AN INDEX OF RIPARIAN INTEGRITY FOR THE AUSTIN AREA

SR-13-09, April 2013

Mateo Scoggins
Aaron Richter
Jon Meade
Kathryn Murray

City of Austin
Watershed Protection Department

ABSTRACT

Riparian zones along a stream have significant influence on the integrity of the adjacent aquatic ecosystem. Traditional field methods of assessing riparian zones in large stream networks may be prohibitively time consuming and expensive. Remote sensing can be used to characterize the riparian zone in aggregate and identify areas with a high potential of functional deficiency. The City of Austin has developed a GIS-based assessment tool to evaluate stream corridor integrity. Aerial vegetative classifications and land use data from two riparian buffer widths (50 ft and 400 ft) were combined in a multivariate spatial cross-regressive model to specify the qualitative riparian integrity of a watershed-scale reach. Accuracy checks showed the results to be mostly accurate with problems potentially arising when a watershed reach was composed of only the 640 acre drainage area or total impervious cover percentages were drastically different between the 50 ft and 400 ft buffer where the land use was primarily commercial. The results of the model produced the Index of Riparian Integrity, which should be considered by project managers in prioritizing riparian restoration.

INTRODUCTION

A riparian zone is a complex assemblage of plants and other organisms in an environment adjacent to water (Lowrance et al. 1985). As a transition zone between the upland and aquatic ecosystem, riparian zones are diverse communities that possess physical attributes, biotic properties, and energy flow processes unique to the interaction of the surrounding ecosystems (Naiman and Decamps 1997). Because of this unique interaction, riparian zones perform a wide range of ecological functions which affect hydrologic dynamics, water quantity, and water quality of the adjacent aquatic ecosystems (Correll 1999, Groffman et al. 2003). Riparian vegetation can reduce erosion by stabilizing bank material or reducing the velocity of water in the channel (Naiman and Decamps 1997). Woody debris produced from fallen or dead vegetation adds habitat for fish and macroinvertebrates (Anderson and Sedell 1979; Harmon et al. 1986). Riparian canopy provides temperature buffering, which protects the biota from the adverse effects of large fluctuations in temperature (Stacey et al. 2006). Live woody vegetation sequesters carbon while decaying organic material acts as a source of nourishment for aquatic biota (Fischer and Fischenich 2000; Stacey et al. 2006; Richardson et al. 2007; Woolsey et al. 2007). Soils and vegetation filter nutrients from nonpoint sources of pollution (Lowrance et al. 1983; Peterjohn and Correll 1984; Jacobs and Gilliam

1985). The level of function provided depends on the integrity of the riparian zone, where less degraded systems provide more function. Thus many comprehensive monitoring programs include riparian zone condition as part of their environmental assessments (Wissmar and Beschta 1998; Barbour et al. 1999).

The City of Austin (COA) developed the Environmental Integrity Index (EII) methodology to assess stream integrity for all streams in the City's jurisdiction (COA 2001). This procedure has been used since 1996 and provides comprehensive biological, physical, and chemical data on a sub-watershed scale (COA 2002). These sub-watersheds are called EII reaches. The method is appropriate and practical for biological and chemical water quality measures since watershed effects aggregate at a downstream point in a fluvial system (Hynes 1970; Wetzel 2001). The COA developed a Riparian Functional Assessment (RFA) procedure in order to provide a detailed assessment of the riparian zone along creeks (Richter and Duncan 2012). While the RFA procedure accurately assesses the riparian function available at a site, it represents a small spatial scale and does not incorporate riparian function throughout a watershed. Riparian zones can vary greatly within a watershed and a large number of assessments using the RFA methodology would be needed to represent the function of all riparian areas in the city. Performing a large number of RFA-type assessments would be time consuming and expensive. Thus a large scale tool was still needed to efficiently quantify riparian integrity throughout the city. The COA developed this Index of Riparian Integrity (IRI), a macro-scale tool based on aerial photography and land use, to make such an assessment.

Aerial mapping technologies have advanced to meet the increasing need of researchers to a point where it is possible to use satellite imagery to evaluate riparian zones rather than labor-intensive field studies (Weng 2012). A comprehensive index of riparian condition based on manually interpreting aerial photography was used to evaluate the effect of riparian condition on stream biota in the Pacific Northwest (Horner and May 1999; May and Horner 2000). The IRI was also developed using aerial images; however, high resolution imagery was analyzed in ArcGIS instead of being manually interpreted, as was done in the Horner and May papers. Functioning riparian zones in Austin are composed of riparian woodlands or well vegetated grasslands, while riparian zones that function poorly are composed of sparse grasses, bare soil, or various forms of impervious cover (Richter and Duncan 2012). Aerial imagery was classified specifically for these vegetation groups in order to quantify riparian condition.

