

CASE STUDY: KERBER CREEK RESTORATION PROJECT: EMPLOYING STATISTICAL TECHNIQUES TO ANALYZE EFFECTS OF RESTORATION ACTIVITIES, SAGUACHE, CO¹

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Abstract: The Kerber Creek watershed, located in Saguache County, CO has been undergoing restoration since 1991 to address the impacts of historic mining activities in the upper watershed. These efforts have produced reasonable, albeit limited, quantities of data on stream morphology, water quality, fish, macroinvertebrate populations, and vegetation cover within the watershed. However, to date there has not been a concentrated attempt to evaluate the effects of restoration on these variables. The objectives of this case study are to employ robust statistical techniques to analyze the effects of restoration on sinuosity in the Kerber Creek watershed and to assess the validity and feasibility of using these statistical methods as project evaluation tools. Sinuosity was measured at five restored sites using National Agricultural Imagery Program one-meter resolution aerial imagery from 2005, 2009, and 2011. The phytostabilization index was used to represent the extent to which the floodplain was restored at each site through in-situ treatment of mine waste deposits, termed phytostabilization. Repeated measures analyses of variance were subsequently performed to evaluate the effects of time (i.e., natural channel evolution) within sites and the extent of restoration among sites on changes in sinuosity. Simple linear regression analysis was then employed to elucidate the nature of the relationship between extent of phytostabilization and within-sites sinuosity means. No treatment was found to have a significant effect on sinuosity at the 0.05 or 0.10 levels of significance. Similarly, the regression coefficient for the phytostabilization index was not significant ($p > 0.20$), and the correlation coefficient was relatively low ($r^2 = 0.357$). Although these results indicate that restoration activities in the Kerber Creek watershed have not significantly improved sinuosity, a number of methodological issues, including the suitability of statistical models and the phytostabilization index, lack of sufficient data, and the presence of outliers, require cautious interpretation. Most importantly, this case study reveals the necessity for intensive monitoring regimes to accurately analyze project results and identifies numerous variables that must be considered when designing a statistically valid restoration project evaluation technique.

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Introduction

The Kerber Creek Restoration Project represents a collaborative effort among federal agencies, local non-profit organizations, and private landowners to restore the Kerber Creek watershed. The watershed is located in northern Saguache County, CO (Fig. 1) and encompasses the Bonanza Mining District, where active mining operations occurred from the early 1890s to the 1970s. During that time, production reached levels as high as 350 tons per day. The largest production occurred from 1925-1930 (Staub and Close, 2012). Dams originally constructed to restrict mine waste and tailings deposits to the upper watershed were destroyed by human activity or failed during high flow events in the mid-twentieth century (J. Coleman, personal communication, 2008), resulting in the down-gradient transport of highly contaminated material and its subsequent deposition along stream banks throughout the lower watershed. The introduction of heavy metals into riparian soils produced phytotoxic conditions that decimated the riparian ecosystem, subsequently leading to bank de-stabilization, increased width/depth ratio, and channel straightening. Water quality degradation due to contributions of contaminants from up-gradient draining adits, leachate mobilized through shallow groundwater and runoff, and tributaries including Rawley Gulch and Squirrel Creek (Fig. 1) exacerbated these alterations of aquatic habitat. According to field investigators in the mid-1970s, aquatic life was almost eliminated from the ecosystem because of these environmental impacts (BLM, 1975).

In 1991, the Environmental Protection Agency, the United States Forest Service, and the Colorado Department of Public Health and Environment (2008) began an investigation of the mining district to determine its eligibility for Superfund status. Although the mining district qualified for Superfund listing, the Bonanza Group, an organization of local stakeholders in the district including the American Smelting and Refining Company, proposed a voluntary cleanup of the area that was accepted by government agencies in 1994 (Staub and Close, 2012; CDPHE, 2008). From 1994 to 1998, extensive restoration work took place throughout the watershed. This included some channel reconstruction and limited riparian restoration along the main stem of Kerber Creek, as well as the diversion of discharge from the Rawley 12 source area (Fig. 1) to an oxidation-sedimentation pond and the installation of a bulkhead at the Rawley 12 portal to prevent further contamination. In addition, over 100,000 yd³ of tailings were removed and relocated to an off-site repository (BLM, 2013a).

