Wildlife Preservation Fund Grant

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Project Title: Assessment of Stream Valley Segments as Determinants of Stream Habitat Quality

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Project Objective:

The outcome of this project was to 1) determine if stream habitat within valley segments is homogenous and 2) determine if adjacent valley segments have varying habitat variables.

Project Description:

Stream habitat assessment procedures have been used to monitor the biological potential of streams and stream habitat restoration projects, predict fish presence and absence, and determine anthropogenic impacts. In the past, the Illinois Department of Natural Resources (IDNR) and the Illinois Natural History Survey (INHS) have determined which stream sites to sample for habitat quality based on historical data, site accessibility, location to point source pollution, relative location to tributaries, relative position within a watershed, and whether or not the site is representative of the entire watershed. To develop a more consistent and unbiased procedure for choosing sites to sample for habitat quality, the IDNR and INHS have proposed a technique by which watersheds are divided into homogenous stream segments called valley segments. The valley segments within a watershed are determined by Geographic Information System (GIS) parameters such as surficial geology, predicted flow class, predicted thermal class, slope, drainage area, and link number. The assumption behind the proposed procedure is that habitat quality within the entire valley segment is homogenous and that the habitat quality of the valley segment can then be determined by sampling one site within that segment. To date no research has been conducted to document that habitat within valley segments are homogeneous, or that different valley segments have varying habitat variables.

My research will help the IDNR and INHS to determine if valley segments are a valid way for selecting stream locations for determination of habitat quality. I will also develop the first protocols for sampling valley segments and create a habitat quality data set that can be used by professionals to make informed management decisions related to overall stream habitat quality. Thus, the objectives of the project are to 1) determine if stream habitat within a valley segment is homogenous and 2) determine if different adjacent valley segments have varying habitat variables.

Total Project Expenditures:

This section will be supplied by the budget department at Eastern Illinois University.

Summary of Project Accomplishments

Introduction

Since the establishment of the Clean Water Act in 1948 (CWA), there has been a need for the maintenance, restoration, and monitoring of the chemical, biological, and physical integrity of waterways. Water chemical analyses, bioassessments, and habitat assessments have been designed and implemented throughout the United States for use in identifying possible aquatic impairments, while playing a critical role in allowing the evaluation of the overall quality of aquatic habitat.

A wide range of analyses are used to detect stressors and evaluate the chemical quality of streams. Different stressors commonly evaluated are acidic deposition, nutrient enrichment, and inorganic contaminants (USEPA 2004). Water clarity, dissolved oxygen, and temperature are also important determinants of water quality. These analyses provide empirical and legal validity to the assessment of stream condition (Conrad 2005).

Anthropogenic disturbance has significantly impacted stream integrity. In Illinois, approximately 80% of the land use is dedicated to agriculture (Rhoads and Herricks 1996). Tilling of agricultural fields and stream channelization are common practices that reduce the flooding of agricultural land (Infante et al. 2006). These practices have resulted in increases in nonpoint pollution such as erosion and runoff of suspended solids and agricultural chemicals (Royer et al. 2006, Sheehan and Rasmussen 1999). According to Sheehan and Rasmussen (1999), suspended solids are the most significant source of pollution in North American streams. Nitrogen and phosphorus from agricultural chemicals have adversely changed stream water quality, causing eutrophication, uncontrolled algal production, decreased dissolved oxygen, and fish kills (Figueroa-Nieves et al. 2006, Morgan et al. 2006, Royer et al. 2006)

Urban land use practices have also contributed suspended solids, biological oxygen demanding wastes, and toxic metals into streams through both point and nonpoint sources (Crunkilton et al. 1996). Point sources of pollution such as wastewater treatment plants and industrial discharges in conjunction with nonpoint sources such as lawn fertilizers and construction site runoff have a profound impact on aquatic community diversity and abundance (Sheehan and Rasmussen 1999, Carpenter et al. 1998, Crunkilton et al. 1996).

The development of biological integrity as a method for water quality monitoring has encouraged the development of biological criteria to assess the health of aquatic communities.

