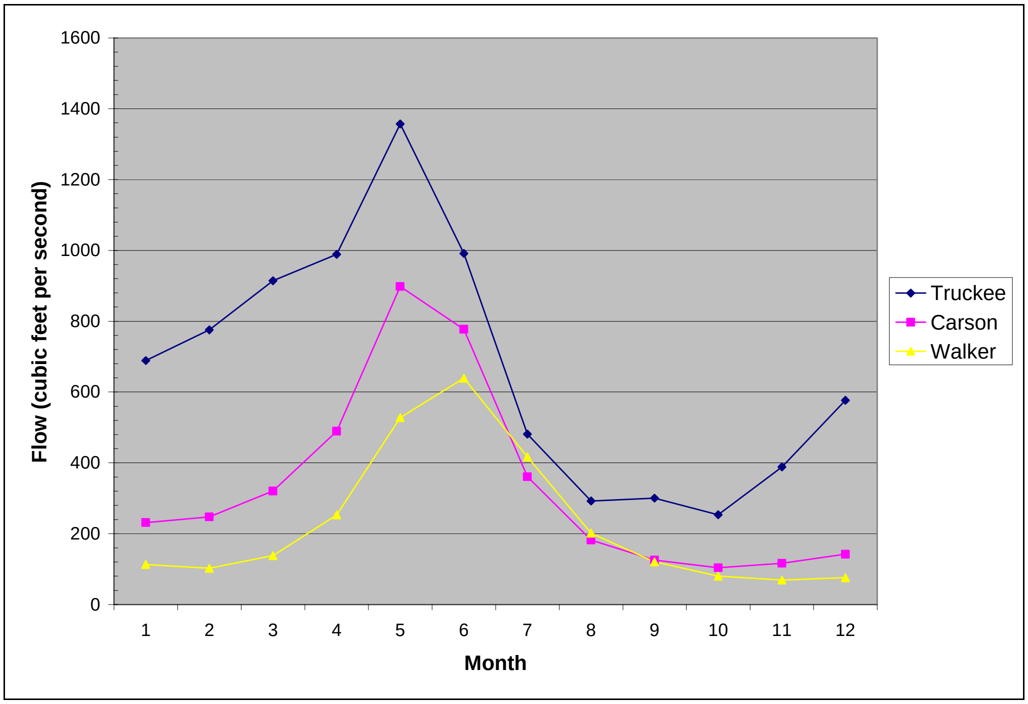

Figure 4. Monthly mean flow from USGS gages in the study area (1980-2005).

We limited the index period of data collection to low flow conditions (less than 500 cfs) in the period of July to November. This time period also coincides with the majority of sample collections. All three rivers in the study area experience high flows due in part to snow melt in the spring. Low flow conditions allow for safer sampling by field personnel and decreases the seasonal variability. The majority of samples are sampled in August of each year. Some samples from late June are included in the analysis (e.g., June 30).

2.2 Reference Condition

Reference sites represent least disturbed conditions as determined by non-biological environmental data (Stoddard et al. 2006). These sites are not pristine but are rather the best sites in this dataset and represent a standard that should be attainable for other sites with similar natural characteristics. A population of reference sites is used to construct a reference condition, which then server as a benchmark for assessment. Available data limited the number of criteria that could be used to set reference conditions. Biological data were not used to set reference criteria to avoid circularity in developing a biological index. Due to the fixed network design of sampling rather than a stratified random network of sites, samples rather than the sites were evaluated for reference class membership.

Reference Class determinations were made according to the parameters listed in Table 2. For sites (or samples) to be considered reference, all parameters must meet the reference criteria. These criteria are similar to those used in bioassessment programs in other western states (Colorado, Montana, and New Mexico) (Paul et al. 2005, Jessup et al. 2006, and Jacobi et al. 2004) and to national programs (WSA) (USEPA 2006).

Table 2. Reference selection criteria.

Type	Parameter	Reference Criteria
Chemical	Dissolved Oxygen (mg/L)	>6
	Conductivity (µS/cm)	<300
	pH	<9
	Total Phosphorus (mg/L)	<25
	Water Temperature (°C)	<20
Physical Habitat	Embeddedness Score (surrogate for percent fines)	≥15
	Channel Alteration	≥15
	Total Score	>150 (75%)
Other	Natural hydrograph	Not below a dam

2.3 Dataset Partitioning

From the total of 377 benthic macroinvertebrate samples, two data sets were created. After removing samples, (1) outside of the index period, (2) with less than the target number of organisms, and (3) field duplicates, 222 samples remained (Table 3).

Table 3. Number of benthic macroinvertebrate samples by river basin and *a priori* class.

River Basin	Reference	Other	Stressed	*Total*
Truckee	11	105	34	*150*
Carson	6	25	19	*50*
Walker	7	19	4	*22*
Total	*24*	*141*	*57*	*222*

The second step in dataset partitioning was to evaluate samples for their non-biological parameters for *a priori* condition classes. Samples meeting reference criteria (as per Table 2) were determined first. The remaining samples were considered either stressed (degraded by human activities) (i.e., ≥ 50% of the parameter values failed the reference criteria), or other (i.e., insufficient data on non-biological parameters or didn't meet the criteria of the other two classes).

A multimetric index is developed with a set of data and is validated with a second, preferably independent, dataset. The dataset of valid samples (222) was partitioned such that approximately 20% (46 samples) were reserved for validation and 80% of the dataset (176 samples) were used for development (Table 4 and Table 5). Samples were randomly selected for the validation dataset in proportion to their representation in the overall dataset (i.e., by river basin and *a priori* class) and such that no two samples from the same station were selected.

Table 4. Number of samples in the validation dataset by river basin and *a priori* class.

River Basin	Reference	Other	Stressed	*Total*
Truckee	3	21	7	*31*
Carson	1	6	4	*11*
Walker	1	2	1	*4*
Total	*5*	*29*	*12*	*46*

Table 5. Number of samples in the development dataset by river basin and *a priori* class.

River Basin	Reference	Other	Stressed	*Total*
Truckee	8	84	27	*119*
Carson	5	19	15	*39*
Walker	6	9	3	*18*
Total	*19*	*112*	*45*	*176*

2.3.1 Sample Classification

In order to be certain that data should be combined across samples, an ordination analysis was performed that examined the composition of organisms in each sample. This was done to test if the biological samples could be grouped and associated with a gradient of natural variables. For this exercise organism identifications were collapsed to genus level, with organisms not at the designated level removed from the analysis. This was done to exclude non-unique and ambiguous identifications from the analysis. To test for potential differences along the spatial gradient, several groupings were examined for differences in taxonomic composition.

Non-metric multi-dimensional scaling (NMS) allows for the comparison of taxa across samples and an arrangement of those samples such that similar samples are plotted closer together and dissimilar samples farther apart. Natural environmental variables can then be associated with the biological gradient. NMS is a robust method for detecting similarity and differences among ecological community samples and works as well using presence/absence data as relative abundance data (McCune and Mefford 1999).

The goal of classification is to identify differences among the biological samples that can be attributed to natural differences among the sites. The environmental, spatial, temporal, and collection metadata and variables available for testing were: river basin, proximity to dams, elevation, ecoregion, hydrologic unit code (HUC), year collected, month collected, collecting method, and collecting entity. None of the examined variables showed discernable difference among reference samples (Figure 5) so no further partitioning of the data was done (Appendix D). Therefore, all three river basins were considered to within the same bioregion for assessment.

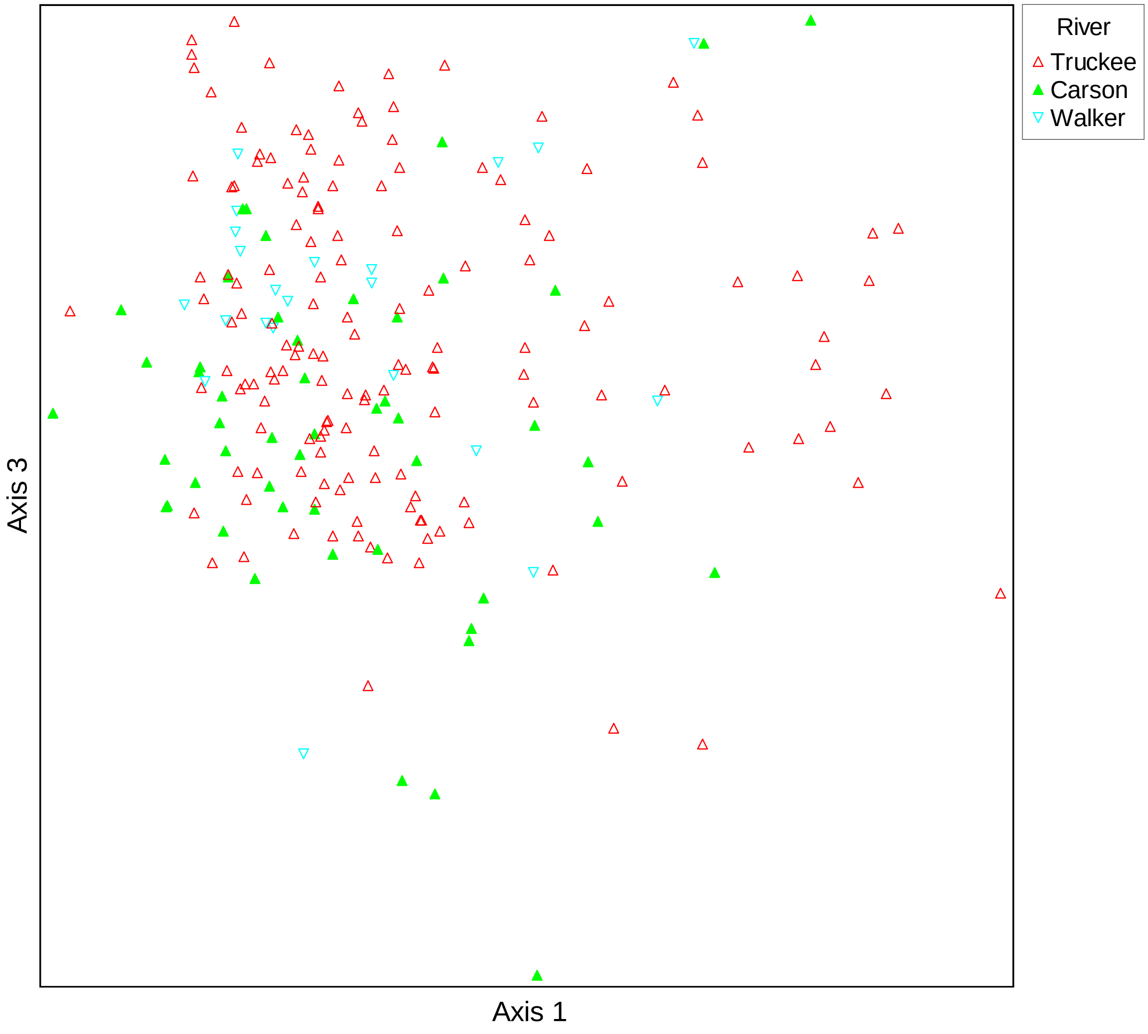

Figure 5. Non-metric multidimensional scaling (NMS) plot of biological samples, categorized by river basin (N = 222)

2.4 Metric and Index Development

2.4.1 Metric selection

A suite of metrics (64) representing a variety of ecological attributes were calculated for all samples (Table 6). Metrics from published indices were also examined for inclusion in the final index. Candidate metrics were selected from the pool of 64 metrics. Criteria for candidate metrics were metrics that had sufficient range of values in the data set, responded in the anticipated direction to an increase in perturbation, ability to discriminate between reference and stressed sites, and ecological meaningfulness (Barbour et al. 1995). Of the 64 metrics, 19 were considered for inclusion in the final index. From these 19 candidate metrics, 5 metrics were ultimately selected for inclusion in the index based on minimizing redundancy among individual component metrics (as measured by Pearson product-moment correlation coefficients) and representation among different aspects of the community (taxa richness, species composition, tolerance, feeding groups, and habits). Only reference samples from the development dataset were used to evaluate metrics for inclusion in the index. No metrics that were correlated greater than |.80| were selected for inclusion in the same index (Appendix C).