In addition to the riparian land cover, the land use within a riparian zone was used as a component of the IRI. Land use in a watershed has been shown to affect both water quality (Barrett 1998; Silva and Williams 2001; Tong and Chen 2002) and stream biota (Booth et al. 2001). The effect land use has on the ecological condition of a stream can differ based on distance between the land use and the stream channel (King et al. 2005) and continuity of the land use (Walsh et al. 2005). The distance of concern in this analysis was the immediate riparian buffer surrounding a creek. This macro-scale, GIS approach should allow the City to efficiently assess the riparian condition throughout an entire stream corridor, improve the City's ability to compare riparian zones to one another, and identify riparian zones that require more intense small-scale assessments to identify potential restoration priorities.

METHODS

In order to analyze the riparian condition, COA acquired 4 band color infrared aerial photography from 2010 with 1 m resolution from Texas Natural Resource Information Systems (TNRIS) covering all the watersheds included in the COA master planning jurisdiction (COA 2001). The imagery was captured through the National Agriculture Imagery Program (NAIP), administered by the US Department of Agriculture's Farm Service Agency (USDA FSA). The high-resolution imagery provides good infrared spectral signatures for many vegetation classes. Photosynthetic plants radiate energy in the infrared spectrum which ranges in aerial imagery from a muddy dark red for minimally active plants to bright pink for highly active or "hot" plants. This photosynthetic signature was used to separate plant types or groups (Figure 1). For this analysis, the imagery used was collected in May 2010 to capture leaf-on conditions.

It is anticipated that this same type of data (leaf-on, color infrared) will be collected on a three year rotation for future analysis.

Figure 1: Example of color infrared photography. Riparian zone of Walnut Creek upstream of US I35. (*NAIP10_Travis County, 30°23'17.895"N, 97°40'29.875"W)*

A supervised classification was completed on the aerial images based on 6 pre-selected vegetative classifications (Figure 2): robust vegetation, sparse vegetation, open water, shadow, woody vegetation, or impervious cover. The selection of these vegetative classes was based on *a priori* ecological grouping by biologists and GIS staff using the available 1 m resolution photography. For each vegetative class, training sites were spatially distributed across the image targeting areas with highly discernible features in the image corresponding to the type of vegetative class. Individual training sites varied in size based on the underlying correct classification. The number of training sites per vegetative class per image varied, but generally was less than 15. Only a small number of training sites for robust vegetation were intentionally selected. The individual training site layers were combined into a multiclass input layer for the supervised classification.

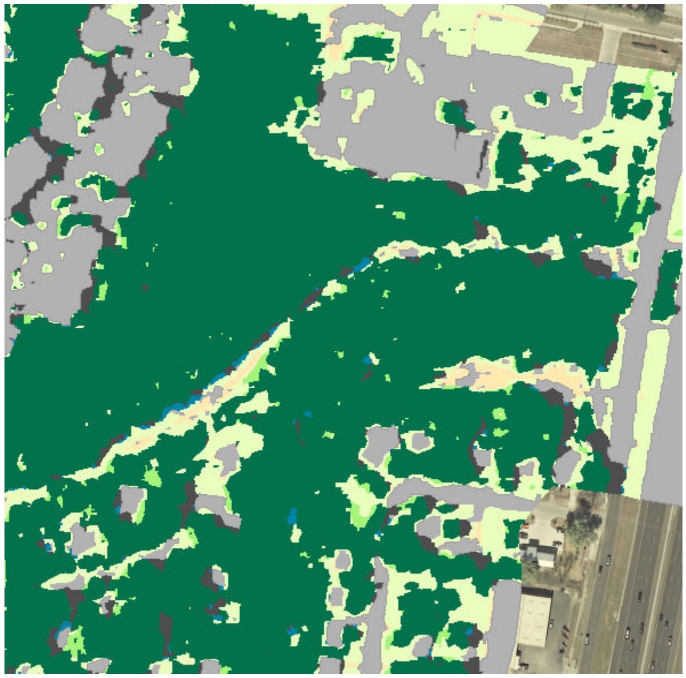

Figure 2: Example of a classified image: Dark Green=Woody Vegetation, Medium Green=Robust Vegetation, Light Green=Sparse Vegetation, Blue=Water, Black=Shadow, Beige=Bare Ground, Grey= Impervious Cover. Riparian zone of Walnut Creek upstream of I35 corresponding to the area of Figure 1.

Land use data was developed by COA based on the Anderson Land Use classification scheme (Anderson et al. 1976) using combined planimetric data and aerial photography. A complete list of land uses and their associated general categories can be found in Appendix A. COA land use data is updated periodically (approximately every 5 years) and analysis used the COA land use coverage and categories from 2010.