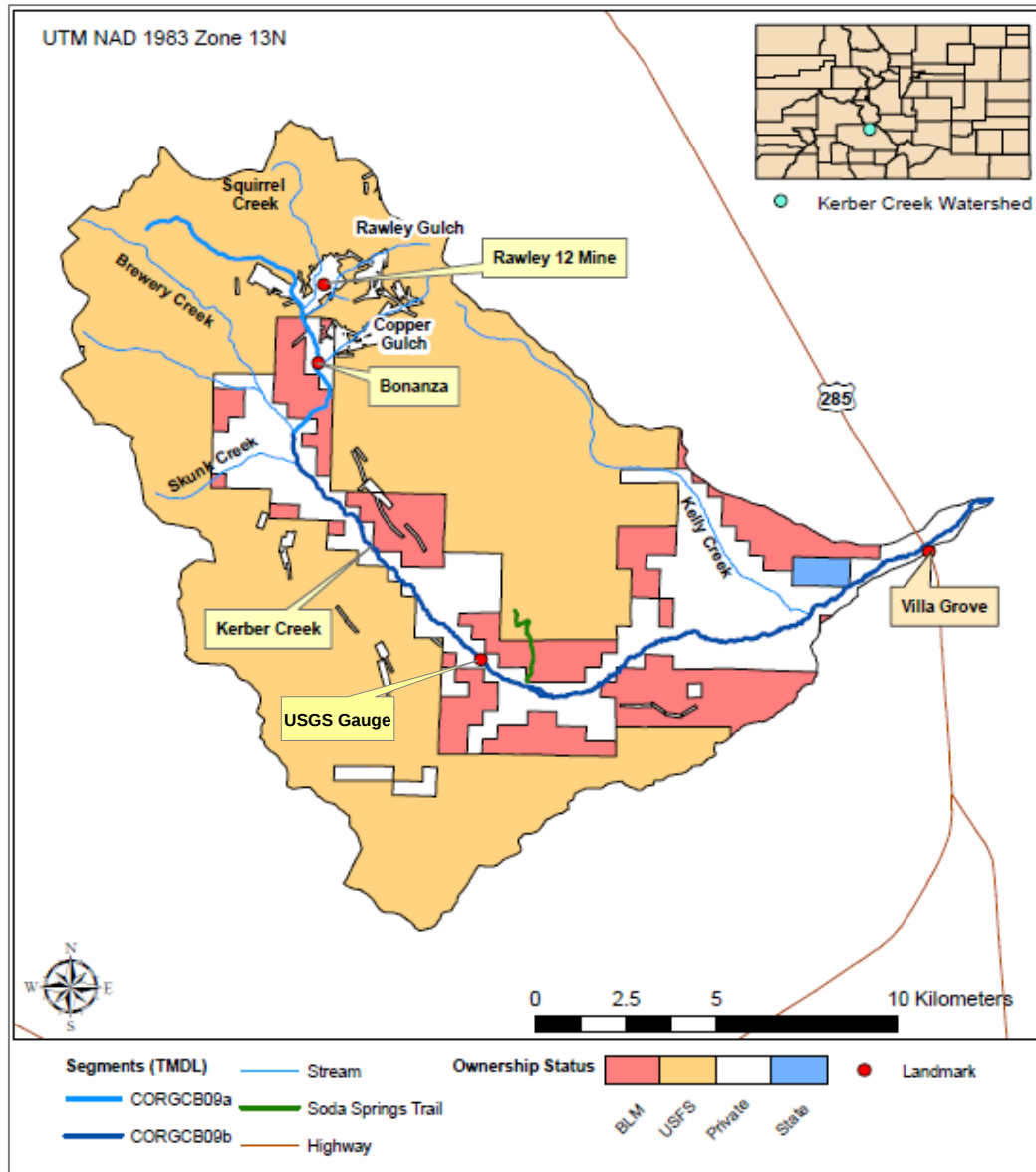


Figure 1. Kerber Creek watershed (Saguache County, CO) location showing ownership, important tributaries, and major landmarks. In 2007,

the Bureau of Land Management (BLM) formed the Kerber Creek Restoration Project to involve lower watershed landowners and non-profit organizations in the restoration effort. Since then, Kerber Creek watershed restoration projects have been dominated by two methods. (1) In-situ remediation of mine wastes deposited in the riparian area using lime, limestone, and organic amendments and subsequent revegetation, termed Phytostabilization, and (2) The installation of engineered in-stream rock structures (e.g., rock barbs, cross vanes, and J-hooks) to redirect the thalweg towards the center of the stream, thereby stabilizing stream banks and improving fish habitat. Other methods used include the re-gradation of overly-steepened stream banks to a 3:1

slope, the return of flow to the historic stream channel, and the installation of erosion control structures (i.e., wattles, curlex blankets) to protect restored stream reaches from excess erosion. A Sampling and Analysis Project Plan (SAPP), updated in 2013, has been implemented since 2009 and has required annual monitoring of vegetation, width/depth ratio, sinuosity, fish and macroinvertebrate populations, and water quality, though drought conditions have occasionally prohibited annual data collection (BLM, 2013b).

Despite relatively consistent implementation of the monitoring plan, little effort has been made to rigorously analyze and interpret the data gathered. This lack of interpretation of restoration project results is common among stream restoration projects (Kondolf, 1995). Bernhardt et al. (2005) reported that only about 46% of stream restoration projects in Colorado engaged in even some type of monitoring activity. Similarly, Schiff et al. (2010) suggest that while scientific evaluation of stream restoration processes is increasing, the need to implement improvements to stream restoration methods based on evaluation data still exists. The failure to consistently monitor and evaluate stream restoration projects results in a gap in the scientific understanding of stream restoration processes and the most successful restoration methods (Klein et al., 2007).

In the interest of both furthering the science of stream restoration and developing a comprehensive understanding of the results of restoration within the Kerber Creek watershed, this case study analyzes the effects of phytostabilization on sinuosity at five sites within the Kerber Creek watershed using robust statistical techniques. For this study, sinuosity is defined as the ratio of channel length to valley length and is a natural characteristic of stream types that allows for the dissipation of kinetic energy and an appropriate degree of sediment erosion and deposition along the stream channel. Stream bank de-stabilization and increased width/depth ratio likely caused channel straightening along the main stem of Kerber Creek, which, according to its Rosgen geomorphic classification, would have a sinuosity greater than 1.2 under natural conditions (Rosgen and Silvey, 1996). Sinuosity was chosen as the variable of interest for this study because it may reflect changes in a number of stream morphology variables and can be measured using remote sensing, which allows for the collection of additional data at any time step for which aerial imagery is available.

This study has three primary objectives. The first is to evaluate the effects of the extent of phytostabilization and time on sinuosity using repeated measures analysis of variance (ANOVA),

a parametric statistical technique. This analysis was conducted under the hypothesis that sites that have been restored to a relatively greater extent will have experienced some change in sinuosity independent of natural channel evolution (i.e., time), or that variation in sinuosity is dependent upon both the extent of restoration and the amount of time that has passed since implementation (i.e., the interaction term). The second objective is to develop a functional relationship between the extent of phytostabilization and sinuosity using simple linear regression, an exercise largely performed to evaluate the relationship between currently implemented restoration techniques and sinuosity. The third is to assess the validity and feasibility of both considering the extent of phytostabilization as a quantitative measurement of restoration and employing these specific parametric statistical techniques to evaluate the effects of stream restoration. Ultimately, this case study provides an analysis of a project evaluation alternative that could be useful to project partners implementing restoration projects in the future.

Methods

Site Description

The Kerber Creek watershed (Hydrological Unit Code: 13010003) is located at approximately 38°13'13" N, 106°05'21" W and is part of the Rio Grande Close Basin. It sits within the Bonanza caldera and is surrounded by mountain ranges on three sides. It is geologically dominated by tertiary igneous rock, predominantly latite (Patton, 1916). Total drainage area is approximately 260 km². The climate is typical of an arid to semi-arid, high altitude region, with the majority of precipitation falling as snowfall in the winter months. Annual precipitation varies widely with elevation. Lower areas of the Kerber Creek watershed receive about 25.4 cm of annual precipitation, while higher mountain areas receive about 76.2 cm (BLM, 2013c).