Discrimination efficiency (DE) was used to evaluate each metric for its ability to differentiate between reference and stressed samples. DE is a measure of the percent of stressed sites scored correctly as defined by being below the 25th percentile of reference sites for metrics that decrease with increasing disturbance. For metrics that increase with increasing disturbance, stressed sites are scored correctly if they are above the 75th percentile of reference (Stribling et al. 2000). Metrics with a high (DE) are preferred over metrics with a low DE but the effects on the DE of overall index were also considered. That is, some metrics with a high DE actually lowered the overall DE of the combined index and thus may have been excluded. Metrics with a DE of less than 50% were not considered for inclusion in this index. Metrics with lower variability in the reference sample population are preferable to those with higher variability. Variability was measured as the coefficient of variation (CV). For reference sites, the CV was calculated as the standard deviation over the mean, expressed as a percentage.

Table 6. List of biological and their expected response to cumulative perturbation.

Category	Metric Name	Expected Response to Perturbation	Candidate Metric	Included in Index
Composition	Shannon Weiner Index (ln)	Decrease		
	Shannon Weiner Index ($\log_2$)	Decrease		
	Shannon Weiner Index ($\log_{10}$)	Decrease		
	% Amphipoda	Decrease		
	% Bivalvia	Decrease		
	% Chironomidae	Increase		
	% Coleoptera	Decrease		
	% Corbicula	Decrease		
	% Cricotopus and Chironomus of Chironomidae	Decrease		
	% Crustacea and Mollusca	Decrease		
	% Diptera	Increase		
	% Ephemeroptera	Decrease		
	% Ephemeroptera, Plecoptera, and Trichoptera (EPT)	Decrease		
	% Gastropoda	Decrease		
	% Non Insecta	Increase		
	% Odonata	Decrease		
	% Oligochaeta	Increase		
	% Plecoptera	Decrease		
	% Tanytarsini	Decrease		
	% Tanytarsini of Chironomidae	Decrease		
	% Trichoptera	Decrease		

Category	Metric Name	Expected Response to Perturbation	Candidate Metric	Included in Index
Feeding	% Collectors	Decrease	X	
	% Filterers	Increase		
	% Predators	Decrease		
	% Scrapers	Decrease		
	% Shredders	Decrease		
	# Collector Taxa	Decrease	X	
	# Filterer Taxa	Decrease	X	X
	# Predator Taxa	Decrease	X	
	# Scraper Taxa	Decrease	X	
	# Shredder Taxa	Decrease		
Habit	% Burrowers	Decrease	X	
	% Climbers	Decrease		
	% Clingers	Decrease		
	% Sprawlers	Decrease		X
	% Swimmers	Decrease		
	# Burrower Taxa	Decrease	X	X
	# Climber Taxa	Decrease		
	# Clinger Taxa	Decrease	X	
	# Sprawler Taxa	Decrease		
	# Swimmer Taxa	Decrease	X	
Richness	# Chironomidae Taxa	Decrease	X	
	# Coleoptera Taxa	Decrease	X	
	# Crustacea and Mollusca Taxa	Decrease		
	# Diptera Taxa	Decrease	X	
	# Ephemeroptera Taxa	Decrease	X	
	# EPT Taxa	Decrease	X	X
	# Oligochaeta Taxa	Decrease		
	# Plecoptera Taxa	Decrease		
	# Tanytarsini Taxa	Decrease	X	
	# Total Taxa	Decrease	X	
	# Trichoptera Taxa	Decrease		
Tolerance	Beck's Biotic Index	Decrease	X	
	Hilsenhoff Biotic Index	Increase		
	Simpson's Diversity Index	Decrease		
	% 1 Dominant Taxon	Increase	X	X
	% 5 Dominant Taxa	Increase	X	
	% Baetidae of Ephemeroptera	Decrease		
	% Hydropsychidae of EPT	Increase		
	% Hydropsychidae of Trichoptera	Increase		
	% Intolerant	Decrease		
	% Tolerant	Increase		

Category	Metric Name	Expected Response to Perturbation	Candidate Metric	Included in Index
	# Intolerant Taxa	Decrease		
	# Tolerant Taxa	Increase		

Tables of the metric score statistics (percentiles and discrimination efficiencies) and a correlation table of candidate metrics are included in Appendices B and C.

2.4.2 Metric Scoring

To provide a common scale for all metrics, each metric was scored on a 0 to 100 scale where values closer to 100 are considered optimal. The metric values are standardized on a "best" value (95th percentile of reference for metrics that decrease with perturbation and 5th percentile for metrics that increase with perturbation). The 95th and 5th percentiles were chosen to eliminate the outliers as a scoring standard and avoid skewing the resultant scores. All scores greater than the 95th percentile were assigned a score of 100, metric values less then the standard were scored as a percentage of the standard:

$$Standardized\ Score = \frac{X - X_{\min}}{X_{95} - X_{\min}} * 100$$

For metrics that increase with increasing perturbation the standard best value is the 5th percentile. Any metric values less than the 5th percentile are assigned a score of 100 with other values scored as a percentage of the range from the maximum (worst) value to the 5th percentile (best) value.

$$Standardized\ Score = \frac{X_{\max} - X}{X_{\max} - X_5} * 100$$

An example of metric values and the conversion to metric scores is given in Table 7.

Table 7. Metric standardization example from Station NV06-TR-2-BIO-1, collected 2003-09-15.

Metric	Response to Perturbation	Percentile for Standard Best Value	Standard Best Value	Measured Metric Value	Standardized Metric Value
# Ephemeroptera, Plecoptera, + Trichoptera (EPT) Taxa	Decrease	95th	18.3	20	100
# Filterer Taxa	Decrease	95th	5.0	5	100
# Burrower Taxa	Decrease	95th	7	4	57.1
% Sprawlers	Decrease	95th	34.5	10.2	29.7
% Dominant 1 Taxon	Increase	5th	17.9	26.5	89.5
				Overall MMI Score	*75.3*

2.4.3 Index Scoring

The overall index value is the average of the metric scores that are included in the index. All metric scores are on the same 0-100 scale so the final index score is also 0-100.

2.4.4 Selecting Among Alternative Indices

Multiple versions of the index with varying number of metrics were tested. Not every combination was tested due to the number of sheer possibilities (for an index of 5 metrics with 19 candidate metrics there are 11,628 possible combinations). Best professional judgment was used to select and examine the most likely combination of metrics to include in the index to represent the most robust ecological information. Five alternative index versions were examined in detail (Table 8).

All five candidate versions of the index had comparable discrimination efficiencies for both the development and validation data (all within one or two samples of each other). The final version of the index that was selected (Index05 in Table 8 and Table 9) had the best mixture of taxa richness and percentage metrics and the best discrimination efficiency. Index01 is the same as Index03 except for the switching of number of EPT taxa for number of Ephemeroptera taxa; this resulted in no change in overall discrimination efficiency. Index05, the selected index, is the same as Index01 but with the addition of one metric (% Sprawlers). Many candidate metrics were not included in any of the index alternatives as they were too closely correlated with other metrics that were included in the index alternatives.

Table 8. Candidate metrics and index alternatives.

Metric Category	Candidate Metrics	Index01	Index02	Index03	Index04	Index05
Feeding	% Collectors		X		X	
	Collector Taxa					
	# Filterer Taxa	X		X		**X**
	# Predator Taxa					
	# Scraper Taxa					
Habit	% Burrowers				X	
	% Sprawlers		X			**X**
	# Burrower Taxa	X		X		**X**
	# Swimmer Taxa					
Richness	# Chironomidae Taxa					
	# Coleoptera Taxa					
	# Diptera Taxa				X	
	# Ephemeroptera Taxa			X		
	# EPT Taxa	X			X	**X**
	# Tanytarsini Taxa		X			
	# Total Taxa		X			
Tolerance	Beck's Biotic Index					

Metric Category	Candidate Metrics	Index01	Index02	Index03	Index04	Index05
	% Dominant Taxon	X	X	X	X	**X**
	% Dominant 5 Taxa					
	Beck's Biotic Index					

Table 9. Performance of index alternatives (discrimination efficiency of stressed samples).

Dataset	Index01	Index02	Index03	Index04	Index05
Development (n=45)	80.0	77.8	80.0	80.0	84.4
Validation (n=12)	75.0	75.0	75.0	66.7	75.0
Combined (n=57)	78.9	77.2	78.9	77.2	82.5

The completed index metrics were compared to other indices that have been developed for the same geographic area. In 2004 a Truckee River Stream Condition Index was developed for the main stem Truckee River using much of the same data as in this study (Tetra Tech 2004). The other index used for comparison was the National Wadeable Streams Assessment (WSA) multimetric index (USEPA 2006). Neither index compares favorably with the Nevada multimetric index (Figure 6).

Table 10. Metrics used in several multimetric indices for Nevada.