The most up-to-date property use descriptions are available in the tax information collected and published by county tax appraisal districts (CAD) in Texas on an annual basis. CAD coverages demarcate parcel use by means of the State Property Tax Board (SPTB) Code (Appendix B). As the COA land use and CAD layers describe similar property parcels (Figure 3), the COA land use data was updated with the CAD parcel data from 2012.

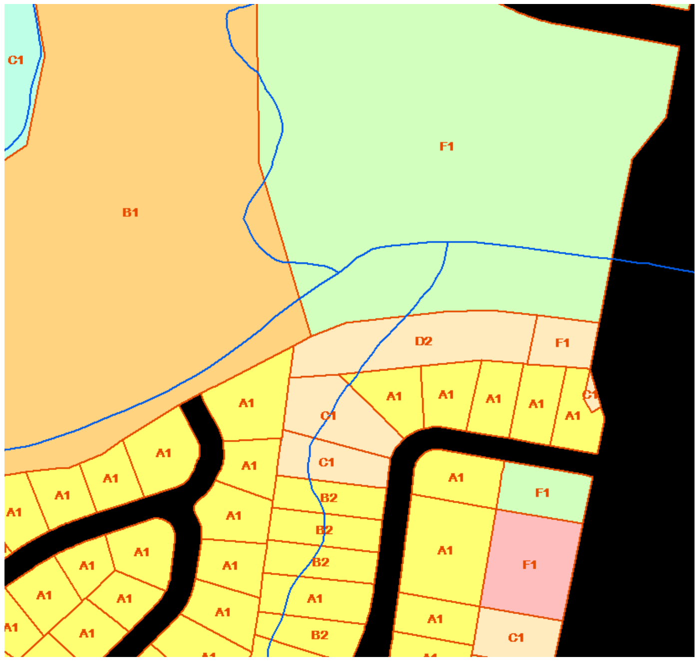

Figure 3: Example of land use polygons along riparian zone of Walnut Creek upstream of I35 corresponding to the area of Figure 1. Yellow=Residential, Orange=Multi-Family, Green=Office, Pink=Industrial, Blue=Open Space/Parks, Black=Transportation, Tan=Undeveloped; Red letters illustrate SPTB category IDs. A1= Single Family Residence, B1=Multifamily, B2=Duplex, C1=Vacant Lot, F1=Commercial.

The vegetative classification and land use layers individually contained some inherent inaccuracies. The vegetative classifications labeled woody vegetation based on canopy cover in the aerial photographs inaccurately if the area underlying the canopy was an impervious surface. To correct for inaccuracies the vegetative classification and land use layers were cross-referenced with the COA planimetric inventory data from year 2006 (Figure 4). Planimetric GIS layers identify areas of transportation infrastructure, building footprints, and landmark boundaries. In the vegetative classification, the impervious cover was updated in areas overlain by transportation, building footprint, and landmark polygons from the planimetric layer. In addition, the vegetative classification values were changed to bare ground where the landmark polygons represented playgrounds or sand volleyball courts because the function of these mulch, gravel, or sand covered areas would be similarly limited. To improve the land use layer, land use derived polygons designated as streets and roads were changed to an appropriate non-transportation land use if they fell within a planimetric building footprint. Conversely, non-transportation land use polygons were reclassified to transportation uses if they fell in the transportation planimetric footprint.

Figure 4: Planimetric data of Walnut Creek upstream of I35 corresponding to the area of Figure 1: Transportation polygons in Blue, Building footprint polygons in Green.

The updated vegetative classification and land use layers were combined with the COA 2006 creek network to include hydrologic information. This is the most accurate and comprehensive compilation of local hydrologic information. The creek line file traces the physical location of Austin area stream centerlines that are within each catch basin unit. The catch basin acreages are grouped into Drainage Acre Threshold (DAT) values, which signify the minimum area of land that drains to the mainstem branch and major tributaries that have a drainage area of at least 64 acres of each creek segment (64, 320, or 640 acres). The DAT value serves as a proxy measurement for the stream order of a creek segment within the River Continuum Concept (Vannote et al 1980). While the creek file traces an extensive network of tributaries, only the mainstem branch and major tributaries up to and including the 64 acre drainage area threshold were utilized for riparian analysis in this study. The small tributaries of first order headwater reaches are often ephemeral and largely undetectable in watershed scale mapping or planning applications. In addition, COA water quality regulations apply only when stream reaches have 64 acres or more of drainage area.