The main stem of Kerber Creek is about 40 km in length and includes B, C, and E Rosgen geomorphic stream classifications with medium to large cobble substrate (BLM, 2006). Stream bankfull width varies from approximately 8 to 21 ft, with an average of about 14 to 16 feet. Bankfull depth on wider reaches is < 1 ft and the depth increases as width decreases. Stream gradient is approximately 3%, with riffle bed form the most common. One active United States Geological Survey gauge station (08224500) is located on Kerber Creek (Fig. 1) between sites KC15 and KC08 (Fig. 2). Average high flow is 60 cfs and generally occurs between May and June. Average base flow (September – March) is 3.89 cfs. As of 2012, the restored Kerber



Creek fishery supports a self-sustaining population of brook trout (*Salvelinus fontinalis*), though longnose dace (*Rhinichthys cataractae*) and brown trout (*Salmo trutta*) sightings have also been reported. Vegetation consists primarily of grasses (Poaceae), willows (*Salix* sp.), and sedges (Cyperaceae), many of which have been planted since the restoration effort began, particularly in the riparian area throughout the lower watershed. The five sites chosen for this study represent a subsample of the sites restored since 2008 and are located within the lower watershed, defined as any area downstream of Brewery Creek (Fig. 2). Site KC15 encompasses multiple privately

owned parcels of land, each of which has undergone different extents of restoration activities. Specific locations for the measurement of sinuosity at each site correspond with sites monitored for other environmental variables in the past, including water quality, width-depth ratio, and fish and macroinvertebrate populations.

Sinuosity Measurements

Measurements of stream sinuosity were taken in ArcGIS 10.1 (ESRI, Redlands, CA) at each site using National Agricultural Imagery Program (NAIP) one-meter resolution aerial imagery from 2005, 2009, and 2011 obtained from the BLM geodatabase (BLM, 2012c). Flights for the collection of NAIP imagery were completed in the agricultural growing season of each year, generally May through October in Colorado, though specific months of collection are not known (USDA, 2012). Discharges in Kerber Creek for the years examined in this case study were comparable during normal low flow periods, though the peak flow event occurred later and was substantially lower in 2011 than in either 2005 or 2009 (Fig. 3).

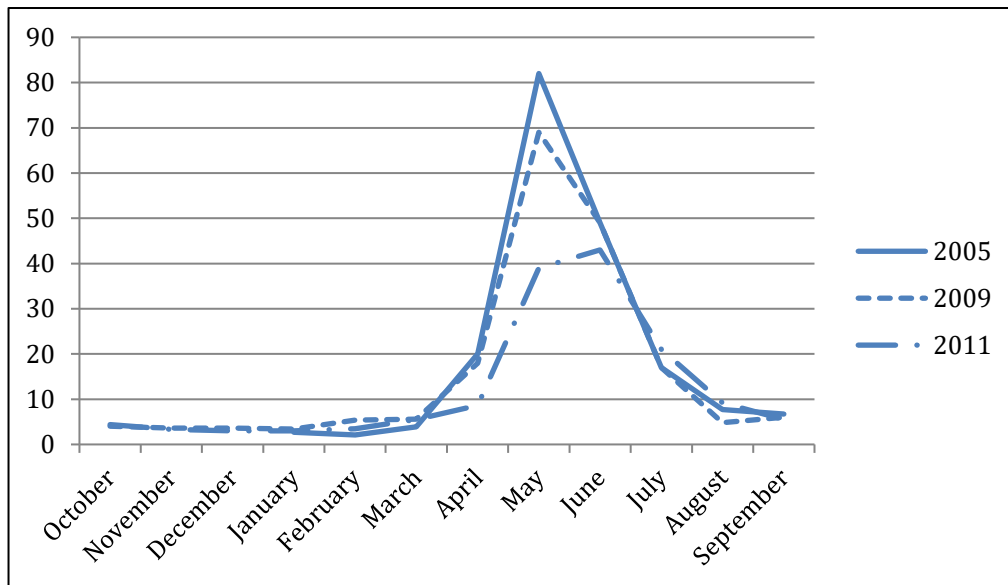


Figure 3. Comparison of discharge among study water years. Taken from Colorado Division of Water Resources website (CDWR, 2012).

The protocol used to measure sinuosity for this study closely follows that which is described in the SAPP (BLM, 2013b). Buffer zones with a radius of 125 m were constructed with centroids positioned within Kerber Creek at each site. The stream was then delineated within each buffer zone for each year using the available NAIP imagery. The resulting feature class was edited to

represent the center of the stream channel, assuming that the channel center corresponded to the stream's thalweg (Fig. 4). Secondary channels, such as narrow ditches, that have formed around former point bars and likely convey water during high flow, were not included in the stream delineation. Although the latter policy deviates from the standard SAPP protocol, it was selected for this study to avoid inconsistencies among measurements due to subjective judgments of the size of a secondary channel based on aerial images that could not be evaluated in the field. Once the stream delineation was complete, the calculate geometry capability of attribute tables in ArcMap was used to determine stream length.

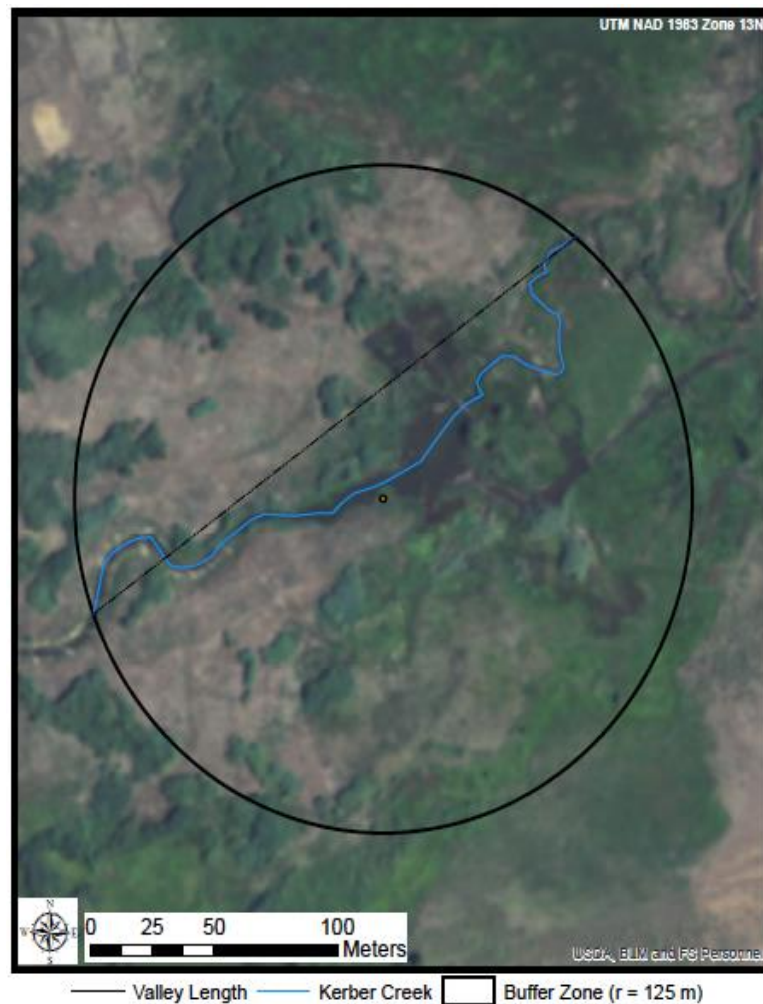


Figure 4. Sample sinuosity measurement for site KC17, 2011. The blue line (Kerber Creek) represents stream length (L_s), and the black line represents valley length (L_v). The ratio of L_s to L_v is sinuosity. Background is 2011 NAIP imagery.