Category	Metrics	WSA WMT MMI	WSA XER MMI	Truckee River MMI 2004	Nevada MMI 2007	Expected Response to Perturbation
Composition	% Chironomidae			X		Increase
	% Ephemeroptera			X		Decrease
	% Ephemeroptera, Plecoptera, and Trichoptera (EPT) Taxa	X				Decrease
	% Non-Insects		X			Increase
Feeding	% Filterers			X		Decrease
	# Filterer Taxa				**X**	Decrease
	# Scraper Taxa	X	X			Decrease
Habit	% Clingers			X		Decrease
	# Burrower Taxa				**X**	Decrease
	% Sprawlers				**X**	Decrease
	% Clinger Taxa	X	X			Decrease
Richness	# Ephemeroptera Taxa					Decrease
	# Ephemeroptera, Plecoptera, and Trichoptera (EPT) Taxa	X	X		**X**	Decrease
	# Total Taxa			X		Decrease
	# Trichoptera Taxa					Decrease

Category	Metrics	WSA WMT MMI	WSA XER MMI	Truckee River MMI 2004	Nevada MMI 2007	Expected Response to Perturbation
	% Dominant 1 Taxon			X	**X**	Increase
Tolerance	% Dominant 5 Taxa	X	X			Increase
	% Tolerant Taxa	X	X			Increase

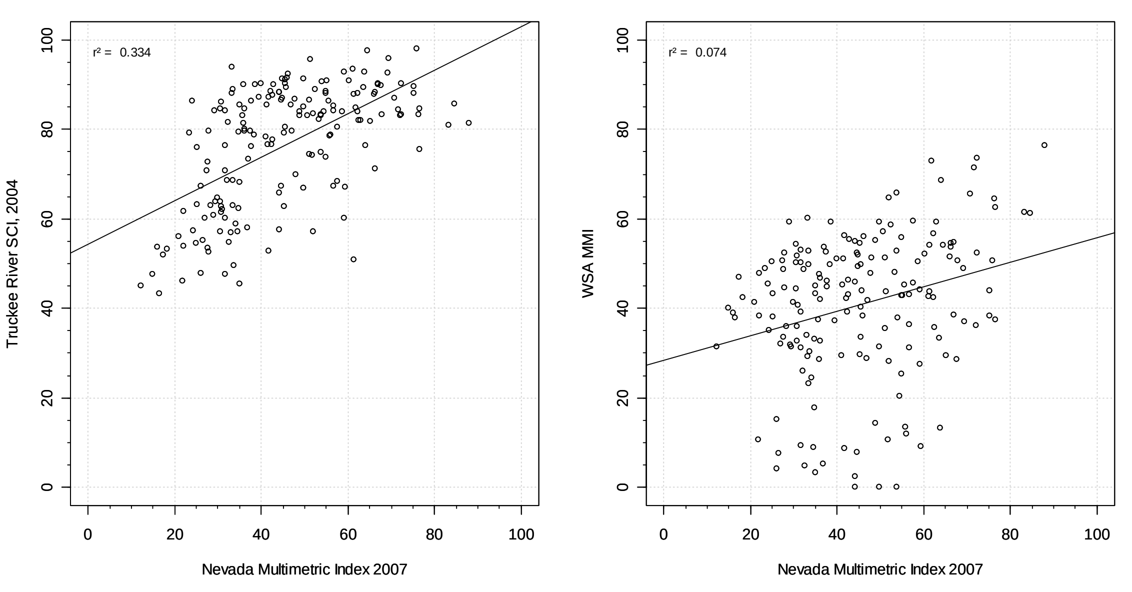

Figure 6. Comparison of Nevada multimetric index (MMI) to other the Truckee River SCI ($r^2 = 0.33$) and the WSA MMI (r^2=0.07), (N=176).

The low DE of each index (Truckee River DE = 24.4%, WSA DE = 26.7%) indicates that neither index is a good predictor of reference and stressed conditions in the study area. The Truckee River SCI was developed specifically for the Truckee River but included midges (Chironomidae) to only the family level. The WSA MMI was designed for the entire arid west (the Xeric regions of the western United States) and may be linked to ecoregional reference conditions outside of the study area.

2.4.5 Assessment Thresholds

Assessment thresholds intended to translate the numerical score into a something that is more easily communicated to managers and the public. This can be done in a number of ways, with terms such as Good, Fair, Poor or by associating with aquatic life uses. The threshold for impairment is often set at the 25th percentile of the reference site distribution (Barbour et al. 1999). Scores above this threshold are considered non-impaired and scores below this threshold are considered impaired; additional categories can also be added to further define the range. To be comparable with other similar studies in the west (Colorado, Arizona, Montana, Wyoming , and National Wadeable Streams Assessment), we decided to use four categories (Exceptional, Good, Fair, and Poor) (Table 11) (Paul et al. 2005, Leppo and Gerritsen 2000, Jessup et al. 2006, Stribling et al. 2000, USEPA 2006). Application of the index and proposed narrative categories resulted in the majority of sites classified as Fair (Figure 7 and Figure 8).

Table 11. Narrative assessment thresholds for the ecoregional multimetric index.

Narrative Category	Percentile of Reference	Numerical Range
Exceptional	≥ 75th	71.9 - 100
Good	≥ 25th	60.2 - 71.8
Fair	Upper bisection of 25th	30.1 - 60.1
Poor	Lower bisection of 25th	0 - 30.0

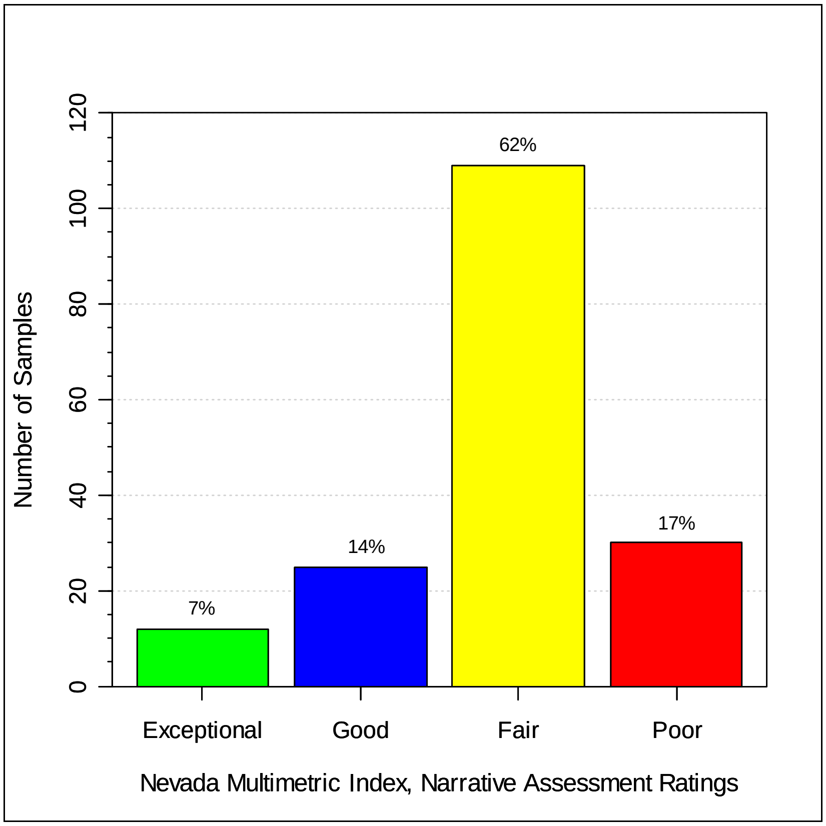

Figure 7. Distribution of samples in the study area by proposed benthic macroinvertebrate index narrative assessment categories (N=222, all samples).

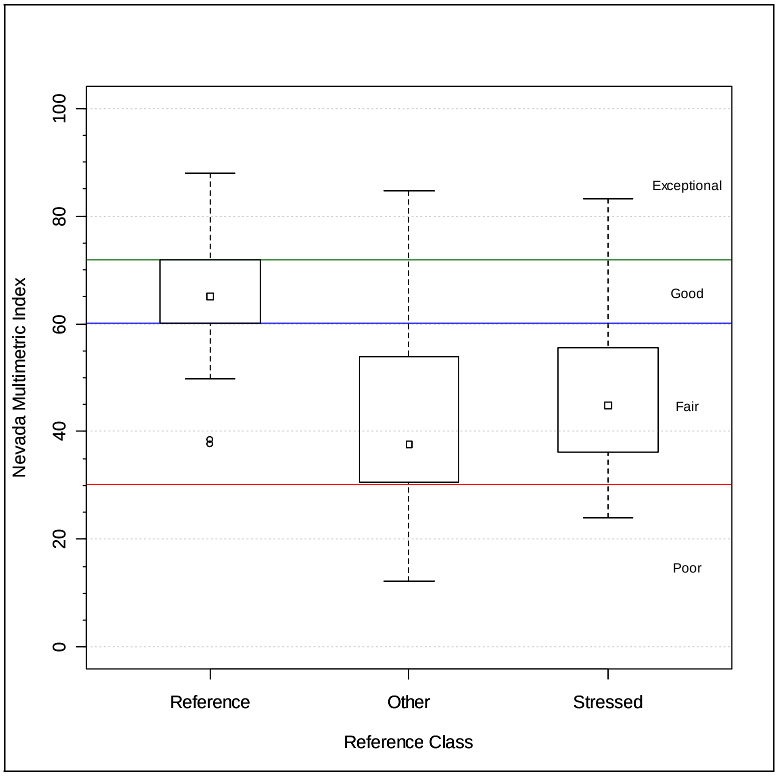

Figure 8. Nevada multimetric index distribution by reference class, N=176.

To get an overall estimate of the health of the waterbodies in the study area MMI scores were averaged at each sampling location (Figure 9). There is a general trend downward in scores near the urban centers of Reno and Carson City on the Truckee River and Carson River, respectively. Only 2 locations, both near the headwaters or the California border, had average scores of Exceptional. No sites had an average score in the lowest category, Poor.