Vegetative classifications, land use, and creek networks were intersected with COA Environmental Integrity Index (EII) reach boundaries allowing for the comparison of riparian and land use metrics with the EII dataset. The DAT was used to represent the basic hydrology of the study areas. The stream centerline established a basis from which to offset riparian zone buffers. Buffer areas with a width of 50 ft and 400 ft on either side of the creek were created to analyze the effect of both immediate riparian conditions and broader scale riparian conditions. The buffer areas were assigned drainage acre threshold (DAT) values based on those of the creek segments they surround. Due to sizing issues, the 50 ft and 400 ft buffer may have different DAT assignments even if located in the same area. For example, within a 640 acre DAT in the 400 ft buffer, a 640 acre DAT and a 64 acre DAT may exist within the 50 ft buffer because of a tributary confluence with the mainstem (Figure 5).

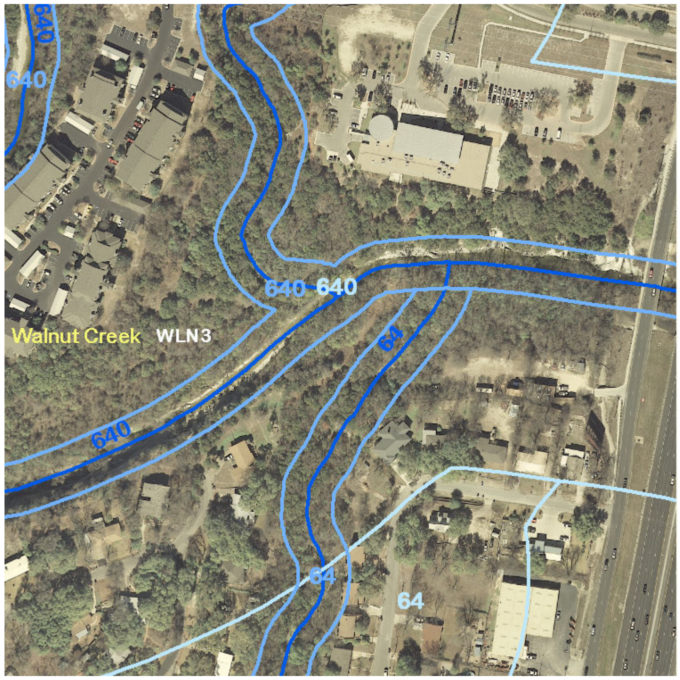

Figure 5: Example of creek line, 50' and 400' buffer base files with respective drainage area threshold values and watershed reach values labeled for same riparian zone along Walnut Creek upstream of US I35 corresponding to the area of Figure 1., Yellow=Watershed Reach, Dark Blue=Creek Centerline, Medium Blue=50' Buffer, Light Blue=400' Buffer.

The 50 ft and 400 ft buffer area polygons were intersected with watershed, EII reach, vegetative classification, land use, and DAT. The distribution and relative percentages of any combination of the land use and vegetative classification can be identified for the 50 ft and 400 ft buffer for each EII reach, DAT, or watershed. This data was used to relate the ecological health of an area to the combination of spatial attributes present.

Metric Selection

For every EII reach, the percent area coverage for each vegetative classification and land use was computed for 50 ft and 400 ft buffer zones in the 64, 320, and 640 acre drainage acreage thresholds. A total of 114 metrics were created and used in the analysis (Appendix D). The COA performs monitoring on 50 watersheds (122 subwatersheds or EII reaches) on a biannual basis. Of the 122 reaches, 7 reaches were removed from analysis due to inadequate planimetric data: reaches 5 and 6 on Barton Creek; reach 3 on Bear Creek; reach 1 on Dry East; and reaches 4, 5, and 6 on Onion Creek.

The land cover metrics were inserted into a spatial cross-regressive model to determine which metrics best explain the environmental integrity of a reach. Reach integrity was represented by the overall EII score, which is a composite of water quality, sediment quality, habitat, aquatic life, contact recreation, and non-contact recreation (COA 2002). To ensure the EII scores varied adequately across a range of riparian integrity, a subset of 'degraded' riparian reaches and 'reference' riparian reaches were chosen for comparison. Degraded and reference reaches were chosen from visual assessments of Austin aerial imagery (Table 1). Wilcoxon rank sum tests were performed on the area classification metrics of these subsets to determine if significant differences existed between the metrics. A Wilcoxon rank sum test was also performed using the EII scores from these reaches to determine if there were significantly lower scores in degraded versus reference reaches.

Table 1: Degraded or reference EII reaches based on GIS aerial vegetation coverage in the riparian zone.