Valley length was determined separately for each measurement to account for changes in position of the beginning or end of the study reach, which may have occurred naturally or during the stream restoration process. To calculate valley length, a linear feature class beginning at the intersection of the stream and the buffer zone and extending to their intersection on the other side of the buffer zone was constructed (Fig. 4). However, if the valley length measured at a given site was within 5 m of the valley length measured in 2005, it was assigned the 2005 value. This resulted in equal valley lengths within sites among years of study and suggested that no major migration of the stream channel occurred between years (Table 1). While the SAPP protocol does not specify that valley length should be separately evaluated for each measurement, this method was selected for the case study to ensure that the maximum variation among years within sites and among sites was incorporated due to either natural or human-induced channel migrations.

Table 1. Stream length, valley length, and sinuosity for each site.

Site	Year	Stream length (m)	Valley length (m)	Sinuosity
KC18	2005	396.2	230	1.723
	2009	409.9		1.782
	2011	399.0		1.735
KC17	2005	306.7	240	1.278
	2009	319.5		1.331
	2011	316.2		1.320
KC15	2005	293.9	250	1.176
	2009	296.3		1.185
	2011	294.2		1.177
KC08	2005	298.1	250	1.192
	2009	289.4		1.157
	2011	281.6		1.126
KC06	2005	283.3	220	1.288
	2009	298.5		1.357
	2011	291.2		1.324

Following the determination of stream (L_s) and valley (L_v) lengths, sinuosity (S) was calculated as the ratio between the two:

$$S = \frac{L_s}{L_v} \quad (1)$$

Calculation of Phytostabilization Index

To investigate the effects of phytostabilization, an index was developed that quantifies site-specific restoration activities referenced to the size of the site. For this purpose, the “site” refers to the buffer zone ($r = 125$ m) used to measure sinuosity. The phytostabilization index (P)

represents the ratio of the area (hectares) of mine waste deposits restored within the floodplain at a given site by 2011 (H_r) to the total area (hectares) of the floodplain located within the site (H_t):

$$P = \frac{H_r}{H_t} \quad (2)$$

Thus, the phytostabilization index corresponds to the proportion of floodplain area that has been restored using the phytostabilization technique. Note that the index was not calculated separately for each available year of sinuosity data; rather, it corresponds to the cumulative phytostabilization work completed by the final year of measurement (2011).

The floodplain was represented by a buffer zone extending 14 m outward from each side of a given stretch of stream for which sinuosity was calculated (Fig. 5). The buffer zone size corresponds to the size used to delineate the floodplain along the entire stretch of Kerber Creek,

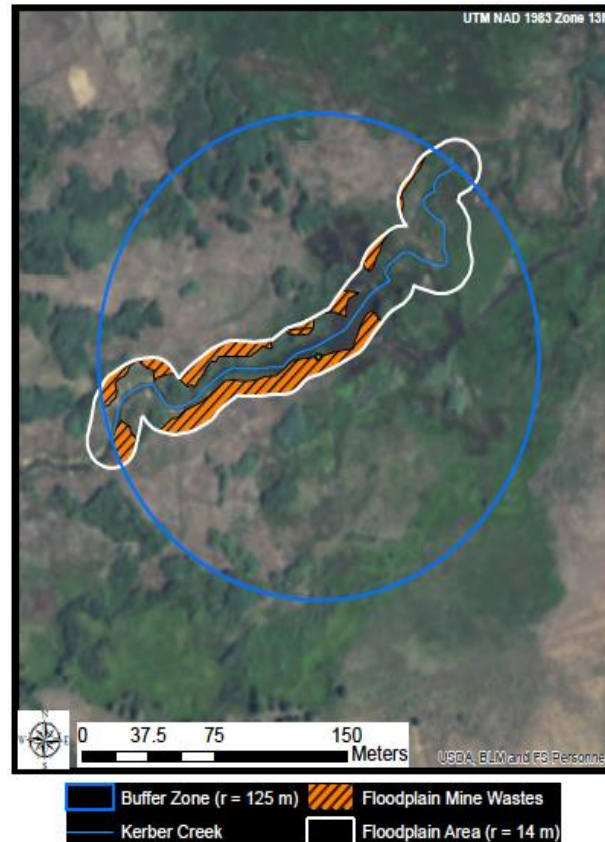


Figure 5. Sample calculation of the phytostabilization index for KC17, 2011. Floodplain mine wastes are represented in eq. 2 by H_r , and floodplain area is represented by H_t .

which was originally based on soil surveys and vegetation data. The stream reach used corresponds to the stream reach delineated for the measurement of sinuosity in 2011. Mine waste

deposits at each site were delineated using NAIP imagery in ArcMap before restoration activities were implemented assuming that areas devoid of vegetation (i.e., pale orange in color) were composed mainly of mine wastes. In most cases, project staff confirmed these delineations in the field using GPS technology. For this case study, work documentation and communications with project staff were used to confirm which of the deposits within the floodplain were treated at each site. Furthermore, because reshaping and re-gradation of banks were generally completed along stream stretches where phytostabilization work was implemented, it is assumed that this index incorporates restoration activities related to physical restoration of stream banks in addition to in-situ treatment of mine wastes. It is referred to as the phytostabilization index for convenience.

The phytostabilization index values, used analytically as ratios, were converted to percentages here to facilitate interpretation of raw data and to illuminate the patterns within the data (Table 2). No mine waste deposits were identified within site KC15, though it is known that deposits were treated elsewhere on the private properties that correspond to the site. In this case, H_r is assigned a value equal to H_a such that P for KC15 is 1, or 100% (Table 2). In the context of this case study, where increasing values of P represent increasing proportions of the floodplain that exist in restored, presumably natural states, a value of 1 for P suggests that the entirety of the floodplain is in a natural state.