Stream bioassessment procedures supplement chemical sampling by providing the most accurate means of detecting and measuring overall water quality (Sheehan and Rasmussen 1999, Plafkin et al. 1989). Bioassessments can also be used to determine the cumulative impacts of pollution and habitat degradation on aquatic communities (Karr et al. 1983). The Index of Biotic Integrity (IBI) was originally developed by Karr et al. (1983) and has since seen several revisions (IDNR 2000, Simon and Dufour 1997). This index provides a sensitive and reproducible measure of the integrity of fish communities (Karr 1983, Karr and Dudley 1981). Total scores are used to assign a narrative description to the biological integrity of the community within the sampled stream segment (Karr 1983, Simon and Dufour 1997).

Stream habitat assessments provide a method to assess improvements made by stream enhancement and restoration projects and identify limiting factors that influence the biological potential (health) of a stream segment (Maddock 1999, Wang et al. 1998, Allan 1997). These assessments are used to guide stream enhancement and restoration projects to improve water quality and biological integrity of river systems as well as assess if these projects are successful (Maddock 1999). This is particularly important in Illinois, where streams have been heavily modified due to this agricultural activity (Rhoads and Herricks 1996). The Qualitative Habitat Evaluation Index (QHEI) is one model utilized in Illinois to measure stream habitat variables generally corresponding to physical factors that influence aquatic communities (Rankin 1989). This index is designed to be a relatively rapid assessment requiring both minimal time and measurement. Habitat variables measured in this index can be used to explain species presence/absence and composition of fish communities within a stream segment (Rankin 1989).

Stream habitat can be used as an estimate of the total "living space" available for aquatic communities (Maddock 1999). Therefore, habitat indices can be used to determine the biological potential of a stream (Barbour et al. 1999). Since habitat quality is often a limiting factor in biological integrity, fish communities rarely exceed the quality of the habitat (Plafkin et al. 1989). Habitat assessments can help identify limiting factors in the stream (Conrad 2005, Simon 1998). Comparison of habitat assessments with bioassessments can often reveal underlying causes of impairment to biological communities (e.g. habitat quality, point and non-point pollution, etc.). For example, sites with severely altered habitat would be expected to have poorer quality fish communities and vice versa. Alternatively, high quality habitat and poor biological communities may be an indication of chemical pollution (Plafkin et al. 1989). This combined determination of the chemical, biological, and physical integrity allows managers to accurately quantify stream water quality.

In Illinois, given the total number of streams, managers lack the time and the resources necessary to visit each stream and determine its ecological status (Seelbach et al. 2005). To date, the Illinois Department of Natural Resources (IDNR) has determined which stream sites to sample for overall stream quality based on historical data, site accessibility, proximity to point source pollution, relative location to tributaries, relative position in the watershed, and whether or not the site is representative of the entire watershed (IDNR 2002). However, determining if these sites are representative of conditions throughout the stream is often difficult due to the spatial variability of streams (Seelbach et al. 1997, Seelbach and Wiley 1997). To develop a more consistent and unbiased procedure for choosing representative sites to sample for stream quality, the IDNR has proposed a technique by which watersheds are divided into homogenous stream segments, called valley segments. Valley segments within a watershed are determined by ArcGIS 9.2 Geographic Information System (GIS) software (ESRI, Redlands, California) parameters such as surficial geology, predicted flow class, predicted thermal class, slope, drainage area, and link number (Brenden et al. 2007, in review, ESRI 2006).

There are three assumptions to the proposed valley segment model. The first assumption is that habitat quality of the entire valley segment is fairly homogenous, and therefore the habitat quality of the valley segment can then be determined by sampling one site within that segment (Seelbach et al. 1997, Seelbach and Wiley 1997). The second assumption is that stream segments with similar GIS parameter criteria will be grouped into one valley segment. Lastly, overall habitat quality within each valley segment is more similar than the habitat quality between adjacent valley segments.

To date no research has been conducted to document that habitat within valley segments are homogeneous, or whether different valley segments have varying habitat variables. Thus, the purpose of this research project is to assess stream valley segments as determinants of stream habitat quality. This research project will help the IDNR, Illinois Natural History Survey (INHS), and Illinois Environmental Protection Agency (IEPA) determine if valley segments are a valid way for selecting stream locations for determination of habitat quality. Research obtained from this project will be used to develop the first protocols for sampling valley segments and create a habitat quality data set that can then be used by professionals to make informed management decisions related to overall stream habitat quality. Thus, the objectives of this project are to 1) determine if the stream habitat within a valley segment is homogeneous and 2) determine if different valley segments have varying habitat variables.