DEGRADED		**REFERENCE**	
CODE	**SITE NAME**	**CODE**	**SITE NAME**
BMK2	Buttermilk Creek @ Providence Ave	BAR1	Barton Creek Between Dams Upstream of Pool
BOG1	North Boggy Creek @ Delwau Lane	BAR3	Barton Creek @ Leif Johnson Pool
BOG2	North Boggy Creek @ Nile Street	BAR4	Barton Creek @ Hwy 71 Downstream of Little Barton
CAR2	Carson Creek @ Hoecke Lane	BEE1	Bee Creek @ Lake Austin
DKR3	Decker Creek @ Lindell Lane	BEE2	Bee Creek @ Road Runner Road
EBO2	East Bouldin Creek @ Elizabeth St	BER2	Bear Creek @ Escondido
ELM1	Elm Creek @ Austins Colony	BRW1	Bear Creek (West) @ Fritz Hughes Park Road
FOR3	Fort Branch Creek Upstream of Manor Rd	BUL2	Bull Creek @ St. Edwards Park Upstream of dam
GIL1	Gilleland Creek @ FM 969	BUL3	Bull Creek Upstream of Tributary 7 (Franklin)
GIL4	West Gilleland Creek @ Cameron Road	BUL4	Tributary 5 ds Hanks Tract Property Line
GIL6	Gilleland Creek @ South Railroad Avenue	CMF1	Common Ford Tributary in Common Ford Park
HRS2	Harris Branch Creek @ Crystal Bend Dr	FOR1	Fort Branch Creek @ North Boggy Creek
JOH1	Johnson Creek @ Woodmont Avenue	TRK1	Turkey Creek @ City Park Road
LWA2	Little Walnut @ Cameron Rd		
LWA3	Little Walnut Creek @ Georgian Dr		
SHL3	Shoal Creek @ Shoal Edge Court		
SHL4	Shoal Creek Downstream of Crosscreek Dr.		
TAN3	Tannehill Creek @ Berkman Dr		
WLN3	Walnut Creek Downstream of IH35		

Using 114 metrics to construct a model with a sample size of 115 EII reaches was mathematically problematic. Thus the number of metrics was reduced prior to model construction. Metrics were not entered into the model if they did not have an interquartile range greater than 5% throughout the dataset. Pearson correlations and a principal component analysis (PCA) were performed as exploratory tools to identify parameter redundancy (Johnson 1998). Redundant parameters were also not entered into the model.

Multivariate linear regression was performed to construct the multi-parameter model that best explained EII scores (SAS version 9.2). The Akaike Information Criteria (AIC) was used to choose the model of best fit (Akaike 1973; Akaike 1974), while the adjusted R^2 value was computed to measure how well each model fit the data (Kutner et al. 2005). Estimated scores from the best fit model were plotted against observed EII scores.

Nutrient loads from headwater sections of a stream can affect the water quality in downstream portions of the stream (Alexander et al. 2007) but can be mitigated by highly functional riparian zones. Riparian zone function in the headwaters can impact the environmental integrity of a downstream reach. To accurately model this phenomenon, metrics from the best fit linear model were input into a spatial cross-regressive model. This also improved the fit of the model and eliminated spatial bias present in the residuals (Florax and Folmer 1992). SAS/IML is a programming language for high-level, matrix-vector computation, and was used to develop the spatial cross-regressive model (Wicklin 2010). For a given reach, upstream metrics were weighted and included in the explanation of the EII score for that reach. Weights typically consist of either binary contiguity or are created based on distance (Florax and Folmer 1992; Anselin 2002). For this model, weights were based on creek distance between EII sampling locations and the edge of the upstream EII reach. Reaches immediately upstream of the sample location would have more influence on the integrity score than reaches further upstream. The adjusted R^2 value was computed for the spatial cross-regressive model and the estimated scores were plotted against the observed EII scores.

Estimated scores from the spatial cross-regressive model were designated as the Index of Riparian Integrity and plotted for each EII reach. While the length based classifications were analyzed, they did not contribute to the spatial cross-regressive model. Length based classifications were redundant to the area based classifications and explained very little of the variation in EII scores. For simplicity of this paper, the length based classifications will not be discussed in the results.

RESULTS

Area classification metrics were significantly different between selected degraded sites and reference sites excluding water cover and bare ground coverage in various buffer/drainage area combinations (Table 2). This supports the hypothesis that selected reaches differed quantitatively and not just qualitatively (visually). No inferences should be made about difference or lack of difference in water coverage between degraded and reference sites. Creek size was not considered when selecting the sites as degraded or reference. Thus there is not an equal representation of each drainage area in the analysis and any difference in the amount of water coverage could be due to a higher or lower representation of a particular drainage area compared to the other two drainage areas.

The selected reaches were used as a representation of the quantitative range of the riparian integrity in Austin creeks between degraded and reference conditions. A measure of environmental integrity that was significantly different between these groups at the reach level could be used as an appropriate measure of riparian integrity in a regression model. COA EII scores are a robust measure of environmental integrity and were significantly lower in the selected degraded reaches (Figure 6; $p = 0.0002$). Thus EII scores were used as the dependent variable in regression models to determine which riparian metrics contributed to the explanation of riparian health.