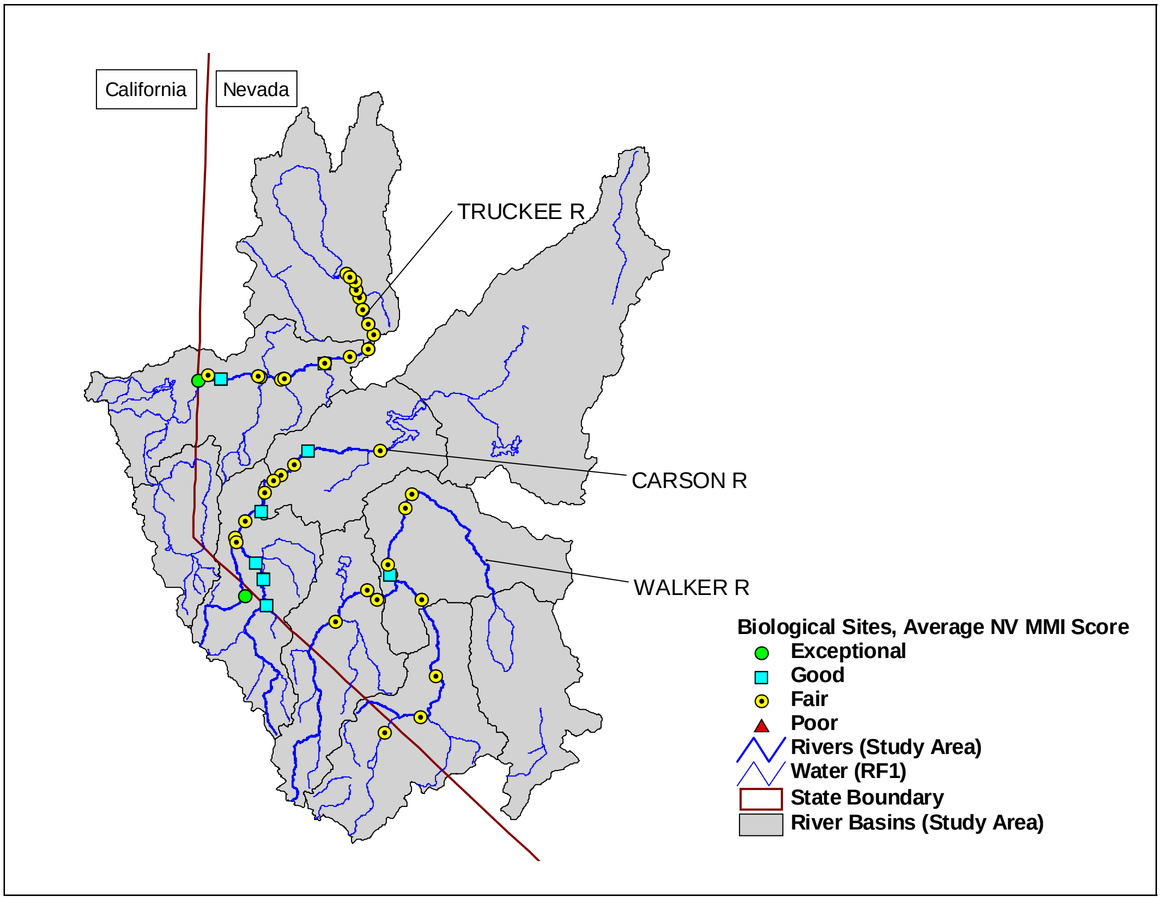

Figure 9. Average Nevada MMI scores for all sampling locations (N=49).

3 Physical Habitat Index

Nevada DEP's second goal was to develop a suite of habitat measurements that would be representative of assessing the physical habitat structure of Nevada's rivers and would be easily collected. To this end, several physical habitat methods and protocols were investigated for use in Nevada: California's SWAMP methods (Ode 2007), Wyoming's WHAM (Quist et al. 2006), and USEPA's EMAP (Kaufmann et al. 1999). Of these methods the EMAP protocols were deemed most appropriate as a framework to meet Nevada's needs and goals. Nevada DEP did not need the full EMAP suite of habitat metrics and wanted a less intensive field collection protocol. Modifications of the method were investigated that would get similarly meaningful results with reduced effort in the field. Relative bed stability (RBS) is the principal metric from the EMAP habitat protocols. RBS is a measure of "stream bed textural 'fining' that occurs as a response to increases in the rate of upland erosion, and the increased mobility or instability of the bed substrate that accompanies such inputs of fine textured substrates" (Kaufmann et al. 1999). RBS is calculated as:

$$RBS = \frac{D_{50}}{D^{*}_{cbf}}$$

Where D_{50} is the observed substrate median diameter and D^*_{cbf} is the average critical diameter at bankfull flow. D^*_{cbf} is calculated as:

$$D^*_{cbf} = 13.7 R^*_{bf} S$$

Where R^*_{bf} is the effective hydraulic radius equal to $R_{bf} - R_w - R_p$, where R_{bf} is the mean bankfull hydraulic radius (=0.5*[mean bankfull height + mean thalweg depth]), R_w is the large woody debris mean depth, and R_p is the cross-section mean residual depth; and S is average slope (Figure 10).

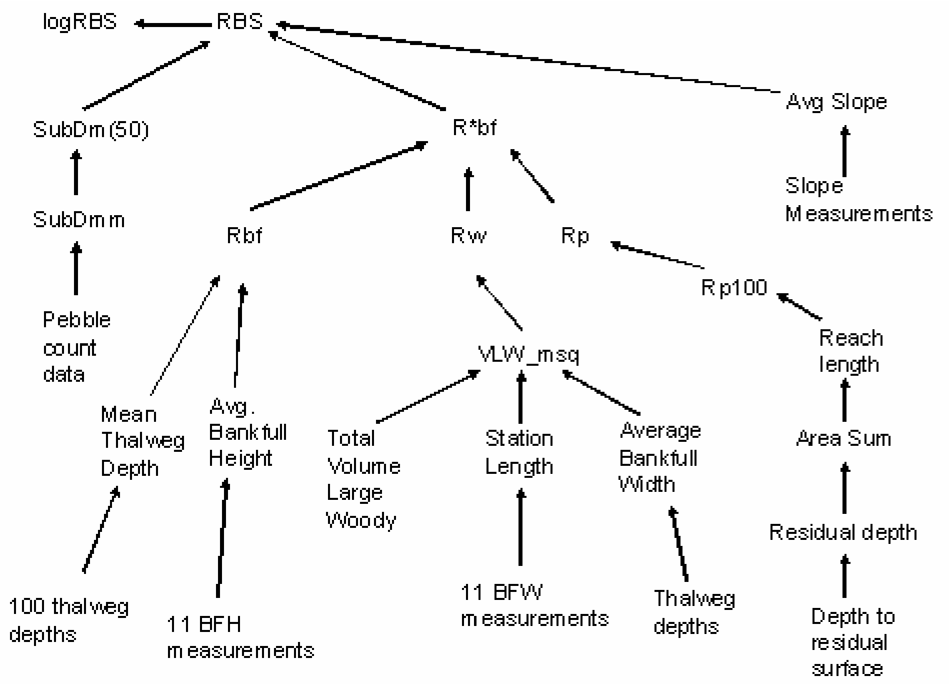

Figure 10. Data components used in calculating RBS.

3.1 Methods

Evaluation of physical habitat methods was done on data from the Truckee River, RBS values are presented here for eight sites on the Truckee River, collected in August and September 2005 (Figure 11). These calculations are based on data collected using modified (reach length 20x average width, opposed to normal 40x) EMAP physical habitat methods. The RBS values were recalculated using several different modifications to the normal procedure for calculating RBS (i.e., modifications to data that are plugged into the above equations). These modifications represent changes that could be made to field procedures to decrease sampling effort and improve time efficiency in the field (i.e., reduce overall time expenditure on data collection efforts). Twenty times channel width was selected to save time during data collection in the field. It was believed that 20x the channel width was an adequate distance to characterize the river.

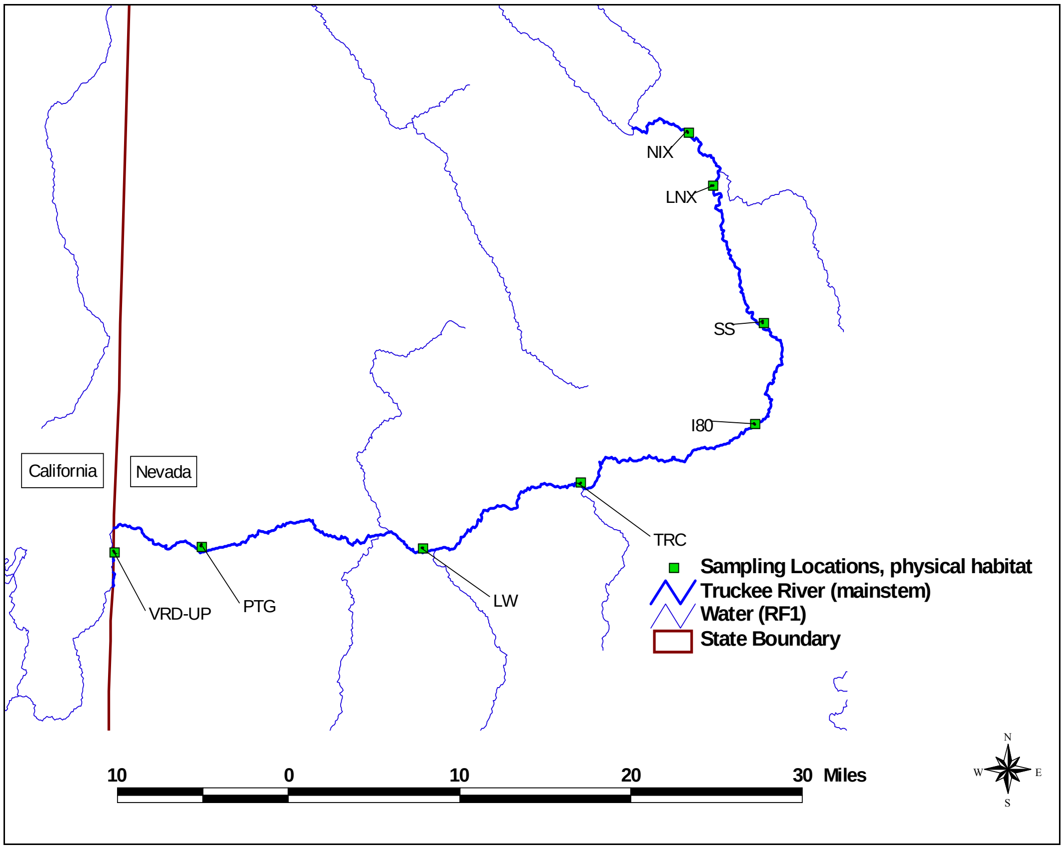

Figure 11. Location of physical habitat sampling sites on the Truckee River.

3.2 Summary

Our analysis focused on data manipulations to reduce or eliminate certain parameters to evaluate the influence on the outcome of RBS, and how the outcome would bias the results. The EMAP protocols use 11 transects spaced out evenly over the length of the sampling reach. Our analysis examined using only 3 transects, at the start, mid-point, and end of the reach, compared to the normal 11 transects. In each analysis below the non-adjusted value is the field measured value or calculation from the field data. The adjusted value is the calculated value with the specified data manipulation.

3.2.1 Modifications to Woody Debris and Residual Depth

Effect on RBS of eliminating large woody debris, "mean depth" (Rw,) and cross-section mean residual depth (Rp) on Relative Bed Stability (logRBS).

- RBS higher when Rbf adjusted (i.e., when Rw and Rp used) (Figure 12).

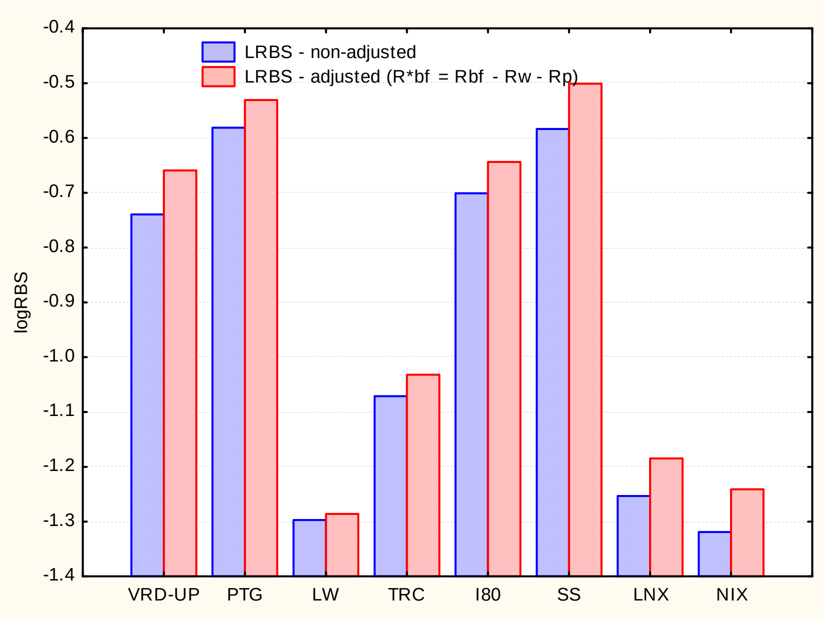

Figure 12. Log RBS (LRBS) values for eight sites on the Truckee River (ordered upstream to downstream). Non-adjusted values included the influence of large woody debris and residual pools on final R*bf values. Adjusted values had these factors subtracted.