Since stream valley segments are determined by grouping similar GIS attribute data, and this data is at a fine enough scale to determine habitat differences within reaches, we would expect that valley segments are true habitat divisions within a stream. Therefore, sample reaches within valley segments will not differ with regard to instream habitat variables. If this assumption holds true one benefit of this classification system is that it can be used for modeling and extrapolation of stream systems and allow for the accurate determination of representative sites and future stream impairments, while still retaining natural ecological variation among streams (Seelbach et al. 2005, Hawkins et al. 2000, Seelbach et al. 1997, Seelbach and Wiley 1997).

Methods

All streams were sampled in the upper Embarras River watershed in east-central Illinois. To test the valley segment model, sampled streams were dispersed throughout the upper portion of this watershed in order to 1) ensure adequate coverage of the upper portion of the watershed and 2) test this model utilizing a variety of streams. Streams within the Embarras River watershed had been previously separated into different valley segments types using GIS parameters (surficial geology, predicted flow class, predicted thermal class, slope, drainage area, and link number). When considering which valley segment types to sample, segment accessibility (i.e. number of bridges crossing a specific valley segment) was considered first. Secondly, valley segments less than 1,600 meters in length were not selected as smaller valley segments would not allow proper spacing of replicate reaches, possibly resulting in reduced variability due to the close proximity of these reaches.

Thirteen streams were identified and sampled within the Embarras watershed between May and August of 2007. Each stream consisted of two adjacent valley segment types for a total of twenty-six valley segments. There were two different types of valley segments sampled: multiple arc valley segments (MAVS) and single arc valley segments (SAVS), with a stream arc defined as a stream segment extending from one confluence to the next downstream confluence (Seelbach et al. 1997).

Seven stream locations consisted of one upstream MAVS and an adjacent downstream SAVS. MAVS were selected because these valley segments are true tests of the stream arc merging routine managers have used to delineate valley segments. The remaining six stream locations were composed of two adjacent SAVS. Adjacent SAVS with similar drainage areas were selected to determine if the VAST should have combined these segments into a MAVS. The assumption is that these similar sized stream segments should have similar habitat structure and quality (Vannote et al. 1980).

Upstream valley segments were separated into representative stream arcs. Each arc was divided into 400 meter increments. This distance was selected in order to 1) ensure that reaches sampled were not in close proximity to each other and 2) to ensure adequate coverage within each valley segment arc. Three reaches were randomly selected and sampled within each valley segment arc to minimize bias. In the field, reaches were not sampled within 200 meters from a bridge, tributary, or beaver dam as research has documented that these factors may influence habitat quality and aquatic community structure (Montgomery and MacDonald 2002, Barbour et al. 1999, Minshall et al. 1985).

Using Arc GIS, adjacent valley segments downstream of each initial valley segment were identified. Within these valley segments, reaches were randomly selected and sampled within each stream arc based on the same protocols used to identify reaches in the upstream valley segments. All downstream valley segments were SAVS. Within each stream, all reaches were sampled within one week in order to minimize temporal variability of habitat variables between reaches.

A modified USEPA Wadeable Streams Assessment (WSA) transect method was used to quantify habitat characteristics at a reach scale (USEPA 2004). This assessment utilizes a random, systematic sampling methodology to minimize bias in the placement and positioning of habitat measurements (USEPA 2004). A quantitative sampling procedure was selected in order to obtain direct measurements of stream habitat variables. Qualitative sampling was not implemented because of its subjectivity which could result in potential loss of resolution when performing statistical analyses and may hinder the ability to detect statistically significant differences between habitat variables, sample sites, and adjacent valley segments (Hannaford et al. 1997, Wang et al. 1996, Roper and Scarnecchia 1995).