Table 2: Lower and upper confidence Intervals (95%) for each vegetative classification in Reference sites and Degraded sites. The p-value is listed for the Wilcoxon sum rank test performed between the two types of sites. Area classification metrics were significantly different between site types when p-value < 0.05. The 50 versus 400 designation reflects buffer width. The 64, 320, 640 designation represents the drainage area threshold in acres. IC = impervious cover

Area Classification	Reference Site	Degraded Site	p-value
A-50-64-Bare	(0.1,0.3)	(0.8,2.0)	0.0005
A-50-64-IC	(0.6,4.5)	(14.6,30.9)	< 0.0001
A-50-64-Robust	(0.3,0.9)	(3.8,7.1)	< 0.0001
A-50-64-Sparse	(2.5,7.7)	(17.7,31.4)	< 0.0001
A-50-64-Water	(0.1,1.2)	(0.4,1.8)	0.6228
A-50-64-Woody	(70.3,96.1)	(37.0,52.5)	< 0.0001
A-50-320-Bare	(0.0,0.3)	(0.8,1.9)	0.0003
A-50-320-IC	(0.0,1.4)	(8.4,19.4)	< 0.0001
A-50-320-Robust	(0.1,0.7)	(4.1,7.8)	< 0.0001
A-50-320-Sparse	(1.3,6.3)	(13.9,23.9)	< 0.0001
A-50-320-Water	(0.0,1.1)	(0.7,9.0)	0.0360
A-50-320-Woody	(73.6,99.8)	(45.6,64.5)	0.0001
A-50-640-Bare	(0.4,1.8)	(1.1,2.5)	0.0594
A-50-640-IC	(0.5,1.4)	(6.5,13.7)	< 0.0001
A-50-640-Robust	(1.1,2.7)	(4.8,7.9)	0.0001
A-50-640-Sparse	(3.3,6.7)	(12.6,20.2)	< 0.0001
A-50-640-Water	(4.3,14.7)	(1.6,3.5)	0.3188
A-50-640-Woody	(75.0,88.1)	(57.2,68.5)	0.0009
A-400-64-Bare	(0.5,1.0)	(1.1,3.3)	0.2381
A-400-64-IC	(4.8,12.8)	(28.9,46.3)	< 0.0001
A-400-64-Robust	(0.3,1.0)	(2.9,5.9)	< 0.0001
A-400-64-Sparse	(9.3,17.7)	(19.8,33.7)	0.0158
A-400-64-Water	(0.2,0.5)	(0.3,0.8)	0.9097
A-400-64-Woody	(57.3,79.1)	(23.1,33.9)	< 0.0001
A-400-320-Bare	(0.3,0.9)	(1.3,3.4)	0.0098
A-400-320-IC	(1.2,7.0)	(25.9,41.4)	< 0.0001
A-400-320-Robust	(0.1,0.7)	(2.9,6.1)	< 0.0001
A-400-320-Sparse	(6.2,13.3)	(20.4,31.9)	0.0002
A-400-320-Water	(0.1,0.4)	(0.4,2.9)	0.0436
A-400-320-Woody	(65.0,89.5)	(25.7,37.7)	< 0.0001
A-400-640-Bare	(0.5,1.0)	(1.3,3.5)	0.0111
A-400-640-IC	(2.5,7.2)	(21.1,34.3)	< 0.0001
A-400-640-Robust	(0.8,2.2)	(4.0,6.3)	< 0.0001
A-400-640-Sparse	(8.2,14.8)	(20.5,33.3)	0.0012
A-400-640-Water	(0.6,2.8)	(0.4,1.2)	0.5446
A-400-640-Woody	(75.8,83.6)	(33.9,40.3)	< 0.0001