- However, the two sets of RBS values closely correlated (Figure 13).

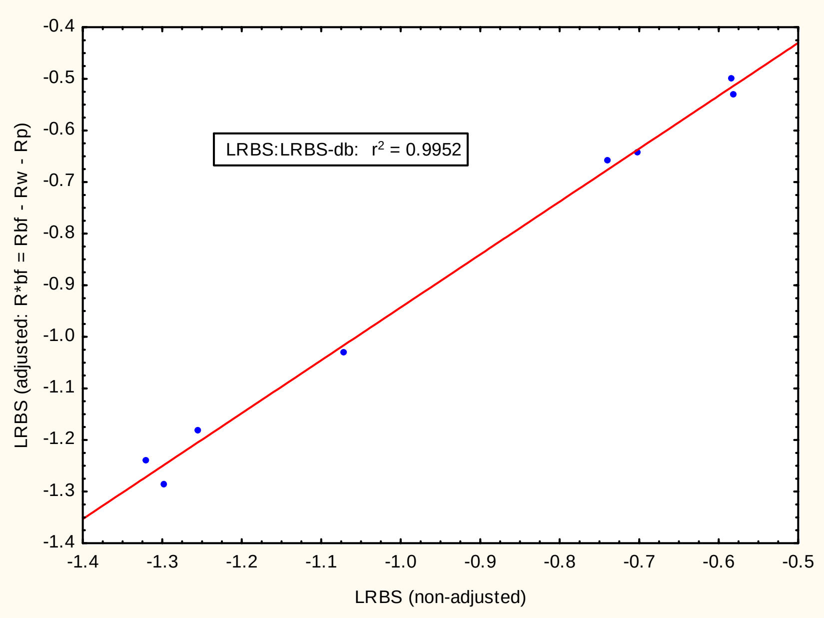

Figure 13. Log RBS (LRBS) values for eight sites on the Truckee River. Non-adjusted values included the influence of large woody debris and residual pools on final R*bf values. Adjusted values had these factors subtracted.

- Large woody debris and cross-section residual depth do not substantially affect RBS values and could potentially be removed from sampling protocol to improve time efficiency.

3.2.2 Modifications to Number of Transects

Effect on RBS of using 3 transects instead of 11 for deriving bankfull height (BFH), mean thalweg depth (Xdepth), slope, and mean residual depth (Rp)

Bankfull height

- Using bankfull height from three transects A-B, F-G, J-K, the RBS was higher in most cases compared to using all 11 transects (Figure 14).

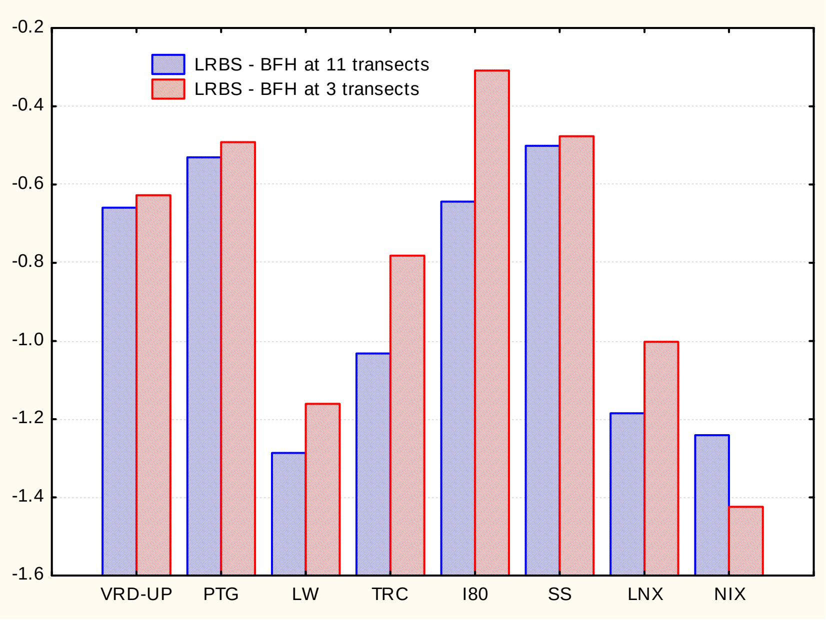

Figure 14. Log RBS (LRBS) values for eight sites on the Truckee River. Blue bars had BFH measurements for all 11 transects (EMAP methods); red bars had BFH measurements at three transects (bottom, middle top).

- However, RBS values were closely correlated between results of 3 and 11 transects (Figure 15). It should be noted that the sampling locations on the Truckee River were relatively homogeneous. The homogeneity of these xeric river systems allowed for a decrease in number of transects without substantive effects on the results of the physical habitat characterization.

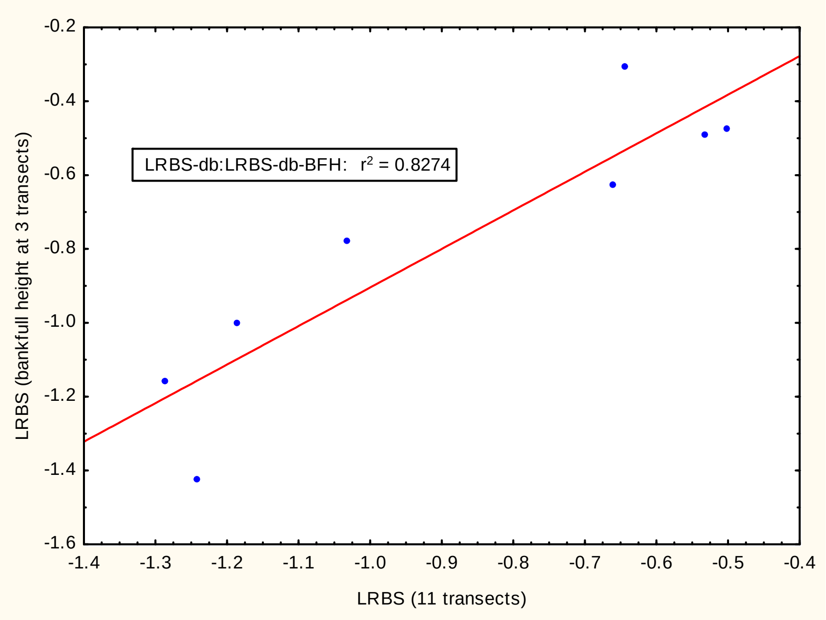

Figure 15. LRBS values for eight sites on the Truckee River. X-axis had BFH measurements for all 11 transects (EMAP methods); y-axis had BFH measurements at three transects (bottom, middle top).

- Average bankfull height calculated from 3 transects as opposed to 11 did not result in statistically different (t-test, $p<0.05$) RBS values. However, several individual sites (e.g., I80) had fairly different RBS values. Using 3 transects instead of 11 could reduce sampling time but the potential error in the RBS values could be greater in more heterogeneous habitats. RBS appears to be more sensitive to bankfull height (BFH) than mean depth (Rw).

Mean thalweg depth

- Using mean thalweg depth from three transects A-B, F-G, J-K, the RBS was similar compared to using all 11 transects (Figure 16).

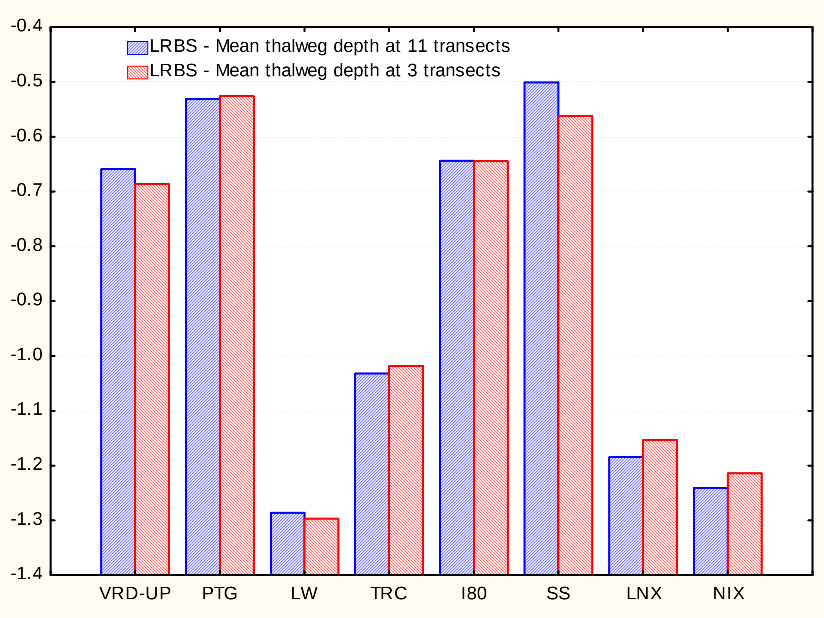

Figure 16. Log RBS (LRBS) values for eight sites on the Truckee River. Blue bars had mean thalweg measurements calculated for all 11 transects (EMAP methods); red bars had mean thalweg measurements calculated at three transects (bottom, middle top).

- Also, RBS values were closely correlated between 3 and 11 transects (Figure 17).