There were several procedures modified from the WSA. The WSA normally spaces transects systematically at forty times the stream's wetted width. For more consistent comparisons among all reaches within a valley segment, reach length was modified to a set distance of 100 meters. Typically, the WSA evenly spaces transects across a sample reach at one-tenth the total reach length (USEPA 2004). Since the reach length was reduced to a set distance of 100 meters, the number of transects was reduced to ten. Riparian vegetation and stream bank structure were determined three meters upstream and downstream of each transect on each bank. These protocols were modified from the original WSA protocol of five meters upstream and downstream of each major transects due to the previously mentioned modification of reach length.

A Garmin ® Global Positioning System (GPS) was used to locate each sample site within the valley segment. All streams were sampled at baseflow conditions. Each reach began at the top of the nearest channel unit and progressed 100 meters upstream. Every ten meters, major transect points were systematically marked using flagging tape over the entire reach length.

Habitat data was collected on variables within four categories: channel, bank, riparian/floodplain, and instream cover structure. Previous stream classification systems have indicated the importance of variables within these categories (Talmage et al. 2002, Gregory et al. 1991, Frissell et al. 1986, Platts 1974). Habitat data was also collected on reach characteristics, as these variables indicate potential stream flow at that point in the stream as well as anthropogenic disturbances (i.e. channelization).

Channel structure is important because it functions to transport water and nutrients as well as supports aquatic communities (Schlosser 1982, Gorman and Karr 1978). Variables within this category included wetted width, thalweg (flow path of the deepest water in the stream channel), water depth, and substrate. Wetted width, thalweg, and water depth were measured to the nearest meter. Organic and inorganic substrate was collected by a modified Wolman pebble count and assigned a categorical value (Wolman 1954). In order to perform statistical analyses on substrate in SAS, these categorical names were then assigned numeric values based on the size of substrate (Table 1).

Bank structure can affect velocity and sediment input into a stream while providing food and cover for aquatic communities (Bohn 1986). Variables in this category included bank angle, bank undercut, bank erosion, and dominant vegetation type. All three variables were determined for both left and right banks. Bank angle was measured with a clinometer to the nearest degree. Bank undercut distance was measured to the nearest 0.01 meter. Bank erosion was categorized into one of four categories (Table 1). A ranking system was used to estimate the abundance of each stream bank vegetation type including herbaceous, woody-shrubs, trees, bare, and bedrock bank (Table 1). For statistical purposes, bank angle, erosion, and dominant vegetation type for both left and right banks were averaged together for each transect.

Riparian vegetation can directly impact bank stability as well as the quantity of instream cover (i.e. woody debris) while floodplain quality influences the storage and release of water and nutrients during high precipitation events and provides potential spawning grounds for aquatic organisms (Allan and Castillo 2007, Meader and Goldstein 2003, Montgomery and MacDonald 2002, Seelbach et al. 1997, Rankin 1989). Variables sampled in this category included width of riparian zone, dominant riparian vegetation type, percent canopy cover, and immediate floodplain quality. All variables were determined for both left and right sides of the stream. Riparian zone width was estimated to the nearest ten meters, and the maximum riparian zone value that could be recorded was 100 meters. Total riparian zone width was determined by adding together both banks at each transect. Canopy cover was measured at the midpoint of each major transect with a convex spherical densiometer model C (Lemmon 1956). Dominant riparian type was categorized into one of four categories that best represented the riparian zone at that transect point: herbaceous, woody shrubs, trees, or mixed (combination of herbaceous, woody shrubs, and trees). Both riparian vegetation scores were then combined for a total score. Landuse within 30 meters of the riparian zone was recorded in order to determine floodplain quality. A ranking system was used based on increasing levels of floodplain disturbance (Table 1).

Instream cover is important not only because it provides areas for aquatic organisms to hide, feed, and spawn but also affects the total density of fish species present (Hayano et al. 2002, Angermeier and Karr 1984). Variables in this category included aquatic macrophytes, root mats, undercut banks, artificial substrate, submerged terrestrial vegetation, rootwads, overhanging vegetation, boulders, small woody debris, and large woody debris. Instream cover was visually estimated and ranked (Table 1). Overhanging vegetation had to be within one meter of the surface of the water. Small woody debris was counted if it had a minimum diameter of 5 centimeters and a minimum length of 0.75 meters. Large woody debris was counted if it was within the wetted width of the channel or at least partially within the bankfull stage of the channel. Large woody debris had to have a minimum diameter of 10 centimeters and a minimum length of 1.5 meters (USEPA 2004).