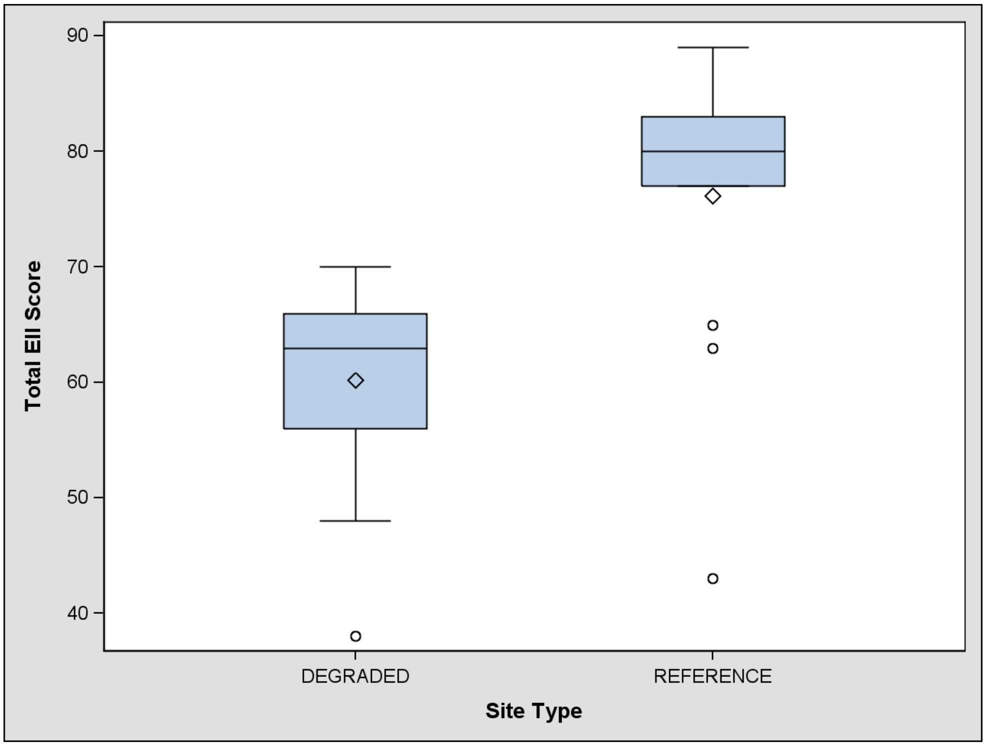

Figure 6: Boxplot of COA EII scores in the subset of degraded and reference reaches based on a visual evaluation and area classification metrics. Diamonds represent the mean, horizontal bars within the box represent medians, and circles indicate outliers.

Strong correlations existed between the 50 ft and 400 ft buffers for most vegetative classifications and land use classifications (Table 3). The A-50-320-IC and A-50-640-Robust classifications formed weaker linear relationships to their respective 400 ft buffers while the A-50-640-Bare classification was not linearly related to its 400 ft buffer. The remainder of the 50 ft buffer vegetative classifications had strong positive linear relationships with their 400 ft buffer counterpart. This suggests that in many reaches the amount and type of vegetation present in the 50 ft buffer was also present in the same proportion in the 400 ft buffer. Results were similar for the land use classifications with the exception of LU-50-64-Comm and LU-50-320-Utility. This was important to note because the inclusion of both 50 ft and 400 ft buffer classifications could introduce multicollinearity into a model. While multicollinearity often does not inhibit the model fit, it can increase the variability in the regression coefficients. One way to reduce this variability is to remove one of the correlated parameters from the model (Kutner et al. 2005). In this case there are too many correlated parameters to knowledgably remove particular parameters without affecting the overall model. Further diagnostics were needed to remove parameters prior to building a model.

The second step in parameter removal was to simply remove classifications where the range of the data was low. All classifications were based on a 0 to 100 scale, thus classifications with a very small range over all reaches are not likely to explain changes to the environmental integrity of a system. Bare area classifications were removed from further analysis as the data ranged from only 0 to 3% in the reaches. Water vegetative classifications and 50 ft buffer robust area classifications were removed from further analysis for similar reasons. Land Use classifications removed from analysis due to a small data range included LU-50-64-Utility, LU-50-320-Utility, LU-50-640-Utility, LU-400-64-Utility, LU-400-320-Utility, LU-400-640-Utility, LU-50-640-Duplex, LU-50-320-Duplex, LU-400-320-Duplex, LU-50-320-Apt, LU-50-320-Comm, LU-50-320-Office, LU-50-640-Office, LU-400-320-Office, LU-50-320-Civic, and LU-400-320-Civic.

Table 3: Pearson Correlation Coefficients for each vegetative and land use classification in the 50 ft buffer compared to the same classification in the 400 ft buffer. The 50 versus 400 designation reflects buffer width. The 64, 320, 640 designation represents the drainage area threshold in acres. IC = impervious cover