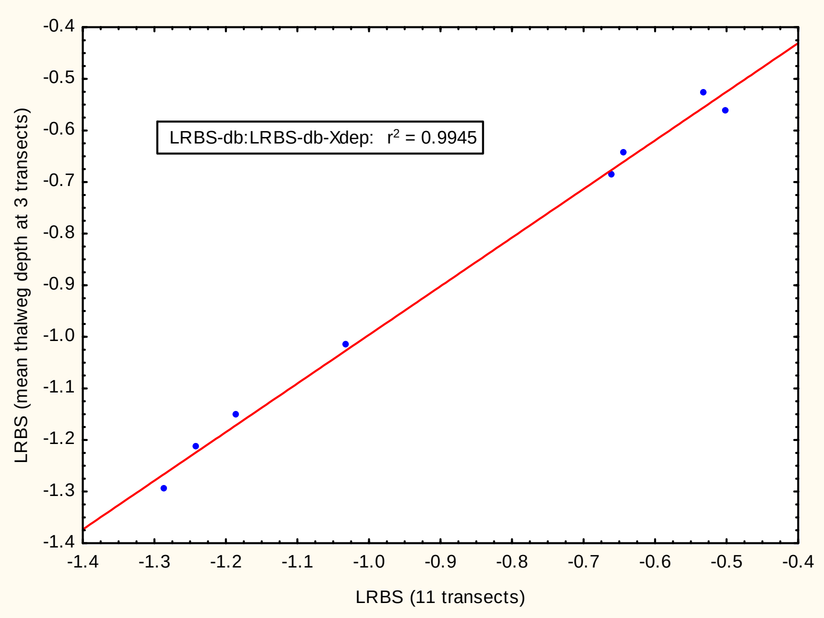

Figure 17. Log RBS (LRBS) values for eight sites on the Truckee River. X-axis had mean thalweg measurements calculated for all 11 transects (EMAP methods); y-axis had mean thalweg measurements calculated at three transects (bottom, middle top).

- Number of thalweg depth measurements does not substantially affect RBS values and could potentially be measured at 3 transects instead of 11 to improve time efficiency. Again, it should be noted that the sampling locations on the Truckee River were rather homogeneous.

Slope

- Using mean slope from three transects A-B, F-G, J-K, the RBS was, at times (e.g., sites TRC and SS) substantially different from RBS values calculated using slope measurements from all 11 transects (Figure 18).

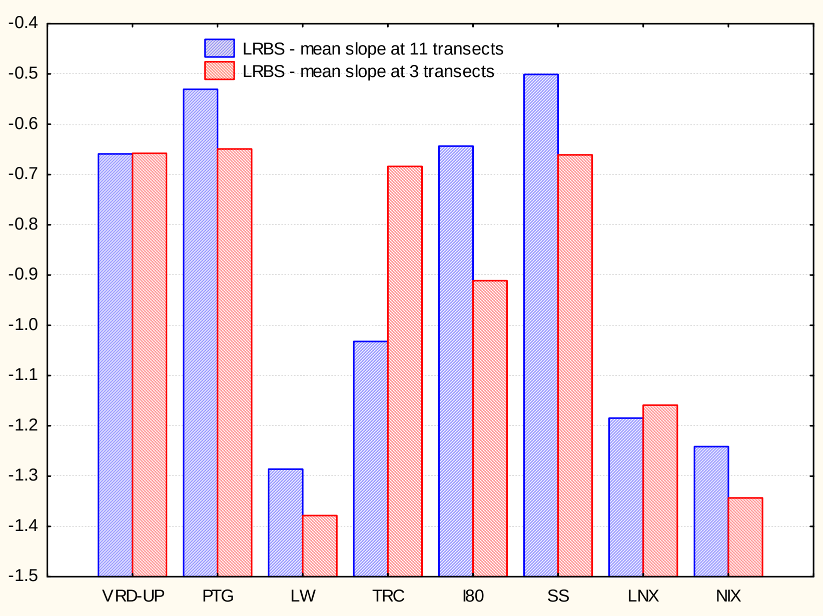

Figure 18. Log RBS (LRBS) values for eight sites on the Truckee River. Blue bars had mean slope measurements calculated for all 11 transects (EMAP methods); red bars had mean slope measurements calculated at three transects (bottom, middle top).

- There was some variability around regression line of the modified and unmodified RBS values (Figure 19).

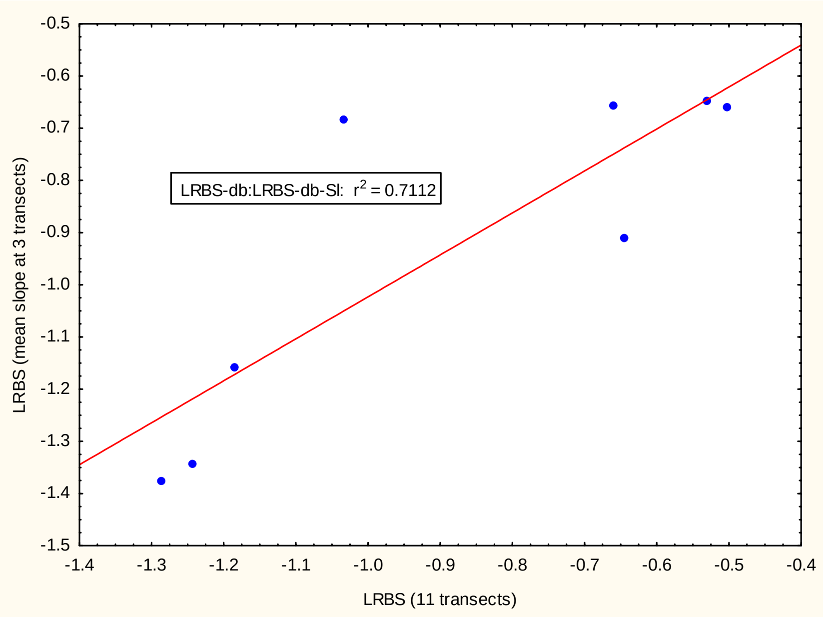

Figure 19. Log RBS (LRBS) values for eight sites on the Truckee River. X-axis had mean slope measurements calculated for all 11 transects (EMAP methods); y-axis had mean slope measurements calculated at three transects (bottom, middle top).

- Using average slope values from three slope measurements from top, middle, and bottom of each reach resulted in RBS values that were, at times, substantially different from RBS values derived using all 11 slope measurements. Using only three transects may cause erroneous results for slope and thus RBS.

Mean residual depth

- Using mean residual depth from three transects A-B, F-G, J-K, the RBS was similar compared to using all 11 transects (Figure 20).

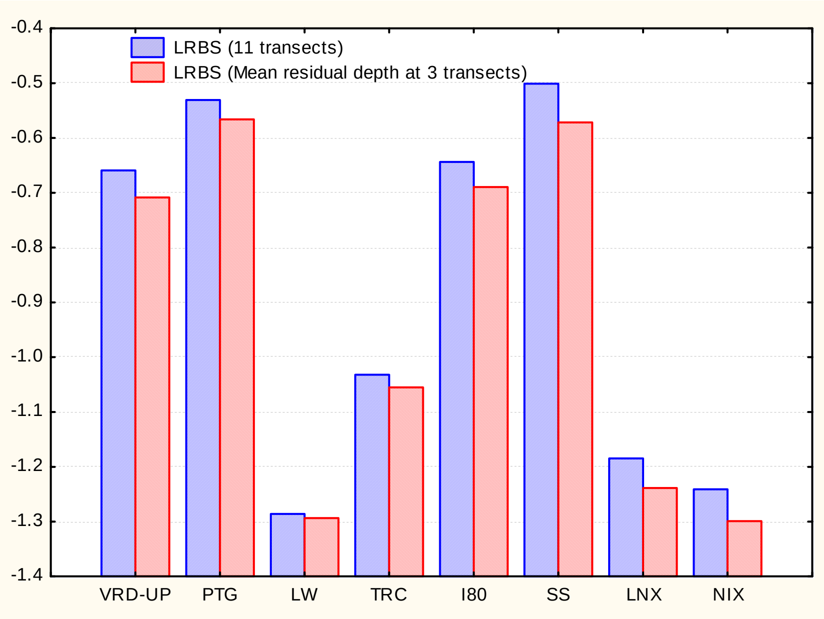

Figure 20. Log RBS (LRBS) values for eight sites on the Truckee River. Blue bars had mean residual depth measurements calculated for all 11 transects (EMAP methods); red bars had mean residual depth measurements calculated at three transects (bottom, middle top).

- However, RBS values were closely correlated between the modified (5 transects) and unmodified (11 transects) data (Figure 21).

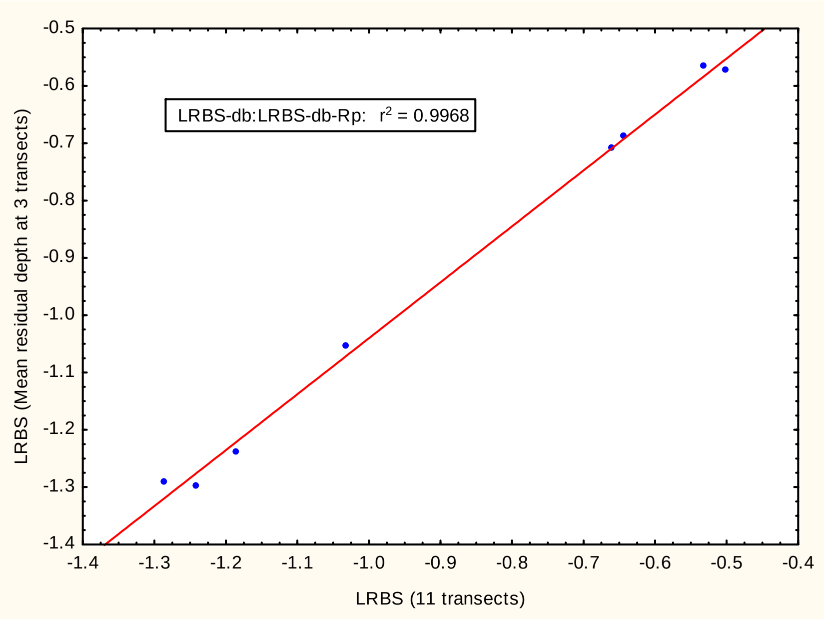

Figure 21. Log RBS (LRBS) values for eight sites on the Truckee River. X-axis had mean residual depth measurements calculated for all 11 transects (EMAP methods); x-axis had mean residual depth measurements calculated at three transects (bottom, middle top).

- Mean residual depth does not substantially affect RBS values and could potentially be measured at 3 transects instead of 11 to improve time efficiency.

Bankfull height and thalweg depth

- Using mean BFH and thalweg depth from 3 transects A-B, F-G, J-K, the RBS was similar compared to using all 11 transects (Figure 22).

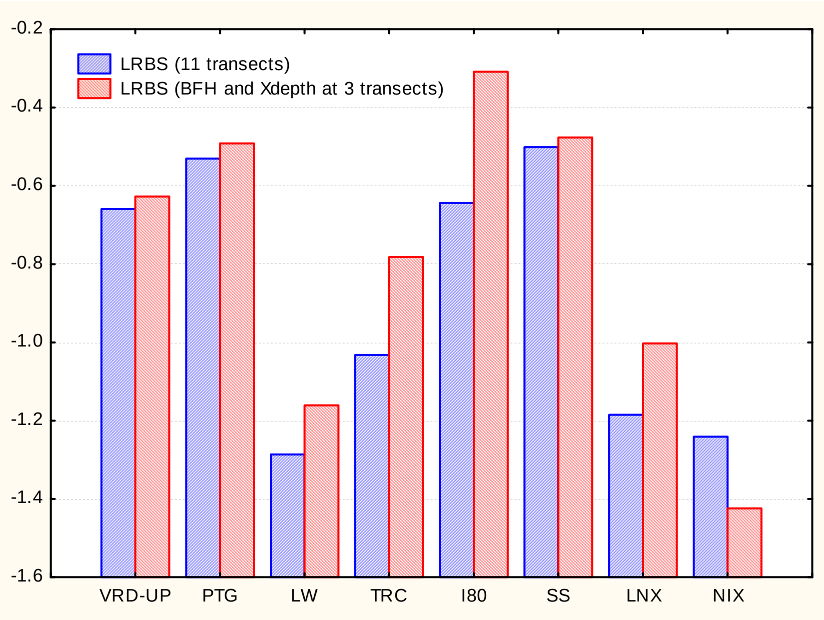

Figure 22. Log RBS (LRBS) values for eight sites on the Truckee River. Blue bars had mean residual depth measurements calculated for all 11 transects (EMAP methods); red bars had mean residual depth measurements calculated at three transects (bottom, middle top).