Table 2. Phytostabilization index for each site.

Site	Mine waste in floodplain (hectares)	Floodplain area (hectares)	Phytostabilization index (%)
KC18	0.294	1.008	29.2
KC17	0.248	0.920	27.0
KC05	0.880	0.880	100
KC08	0.012	0.841	1.4
KC06	0.116	0.859	13.5

Analysis of variance requires the partitioning of phytostabilization index values into numerically represented categorical variables that serve as levels of each treatment. Sites were grouped into treatment levels based on similarities in the value of their indices and assigned numeric representations (1 to 3) based on the magnitude (low to high) of the index (Table 3). Note that not all levels have equal sample size.

Table 3. Restoration index treatment levels assigned to each site for repeated measures ANOVA.

Sites	Phytostabilization Level
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KC15	1
KC18, KC17	2
KC08, KC06	3

Statistical Analysis

SAS software (SAS Institute, Inc., Cary, NC) was used to complete the statistical analyses employed in this study, which include repeated measures ANOVA and simple linear regression. Repeated measures method of the ANOVA, allows for the partitioning of variation into three possible sources; (1) that which results from time within sites, representing change as a result of natural processes; (2) that which results from the extent of phytostabilization among sites, representing change as a result of restoration alone; and (3) that which results from the interaction of time effects and the extent of restoration, indicating that the effects of restoration on sinuosity at a given site depend on the amount of time that has passed. If changes in sinuosity are the result of restoration, either one or both of the latter two sources should produce significant differences in sinuosity. The repeated measures method was selected because the samples taken at the same site are not independent, thus rendering standard ANOVA methods invalid. The mixed procedure was chosen because it allows for the manual selection of covariance structures, removing the sphericity assumption required for repeated measures ANOVA in less powerful statistical procedures. In this case, the autoregressive model was selected for use based on its low Akaike Information Criterion value.

Following the repeated measures ANOVA, simple linear regression using the regression procedure was performed to identify a quantitative relationship between the extent of phytostabilization (independent variable) and average stream sinuosity within sites (dependent variable). Significant differences in sinuosity because of restoration illuminated by the ANOVA should be reflected as significant regression coefficients and high correlation coefficients in the regression analysis. More importantly, the regression analysis should provide information about the direction (positive or negative) of the relationship between sinuosity and the extent of restoration.

Initially, the regression procedure was performed for all five sites; however, examination of the plots of studentized (i.e., divided by standard deviation) residuals versus leverage values and the Cook's D statistic versus site number revealed that site KC15 was an outlier (Fig. 6), exerting high leverage on the relationship between sinuosity and the phytostabilization index. The removal

of site KC15 drastically altered the regression diagnostics (Fig. 7) and substantially improved the model fit, though sites KC18 and KC17 displayed high values for the Cook's D statistic. Once site KC15 was removed from the analysis, the univariate procedure was performed to examine the distributions of each variable to ensure attainment of the normality assumption. This procedure revealed that both the phytostabilization index values and the within-sites sinuosity means were normally distributed according to the Shapiro-Wilk test for normality (Table 4), permitting the regression procedure.

Table 4. Results of Shapiro-Wilk normality tests for phytostabilization index and sinuosity.

Variable	Mean	Shapiro-Wilk statistic	P-value
Phytostabilization index	0.178	0.908	0.472
Sinuosity	1.384	0.862	0.266

Once the normality of both variables had been tested, a simple linear regression model was developed:

$$S = \beta + P\alpha + \varepsilon \quad (3)$$

In this model, S is the mean sinuosity for each site, β is the intercept, ε is the error term, P is a given phytostabilization index, and α represents the regression coefficient.

Results

Repeated Measures ANOVA

The repeated measures ANOVA revealed no significant differences in sinuosity at the 0.05 or 0.10 levels within sites as a result of time or among sites due to the phytostabilization index (Table 4). Furthermore, the interaction term was not significant; thus, the effect of the phytostabilization index does not depend on time.

Table 4. Results of repeated measures ANOVAs considering the effects of phytostabilization and time on sinuosity in Kerber Creek.

Independent variable	Numerator DF	Denominator DF	F-value	P-value
Phytostabilization index	2	2	1.13	0.470
Time	2	4	1.94	0.258
Interaction term	4	4	0.41	0.793