Sinuosity and bankfull width were measured at each reach scale. Sinuosity was measured by using a rangefinder to determine the straight line distance and a surveyor's rope to determine the thalweg distance of each reach. Thalweg distance was then be divided by the straight line distance to determine sinuosity. Bankfull width was defined as the channel that is filled every one to two years by a moderate sized flood event (USDA 2005, USEPA 2004). Bankfull width was recorded at three major transects within the sample reach based on the procedures outlined by the USDA (2005). Perturbations such as removal of natural vegetation, channel modification, bank erosion, and presence of tile drains were noted for each reach.

Statistical Analyses

Multiple arc valley segments were first analyzed to determine the effectiveness of the stream arc merging routine at combining similar stream arcs. Using statistical analysis software (SAS), a principle components analysis (PCA) of all stream habitat variables was used to determine if similarities exist within stream arcs and differences existed between stream arcs. A PCA reduces the dimensionality of a data set by decreasing the total number of variables used within the analysis into principle component axes (Gotelli and Ellison 2004). These axes represent a large portion of the variation from the original data set (Gotelli and Ellison 2004, McCune and Grace 2002). When PCA axes are graphed, the relative distance between sample points indicates how similar or dissimilar points are in relation to each other (Dytham 2003).

The number of habitat variables collected at each reach was greater than the number of reaches sampled within each valley segment. Large sample size improves the consistency of PCA axes (McCune and Grace 2002). Tabachnik and Fidell (1989) suggested there should be approximately five sample units for each observed variable. Therefore, transects within each reach were used as replicates instead of the reaches in order to increase the sample size for each PCA. By increasing the sample size, there was a more appropriate ratio between observed variables and sample size. Analyzing habitat data using transects was also beneficial in that reach variability was able to be compared within valley segments while arc variability was able to be compared between valleys segments.

A PCA was performed for each MAVS for a total of seven PCAs. Each principle component axis was selected only if it had a minimum eigenvalue greater than one (McCune and Grace 2002). Based on the amount of variation explained by each PCA axis, a set number of axes were selected as the measure of environmental variability within and between valley segment arcs. In other words, it was not the focus of this project to determine how a single variable (e.g. wetted width) varied within and between stream arcs. Instead, it was more important to focus on how a suite of habitat variables described the environmental variation within and between stream arcs. Since each principle component axis is an aggregate of all environmental variables, each axis was analyzed using a multivariate analysis of variances (MANOVA).

A MANOVA compares multivariate means of two or more groups to determine if significant differences exist between them (Gotelli and Ellison 2004, Dytham 2003, McCune and Grace 2002). Two MANOVAs were performed since the objectives of the project were looking at two different spatial scales. The first spatial scale focused on the scale of the stream reach (i.e. were there differences between reaches within a stream arc). The second spatial scale focused on the scale of the stream arc (i.e. where there differences between arcs within a MAVS). A Pillai's trace was selected to determine the p-value as it is more robust against violations of multivariate normality and significant levels were accepted at a p-value less than 0.05 (Gotelli and Ellison 2004). Depending on the MANOVA results, these MAVS valley segments would then be compared to adjacent downstream SAVS.

Adjacent valley segment within each stream were then tested using the same methodology used to test the MAVS. A PCA was used to determine if similarities exist within valley segments and differences exist between adjacent valley segments. A PCA was conducted for each valley segment group for a total of thirteen PCAs. Based on the amount of variation explained by each PCA axis, a set number of axes were selected as a measure of environmental variability. Two MANOVAs were then used on these principle component axes to determine if significant differences occurred 1) at the level of the stream reach (i.e. were there differences between reaches within each valley segment) and 2) at the level of the valley segment (i.e. were there differences between adjacent valley segments).