- However, RBS values were closely correlated for 3 versus 11 transects (Figure 23).

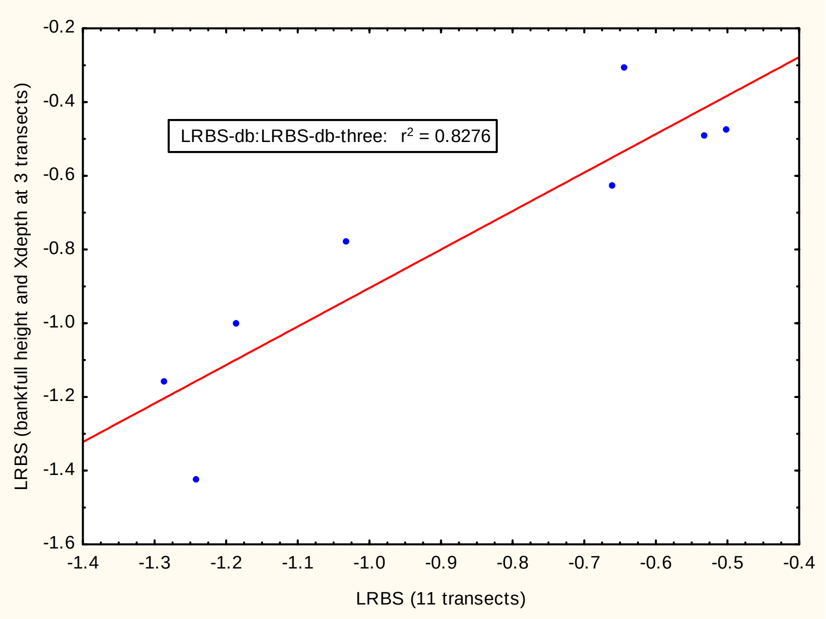

Figure 23. Log RBS (LRBS) values for eight sites on the Truckee River. X-axis had mean residual depth measurements calculated for all 11 transects (EMAP methods); y-axis had mean residual depth measurements calculated at three transects (bottom, middle top).

- Average bankfull height and thalweg depth calculated from 3 transects as opposed to 11 did not result in statistically different (t-test, $p<0.05$) RBS values. However, several individual sites (e.g., I80) had fairly different RBS values. Using 3 transects instead of 11 could reduce sampling time but the potential error in RBS estimations is probably too great. Results most likely due to the sensitivity of LRBS to bankfull height (see Figure 15).

Effects on RBS of coarse measurements of bankfull height and thalweg depth

Bankfull Height

- Existing bankfull height measurements were rounded to the nearest whole number (except measurements of 0.3-0.65 which were rounded to 0.5). These coarse estimates resulted in RBS values that were very similar to the values derived from precise measurements collected using standard EMAP methods (Figure 24 and Figure 25).

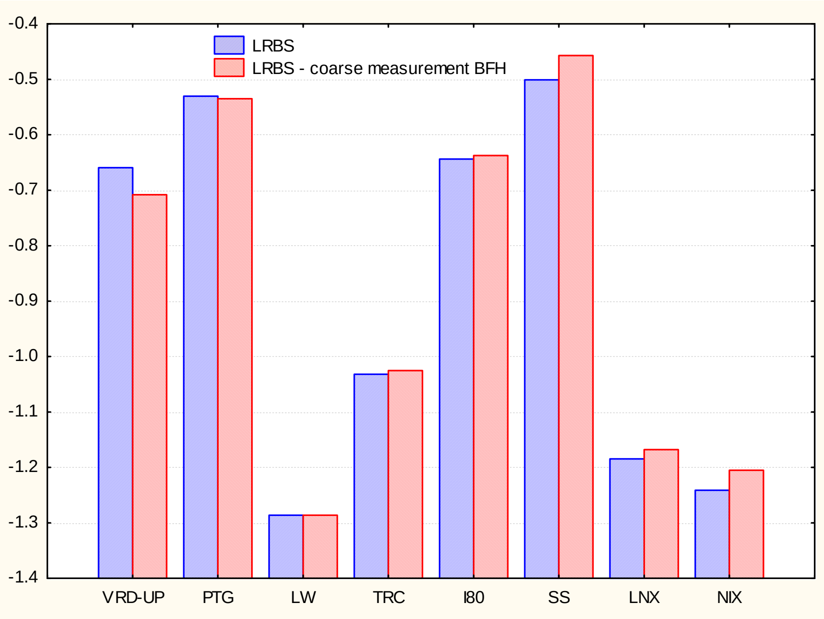

Figure 24. Log RBS (LRBS) values for eight sites on the Truckee River. Blue bars had BFH measured according to EMAP methods; red bars had coarse BFH measurements.

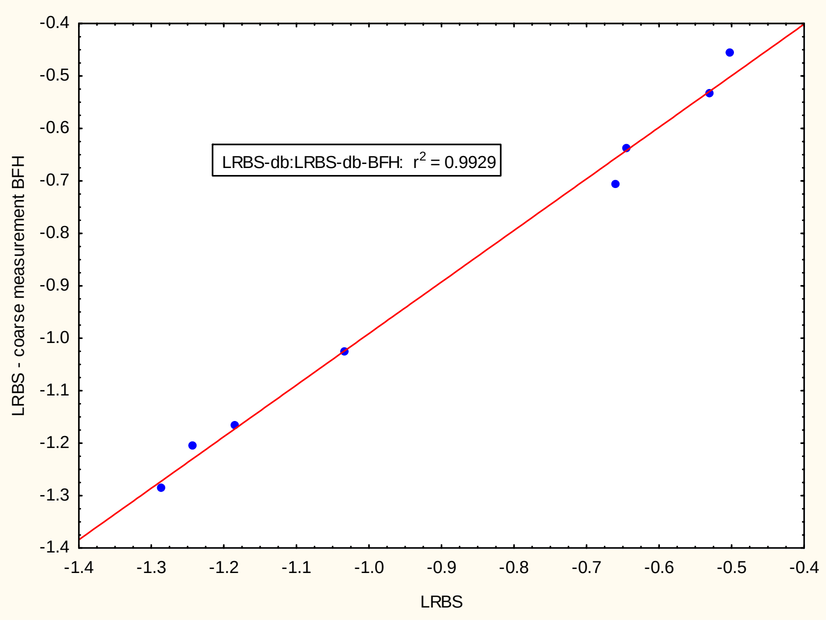

Figure 25. Log RBS (LRBS) values for eight sites on the Truckee River. X-axis had BFH measured according to EMAP methods; y-axis had coarse BFH measurements.

Thalweg Depth

- Existing thalweg depths were rounded to the nearest 10 (e.g., 12cm to 10cm, 26cm to 30cm, etc.). These coarse estimates resulted in RBS values that were very similar to the values derived from precise measurements collected using standard EMAP methods (Figure 26 and Figure 27). IN the field, coarse measurements can be taken faster than precise measurements and over the length of the reach can reduce overall time spent at the location.

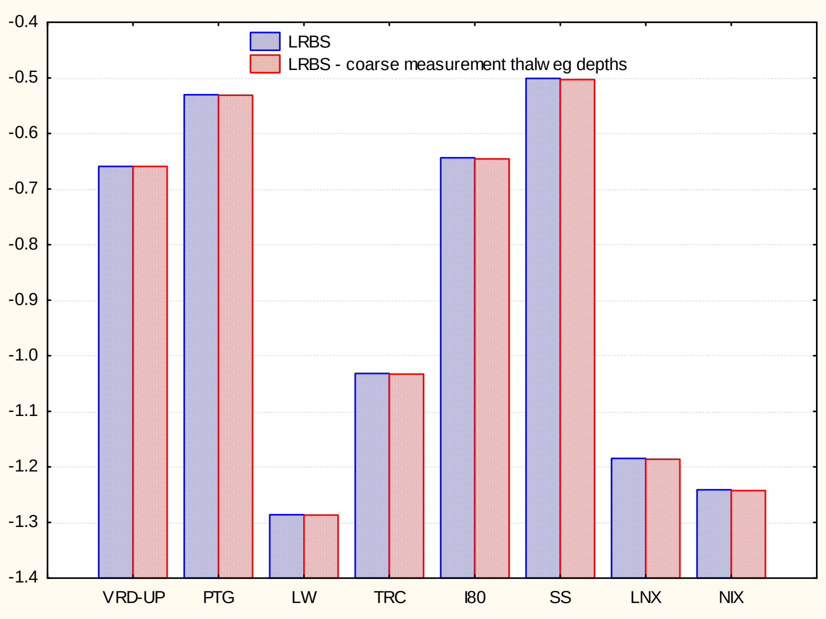

Figure 26. Log RBS (LRBS) values for eight sites on the Truckee River. Blue bars had thalweg depths measured according to EMAP methods; red bars had coarse BFH measurements.

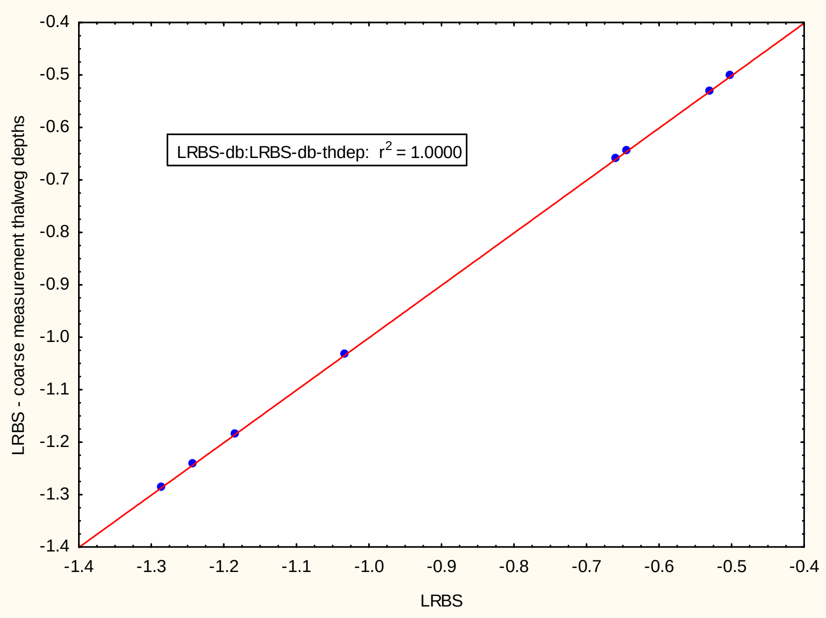

Figure 27. Log RBS (LRBS) values for eight sites on the Truckee River. X-axis had thalweg depths measured according to EMAP methods; y-axis had coarse thalweg depth measurements.