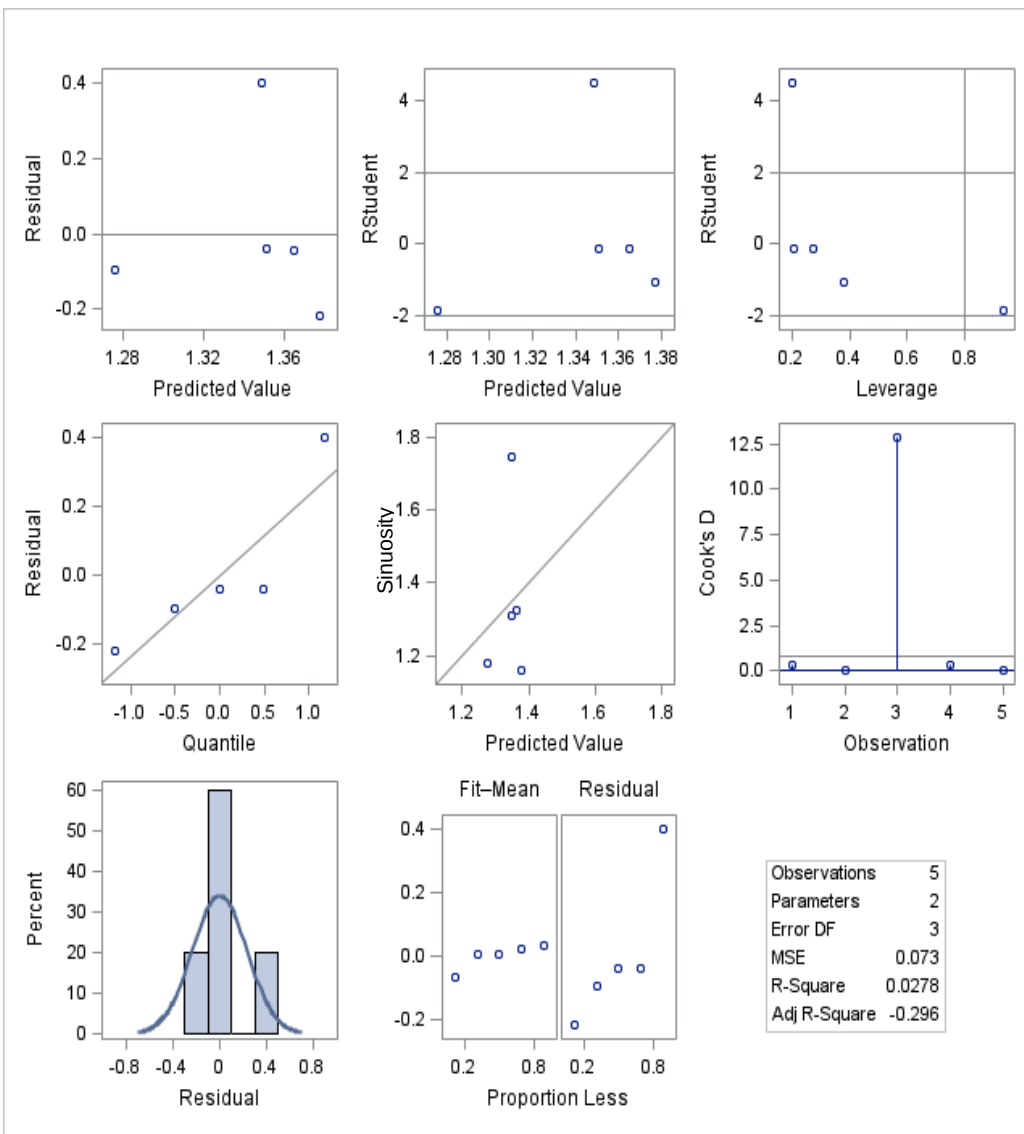


Figure 6. Regression diagnostics for sinuosity versus phytostabilization index with outlier (site KC15, observation 3).

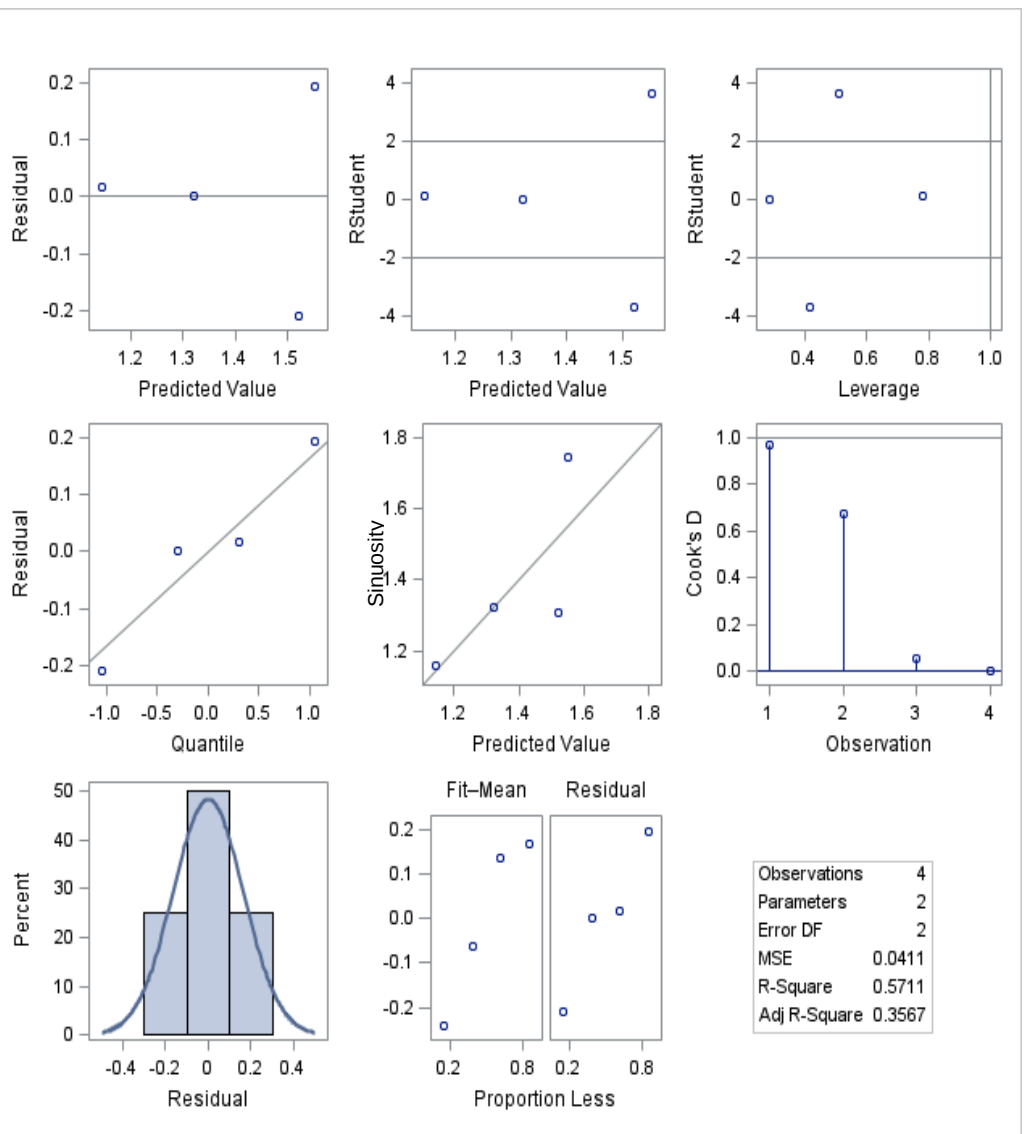


Figure 7. Regression diagnostics for sinuosity versus phytostabilization index without outlier.

Simple Linear Regression

The ANOVA included as part of the regression procedure indicated that the model was not statistically significant at either the 0.05 or the 0.10 level (Table 5). In simple linear regression, the model p-value is the same as the p-value for the regression coefficient; thus, the regression coefficient is not significant. However, the intercept for the regression is statistically significant at the 0.05 level (Table 6). The adjusted correlation coefficient for the linear regression model is 0.3567.

Table 5. Results of linear regression model ANOVA for the relationship between Phytostabilization index and sinuosity.

Source	DF	Sum of squares	Mean square	F-value	P-value
Model	1	0.109	0.104	2.66	0.244
Error	2	0.082	0.041		
Corrected total	3	0.192			

Table 6. Results of linear regression analysis: Estimates of regression coefficients for sinuosity vs. phytostabilization index.