Results

Multiple Arc Valley Segments

Comparing the PCA for each MAVS, 47-62% of the variation within the habitat data was explained by the first three principle component axes. These three axes were then used in two MANOVAs to compare environmental variability within and between stream arcs. In every MAVS, stream arcs were significantly different from each other ($6.61 \leq F \leq 46.02$; $p \leq 1.23E\text{-}04$; Table 2). Within each stream arc, reaches were significantly different from each other ($2.64 \leq F \leq 18.07$; $p \leq 0.0203$; Table 2), indicating a relatively heterogeneous habitat quality within these arcs.

Total Valley Segment Model

When comparing the PCA for each stream, 49-73% of the variation within the habitat data was explained by the first three principle component axes. These three axes were then used to compare environmental variability within and between valley segments. In 12 of 13 streams, adjacent valley segments significantly differed from each other in regards to this environmental variation ($5.37 \leq F \leq 245.13$; $p \leq 0.002$; Table 3). Within all valley segments, reaches significantly differed from each other ($3.52 \leq F \leq 19.69$; $p \leq 0.0003$; Table 3), suggesting a great deal of habitat heterogeneity exists within each valley segment.

Discussion

The Illinois stream valley segment model was designed to provide stream managers with a consistent and unbiased procedure for selecting representative sampling locations as well as provide the ability to extrapolate reach specific information to a larger spatial context. According to the assumptions of this model, stream arcs within each valley segment should have similar channel morphology and hydrology, and adjacent valley segment types should have differences among these characteristics (Brenden et al. 2007, in review, Seelbach et al. 1997). These parameters should influence stream habitat; therefore, it is expected that habitat follows a similar pattern within and between valleys segments (Inoue and Masanori 2002, Walters et al. 2003, Montgomery 1999).

Multiple Arc Valley Segments

The effectiveness of the valley segment arc merging routine was evaluated by looking at seven MAVS. Reaches within each stream arcs were significantly different from each other indicating a great deal of habitat variability was present within each stream arc. Comparisons between arcs within each MAVS revealed that arcs were significantly different from each other. This contradicts one assumption for MAVS, since the arc merging routine should be combining similar stream arcs together. However, stream arcs appear to be adequately partitioning habitat variation since the variation between reaches within each stream arc was less than the variation between stream arcs.

Since a great deal of habitat heterogeneity is present within MAVS, there is concern for whether or not the stream arc merging routine is effectively merging similar stream arcs. Therefore, it is necessary to determine if the combined habitat variability within a MAVS is significantly different than the combined variability within the adjacent downstream SAVS. Despite the apparent habitat heterogeneity within MAVS, comparisons were still made between MAVS and the downstream SAVS within the same stream.

Valley Segment Model

There was a consistent pattern in regards to stream habitat within and between adjacent valley segments in spite of the variety of stream used to test the valley segment model. Within each valley segment, reaches were significantly differed from each other, contradicting a main assumption of the valley segment model that stream quality is homogenous within each valley segment. Habitat heterogeneity was already expected in the MAVS, which were already determined to be relatively heterogeneous, but it was interesting to note that SAVS were also heterogeneous in regards to habitat structure. In the majority of streams, adjacent valley segments were significantly differed from each other, indicating environmental variation within each valley segment was partitioned appropriately by the valley segment model. Therefore, it can be concluded that valley segments are adequately partitioning variation since the environmental variation between reaches within a valley segment is less than the variation between adjacent valley segments.

One expectation would be that given the large amount of environmental variability within a MAVS, these valley segments should be significantly different when compared to the amount of environmental variability within the downstream SAVS. However, even with variation within MAVS, when compared to the downstream SAVS, these two valley segments were still significantly different from each other. These results support that the stream arc merging routine has effectively merged similar stream arcs together such that the MAVS are still different than other valley segment types. Therefore, valley segments contain a relatively homogenous habitat compared to other valley segment types.

Conclusion

In conclusion, these initial results support the valley segment model proposed by the IDNR and INHS, and indicate that it is an effective management tool. While the valley segment model encompasses temporal and spatial scales, it integrates both structure and function into a relatively low cost procedure that creates consistent understanding among stream managers (Seelbach it al. 1997). This model 1) retains the stream's natural ecological variation, 2) allows for modeling and extrapolation of stream systems, and 3) provides both accurate and practical state-wide planning of representative sites and identification of stream impairments. Given these benefits, valley segments is an appropriate system for evaluation, management, and extrapolation of stream condition.