Bankfull Height and Thalweg Depth

- These coarse estimates resulted in RBS values that were very similar to the values derived from precise measurements collected using standard EMAP methods (Figure 28 and Figure 29).

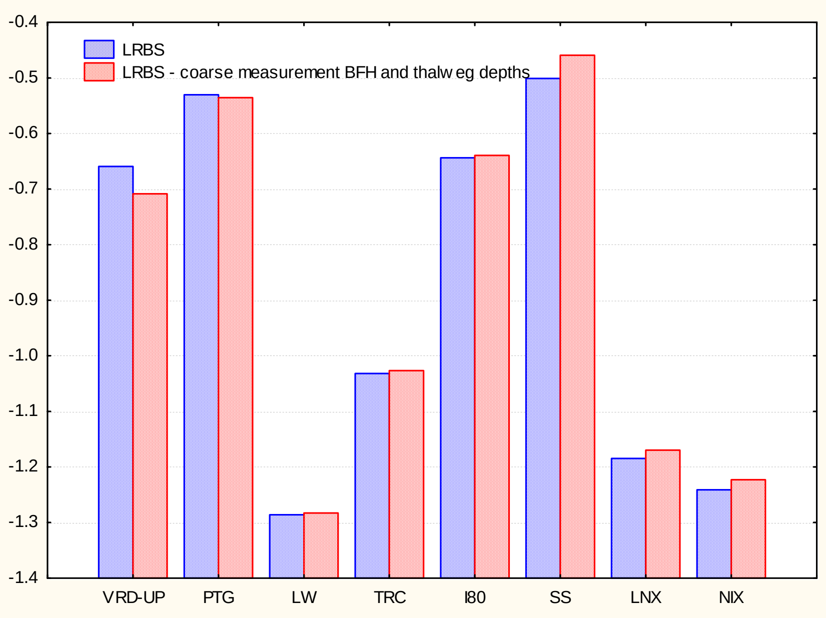

Figure 28. Log RBS (LRBS) values for eight sites on the Truckee River. Blue bars had BFH and thalweg depths measured according to EMAP methods; red bars had coarse BFH and thalweg depth measurements.

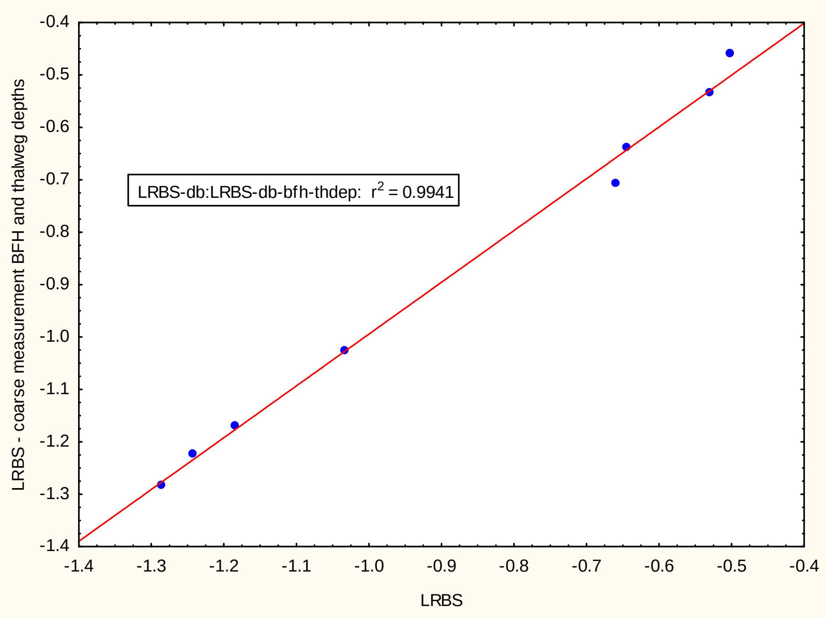

Figure 29. Log RBS (LRBS) values for eight sites on the Truckee River. X-axis had BFH and thalweg depths measured according to EMAP methods; y-axis had coarse BFH and thalweg depth measurements.

- Coarse measurements of bankfull height and thalweg depths may be suitable for increasing field efficiency while retaining accuracy of the more precise EMAP methods.

3.2.3 LRBS Values at Sampling Locations

For the eight sites on the Truckee River the LRBS values were all below 0 (Figure 30). Values of 0 are the average 2 year storm. Values greater than 0 are stable habitats and values less than 0 suggest unstable habitats (Kaufmann 1999).

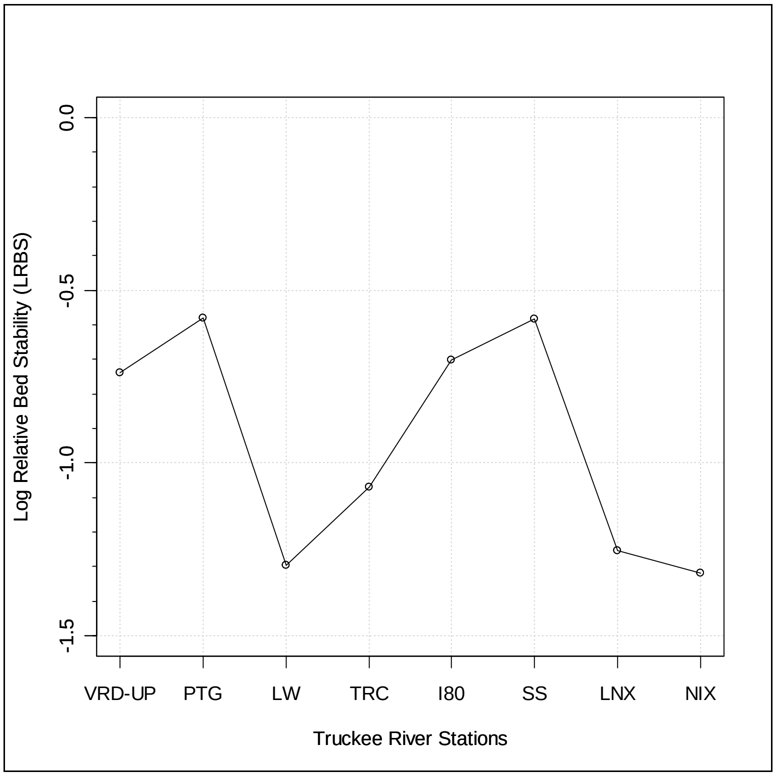

Figure 30. Log relative bed stability (LRBS) at stations along the Truckee River (Nevada). Stations are arranged from left to right as upstream to downstream. VRD-UP and PTG are upstream of Reno. Sites SS, LNX, and NIX are on the Pyramid Lake Reservation.

The eight sites can be divided by those less than -1 and those greater than -1. The sites that are tending toward stability (closer to zero) are the two sites above Reno (VRD-UP and PTG), I80 (just upstream of the Pyramid Lake Paiute Reservation) and SS (the first site within the Reservation). The other four sites, LW and TRC, both below Reno, and LNX and NIX, on the Reservation, upstream and downstream of Nixon, had LRBS values of less than -1 suggesting much more unstable habitat and indicative of stresses not present at the other sites.

4 Recommendations

4.1 Benthic Macroinvertebrates

The Nevada multimetric index (NV MMI) was developed as a tool to assess the biological integrity of the rivers of west central Nevada (i.e., the Truckee River, Carson River, and Walker River). The index categories and narrative descriptions proposed here are tentative and should be examined by NDEP to ensure that each level conveys the proper meaning and is in line with what action may be necessary. We recommend that

NDEP recalibrate and validate the index as more data become available. The metrics in this index should also be tested for use state-wide, as much of the state is in the same ecoregion (Northern Basin and Range) as the data used for this study.

Precision estimates were not calculated for this analysis due to the lack of significant numbers of replicate samples. We recommend that NDEP and PLPT establish and maintain replicate sampling to calculate precision of the individual methods. Comparability among agencies could also be examined using samples collected at the same locations during the same time periods by different agencies.

Taxonomic quality control by an independent taxonomist is always desirable to ensure that otherwise comparable data are not compromised in any way by potential error in the taxonomy (Stribling et al. draft 2007).

4.2 Physical Habitat

The goal of this study was to develop a suite of metrics that could be used to assess the physical habitat of the Truckee River with less intensive field work than is involved in the EMAP protocols. The Relative Bed Stability (RBS) metric was the primary focus of this project.

Parameters that are collected using EMAP physical habitat protocol but are not used in calculating RBS include:

- Substrate cross-sectional info: distance, depth, embeddedness
- Bank angles
- Incised height
- Fish cover
- Visual riparian estimates
- Canopy cover measurements
- Thalweg profile parameters:
  - Soft/small sediment
  - Channel unit code
  - Pool form code
  - Side channel
  - Backwater

These parameters that are not used in calculating RBS could potentially be eliminated from sampling protocols.

The field parameters that are necessary to calculate RBS include the following:

- Pebble count
- Thalweg depth
- Bankfull height
- Bankfull width
- Large woody debris
- Stream reach length

- Residual depth

According to the results presented above, measurements for numerous variables could be eliminated or condensed. All of these alterations, however, would result in at least slight changes in final RBS values. Therefore, it would be necessary to determine an acceptable degree of error for the data based on management goals and objectives and the balance between cost effectiveness and precision. Reducing the number of slope measurements was the modification that affected the modification in RBS values the most dramatically.

It appears that the most conservative approach to simplifying the field measurements used in calculating RBS would be to use coarse measurements of bankfull height and thalweg depth. Both of these measurements are relatively time consuming when done according to EMAP protocols. Because the data are averaged, however, much of the precision that is gained through the detailed measurements is essentially lost. Although the other proposed method alterations appear to have little effect on the final RBS values, they result in a lower number of data points which may increase the potential for error, particularly in more heterogeneous systems. Using a coarse measurement of bankfull height and thalweg depth would allow for the same number of data points to be collected but in a less time-consuming process. Sampling according to the full EMAP protocol on the Truckee River limits data collection to, at most, two sites per day. Reducing the protocols to 20x stream width and reducing the number of transects could, in some cases, double or triple the number of sites that could be sampled in a single day. This might be the case for the Truckee River where the sampling locations were, for the most part, homogeneous. The reduction in sampling points (i.e., number of transects) in a more heterogeneous river would likely result in more pronounced differences in calculated RBS values.

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