Variable	Estimate	Standard Error	T-value	P-value
Y-Intercept	1.122	0.190	5.90	0.028
Slope	1.476	0.904	1.63	0.244

Because the regression coefficient for the phytostabilization index is not statistically significant, a valid regression model cannot be derived. However, a fit plot for the regression analysis was constructed to visually represent the model and to provide 95% confidence intervals and prediction limits (Fig. 8). The correlation coefficient for the model is also presented.

DiscussionRepeated Measures ANOVA

No effect examined in the repeated measures ANOVA displayed statistical significance at the 0.05 or 0.10 levels, suggesting that variation in sinuosity can be attributed neither to time nor to the extent of phytostabilization. Furthermore, the interaction between time and phytostabilization was not significant, indicating that regardless of the extent of restoration, its effect on sinuosity is independent of the amount of time that has passed. These results directly contradict both

components of the study hypothesis and suggest that sinuosity within sites has not changed significantly as a result of natural channel evolution, represented, in this case, by the time effect.

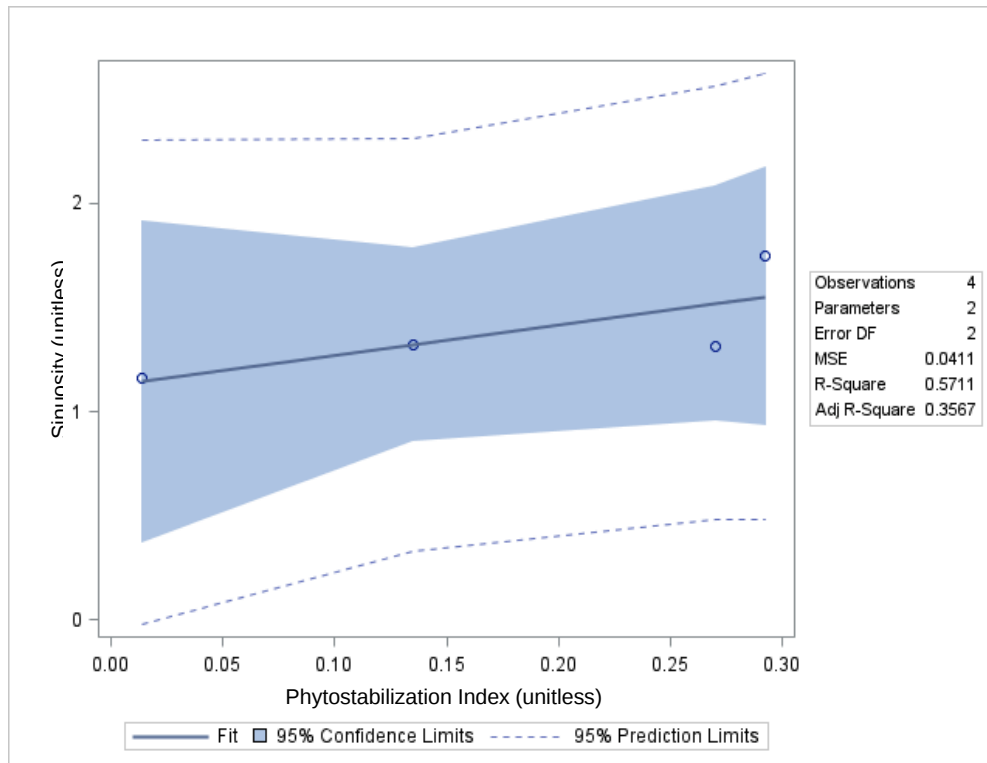


Figure 8. Fit plot showing regression line and 95% confidence and prediction limits for sinuosity versus phytostabilization index (adj. $r^2 = 0.357$, $p = 0.244$).

While there are some studies that report the effects of riparian vegetation on channel morphology (e.g., Allmendinger et al., 2004), the failure to reject the null hypothesis for the phytostabilization index is generally consistent with similar studies in the literature. For example, Hession et al. (2003) report no significant difference in sinuosity between forested and nonforested stream reaches, indicating that changes in the density of riparian vegetation do not significantly affect sinuosity. In this case study, however, it was expected that variation due to other restoration activities implemented along the stream bank at phytostabilization sites, such as the direct manipulation of the stream channel, the installation of in-stream rock structures, and the re-gradation of stream banks, would be incorporated into the phytostabilization index under the assumption that the extent of these restoration activities varied directly with the extent of phytostabilization. Among the primary objectives of these practices is to decrease the stream's

width-to-depth ratio, a factor that largely determines the extent to which a stream is sinuous (Schumm, 1963). Thus, had the variation in sinuosity as a result of the phytostabilization index proved statistically significant, it would likely have been interpreted primarily as the result of in-stream restoration activities associated with areas that were treated. If the results of this study in fact constitute a Type II error resulting from the use of an indirect measurement of the extent to which a stream reach has been restored, then such an error may be corrected by the use of a restoration index that logically expresses the quantity of in-stream restoration that each site has undergone.

In addition, the lack of any statistically significant effect of the phytostabilization index may be related to the relatively short period of time that has passed since restoration. Kondolf (1995) suggests that at least 10 years of monitoring data are required to effectively evaluate the success of stream restoration efforts. This case study covers a total of six years; however, restoration activities from 2005 to 2009 included the phytostabilization of only 10.8 acres of mine wastes throughout the entire Kerber Creek watershed, including both within and outside of the floodplain, and no documented installation of in-stream rock structures or other manipulation of the stream channel. Thus, further increases in sinuosity may be observed as restoration and monitoring activities proceed. The short duration over which sinuosity could be measured for the purposes of this case study may also explain the failure to reject the null hypothesis for either the time effect or the interaction term. The choice of statistical model may also explain this finding. The autoregressive model has been used to account for serial correlation because it assumes that measurements taken at closer time steps are more correlated than those taken at longer time steps (Worrall et al., 2003). However, this model assumes a specific form of the serial correlation that may or may not be true for the dataset used in this study. Nonparametric methods may have been more appropriate in this case, particularly given the small sample size, the uneven amount of years among measurements, and the unequal distribution of restoration activities, which occurred mainly from 2009 to 2010 (Tague et al., 2008).