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Table 1: Rank category values associated with habitat variables collected during the quantitative habitat assessment of each sample reach. Rank values were then analyzed in PCA for each stream.

Rank	Substrate	Bank Erosion	Bank Vegetation	Floodplain Quality	Instream Cover	Dominant Riparian Type
0			0-25%	No disturbance	0%	
1	Clay	0-10%	26-50%	Old field	1-10%	Herbaceous
2	Silt	11-25%	51-75%	Cow pasture	11-40%	Woody-shrub
3	Sand	26-50%	>75%	Agriculture	41-75%	Tree
4	Detritus	>50%			>75%	Mix of types
5	Fine gravel					
6	Gravel					
7	Cobble					
8	Boulder					
9	Rip rap					
10	Bedrock					

Table 2. MANOVA results of both stream arc and reach spatial scales for each of the seven MAVS.

Stream	Type	Pillai's Trace	F	NumDF	DenDF	P
HC	Stream arc	0.3831231	10.35	3	50	2.07883E-05
	Reach	0.97243091	16.09	6	102	6.00964E-13
KCU	Stream arc	0.59665904	25.15	3	51	3.97601E-10
	Reach	0.9430189	15.46	6	104	1.32405E-12
LER	Stream arc	0.46520981	6.61	9	324	1.11719E-08
	Reach	0.50445909	12.03	6	214	1.23331E-11
LC	Stream arc	0.58122576	24.06	3	52	6.67941E-10
	Reach	0.35873641	3.86	6	106	0.0016
RiC	Stream arc	0.69685719	39.85	3	52	1.63536E-13
	Reach	0.87609098	13.77	6	106	1.62336E-11
SF	Stream arc	0.32570204	8.37	3	52	1.22888E-04
	Reach	1.01132997	18.07	6	106	2.43139E-14
WC	Stream arc	0.7420349	46.02	3	48	3.67484E-14
	Reach	0.27860398	2.64	6	98	0.0203

Table 3. MANOVA results of valley segment and reach spatial scales for each stream.

Stream	Type	Pillai's Trace	F	NumDF	DenDF	P
BF	Valley segment	0.93395942	245.13	3	52	1.16683E-30
	Reach	1.0541013	19.69	6	106	2.47509E-15
CC	Valley segment	0.4693152	15.03	3	51	3.90365E-07
	Reach	0.7051424	9.44	6	104	2.89448E-08
HC	Valley segment	0.4577553	21.39	3	76	3.81426E-10
	Reach	1.2927842	11.81	15	234	1.88637E-21
KCL	Valley segment	0.0554737	1.02	3	52	**0.3923**
	Reach	0.4179149	4.67	6	106	0.0003
KCU	Valley segment	0.620696	42.00	3	77	3.47084E-16
	Reach	1.3069405	12.20	15	237	3.41542E-22
LER	Valley segment	0.1459291	7.52	3	132	1.11019E-04
	Reach	1.1243696	7.30	33	402	5.21609E-25
LC	Valley segment	0.19813255	6.51	2	79	0.0005
	Reach	0.53512681	3.52	15	243	1.73311E-05
MB	Valley segment	0.2365331	5.37	3	52	0.0027
	Reach	0.5070595	6.00	6	106	1.98114E-05
PC	Valley segment	0.8037138	70.97	3	52	2.16849E-18
	Reach	0.8154113	12.16	6	106	2.29549E-10
RaC	Valley segment	0.428246	12.98	3	52	1.90889E-06
	Reach	0.501906	5.92	6	106	2.32678E-05
RiC	Valley segment	0.6553495	50.07	3	79	3.11109E-18
	Reach	1.5539152	17.41	15	243	1.04283E-30
SF	Valley segment	0.577842	36.04	3	79	8.85368E-15
	Reach	1.18225793	10.54	15	243	2.12523E-19
WC	Valley segment	0.7334337	68.79	3	75	1.75945E-21
	Reach	0.9115372	6.72	15	231	5.69187E-12