Simple Linear Regression

Because the linear regression model was not statistically significant ($p = 0.244$), no functional relationship between sinuosity and the phytostabilization index could be developed. The failure to reject the null hypothesis that the regression coefficient for the phytostabilization index is 0 may have been influenced by a number of factors, including the possible presence of outliers in the

revised data set. Although site KC15 was removed from the data due to its high Cook's D statistic and leverage (Fig. 5), sites KC18 and KC17 exhibited high Cook's D statistics in the revised data set, and site KC18 displayed high leverage (Fig. 6). These results indicate that the regression model is highly influenced by sites KC18 and KC17, both of which exhibited the highest phytostabilization index values (29.2% and 27.0%, respectively) once site KC15 was removed. Furthermore, site KC18 had the highest average sinuosity value (1.746). In addition to its high sinuosity and phytostabilization index value, site KC18 is located furthest downstream, where greater sinuosity would be expected to occur naturally because of decreased channel gradient. Thus, the final regression model may have been influenced by differences among sites as a result of location within the watershed rather than the extent of restoration. Future regression models would likely need to account for these differences in order to accurately portray the relationship between sinuosity and the extent of restoration. Methods to address this issue could include the use of a larger, more representative sample of stream reaches along the watershed, the inclusion in the regression model of only those stream reaches that exhibit no significant difference in channel slope, or the incorporation of a quantitative measurement of site location into the regression model such that variation as a result of location is partitioned from the error term.

While site KC18 exerts a positive directional influence on the regression model since the measured sinuosity value is greater than the predicted value (Fig. 6, plot of sinuosity vs. predicted value), site KC17 exerts a negative influence because the measured sinuosity value is less than the predicted value. Beaver activity, which has been observed since the restoration effort was completed at site KC17 in 2010, may partially explain this negative directional influence. Although beaver dams often have a positive effect on certain hydrologic functions of degraded stream channels (Pollock et al., 2007) and may increase sinuosity over time as a result of dam breaches (Demmer and Beschta, 2008), sediment deposition and flow impedance behind dams could have delayed the effects of restoration or led to short-term decreases in sinuosity. The presence of one beaver dam is evident from the 2011 NAIP imagery used for the measurement of sinuosity (Fig. 9). This dam was also confirmed in the field by the landowner and project staff.



Validity and Feasibility of Study

This case study suggests that the phytostabilization index as defined may be neither a valid nor a comprehensive measure of restoration activities in the Kerber Creek watershed, at least when compared directly to stream sinuosity. Since the phytostabilization index is a measure of the percentage of land located within the floodplain that has been restored, it is biased towards the sites that initially encompassed the largest area of mine waste deposits that required restoration—in this case, once site KC15 is removed, the downstream-most sites (KC18 and KC17). As observed in the simple linear regression, the inherent bias towards downstream sites confounds the effects of phytostabilization with the effects of location when it is compared directly to a variable, such as sinuosity, that is highly dependent on channel gradient. Possible solutions to this bias include: (1) developing a phytostabilization index that indexes the area of restoration (numerator) to the initial area of degraded land within the floodplain (denominator) rather than the area of the floodplain; (2) accounting for variation due to location through a more representative or uniform data set; and (3) using a dependent variable that is not highly dependent on channel gradient or

location within the watershed, such as vegetation cover. Due to limited data, these solutions could not be implemented for the purposes of this case study.

Furthermore, the failure of the phytostabilization index to incorporate the relative success rate of the phytostabilization technique requires that all models that use it assume that every site had an equal success rate in terms of vegetation survival and stream bank stabilization, neither of which has been quantitatively monitored since project implementation. Though the effects of this assumption were not evident in the results of the case study, they demand cautious interpretation of the case study results since it is known that the phytostabilization success rate varied substantially both among sites and within sites among treated mine waste deposits.

The use of parametric repeated measures ANOVA for this study, even under the assumption of an autoregressive covariance structure, may not have been appropriate given the total sample size and the number of time steps available for inclusion in the analysis. While the results of this case study do not confirm this inference, it is clear that the error term for all factors examined in the ANOVA was very large, thus decreasing the F statistic and subsequently increasing the p-value. The inclusion of additional sample sites or time steps may have reduced the error term, though given the correlation between the phytostabilization index and the location of the site, future studies may benefit further from the utilization of nonparametric methods or the development of an alternative restoration index. Similarly, the simple linear regression model could prove statistically significant if a larger sample size were used; however, the biases inherent in the phytostabilization index would likely lead to misinterpretation of its relationship to sinuosity. Thus, in order to develop a scientifically meaningful relationship between the extent of restoration and stream health, variables that are more directly related should be employed in future studies.

Other Considerations

In addition to the factors mentioned above, variable time periods since completion of restoration activities at each site and errors that result from remote sensing may have contributed to the results of the case study. At site KC17, for example, restoration was completed in 2010, while at site KC18, restoration was completed in 2011. This may have affected the extent to which sinuosity was allowed to adjust at each site to the anthropomorphic modifications to stream path associated with restoration activities before sinuosity could be measured, further confounding the

results of the study. At site KC08, inaccurate remote sensing of stream length due to cloud cover in the 2011 NAIP imagery likely contributed to the observed decrease from 2009 to 2011. NAIP imagery is required to include no more than 10% cloud cover per quad tile (USDA, 2012); in this case, while cloud cover was generally minimal, one cloud obscured the downstream-most stretch of stream along which sinuosity was measured at KC08 in 2011, requiring that the 2009 delineation of the stream be used for this portion. Thus, variation in stream length between 2009 and 2011 could not be accurately delineated.

Conclusions

Although this case study does not support the assertion that restoration activities in the Kerber Creek watershed have significantly improved sinuosity, the numerous confounding factors and the nature of the phytostabilization index used as a measurement of restoration render these findings inconclusive. Primarily, this study identifies the need for further, more rigorous data collection and the establishment of an appropriate measure of the extent of restoration in order to more accurately determine the effects of restoration on sinuosity and other environmental variables. Future efforts to evaluate project success should quantify the extent of restoration relative to the restoration initially required at a site and employ environmental variables that are directly related to the restoration activity examined. They should also avoid or account for confounding variables, particularly site location. Finally, further research is required to identify more appropriate statistical techniques for the analysis of the effects of restoration activities. While repeated measures ANOVA and regression methods can be useful, given the relatively small data sets and time scales over which most restoration projects are monitored, nonparametric techniques would likely prove more representative of qualitative, field-based observations of the effects of restoration activities at a given site. Most importantly, this case study reflects the need for further evaluation efforts of the effects of the Kerber Creek Restoration Project and serves as an example of the factors that must be addressed when analyzing the effects of similar stream restoration projects.

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