Area Classification	400 FT BUFFER	Land Use Classification	400 FT BUFFER
A-50-64-Bare	0.74	LU-50-64-Apt	0.91
A-50-64-IC	0.84	LU-50-64-Civic	0.95
A-50-64-Robust	0.89	LU-50-64-Comm	0.66
A-50-64-Sparse	0.91	LU-50-64-Duplex	0.92
A-50-64-Water	0.95	LU-50-64-Office	0.72
A-50-64-Woody	0.90	LU-50-64-Park	0.89
A-50-320-Bare	0.79	LU-50-64-Road	0.85
A-50-320-IC	0.68	LU-50-64-SF	0.91
A-50-320-Robust	0.73	LU-50-64-Undev	0.99
A-50-320-Sparse	0.90	LU-50-64-Utility	0.70
A-50-320-Water	0.87	LU-50-320-Apt	0.74
A-50-320-Woody	0.90	LU-50-320-Civic	0.86
A-50-640-Bare	0.34	LU-50-320-Comm	0.94
A-50-640-IC	0.79	LU-50-320-Duplex	0.73
A-50-640-Robust	0.68	LU-50-320-Office	0.83
A-50-640-Sparse	0.84	LU-50-320-Park	0.89
A-50-640-Water	0.85	LU-50-320-Road	0.75
A-50-640-Woody	0.79	LU-50-320-SF	0.83
		LU-50-320-Undev	0.98
		LU-50-320-Utility	0.68
		LU-50-640-Apt	0.94
		LU-50-640-Civic	0.96
		LU-50-640-Comm	0.86
		LU-50-640-Duplex	0.82
		LU-50-640-Office	0.91
		LU-50-640-Park	0.92
		LU-50-640-Road	0.86
		LU-50-640-SF	0.92
		LU-50-640-Undev	0.99
		LU-50-640-Utility	0.96

Area and land use classifications were used in a principal component analysis (PCA) to examine the true dimensionality of the data set, which could be viewed as the number of classifications necessary to fully explain the data set. If the dimensionality was less than the number of input classifications, then a smaller number of classifications may be used to represent the data without losing any explanatory power. The PCA showed that cumulative proportion of the variation explained did not reach 100% until the 90th principal component (out of 96), suggesting that most of the classifications were necessary to completely explain the variation in the dataset. However, only 29 principal components were needed to explain 90% of the variation and 19 to explain 80% of the variation. This indicates that the majority of the information held in the data set could be explained with much fewer variables. Thus, linear regression was performed using 65 classifications that spanned a range larger than 5% without the loss of the majority of the information within the data set.

Linear regressions were performed on every combination of the 65 classifications. The model chosen to represent the riparian integrity of the system was selected using the Akaike Information Criteria (AIC).

The lower the AIC, the better the goodness of fit of a model compared to the other models. Numerous models were similar in AIC value, thus many of the models were similar in goodness of fit. The classification which explained the most variation in EII scores was forced into the model to trim the number of considered models. Linear regression showed that the best fit model with a single classification included the A-400-320-Woody classification. The lowest AIC multivariate models which included the A-400-320-Woody classification were examined for possible multicollinearity (Table 4). The two best fit models which included A-400-320-Woody also included A-50-320-Woody. These classifications were strongly correlated and introduced multicollinearity to the model. The third best fit model that included A-400-320-Woody contained both A-50-64-IC and A-400-64-IC, which were strongly correlated and introduced multicollinearity into the model. The fourth model of best fit which included A-400-320-Woody was selected as the model to represent riparian integrity as no classifications included in the model would introduce multicollinearity. In comparison, the model with the lowest AIC (480.23) that did not include A-400-320-Woody had an adjusted R^2 value of 0.5595, while the selected model had an adjusted R^2 value of 0.5818. Thus the model fit of the selected model was better according to the adjusted R^2 value.

Table 4: Top four models which contained A-400-320-Woody based on the AIC. The adjusted R^2 is given for each model. Orange cells indicate strongly correlated classifications. The model in blue was selected as the best linear model with no redundant classifications.

Classification	AIC = 481.65 R^2 = 0.5935	AIC = 481.98 R^2 = 0.5954	AIC = 482.29 R^2 = 0.5882	AIC = 482.34 R^2 = 0.5818
A-50-64-IC			X	X
A-50-64-Sparse			X	X
A-50-64-Woody			X	X
A-50-320-Sparse	X	X	X	X
A-50-320-Woody	X	X		
A-50-640-IC		X		
A-400-64-IC	X	X	X	
A-400-64-Robust	X	X	X	X
A-400-64-Sparse	X	X		
A-400-64-Woody	X	X		
A-400-320-Woody	X	X	X	X
LU-50-64-Apt	X	X	X	X
LU-50-64-Comm	X	X		
LU-50-64-SF	X	X	X	X
LU-50-640-SF	X	X	X	X
LU-400-64-Comm	X	X	X	
LU-400-64-Road	X	X	X	X
LU-400-640-Duplex	X	X	X	X

The modeled score plotted against the observed EII score for each reach showed relatively good fit with no outliers (Figure 7). A spatial component was added to the selected model as the upstream riparian zones will alter the ecological integrity of an EII reach. The classifications present in the selected model were used as inputs to a spatial cross-regressive model based on creek distances to obtain a better fit and eliminate spatial bias.

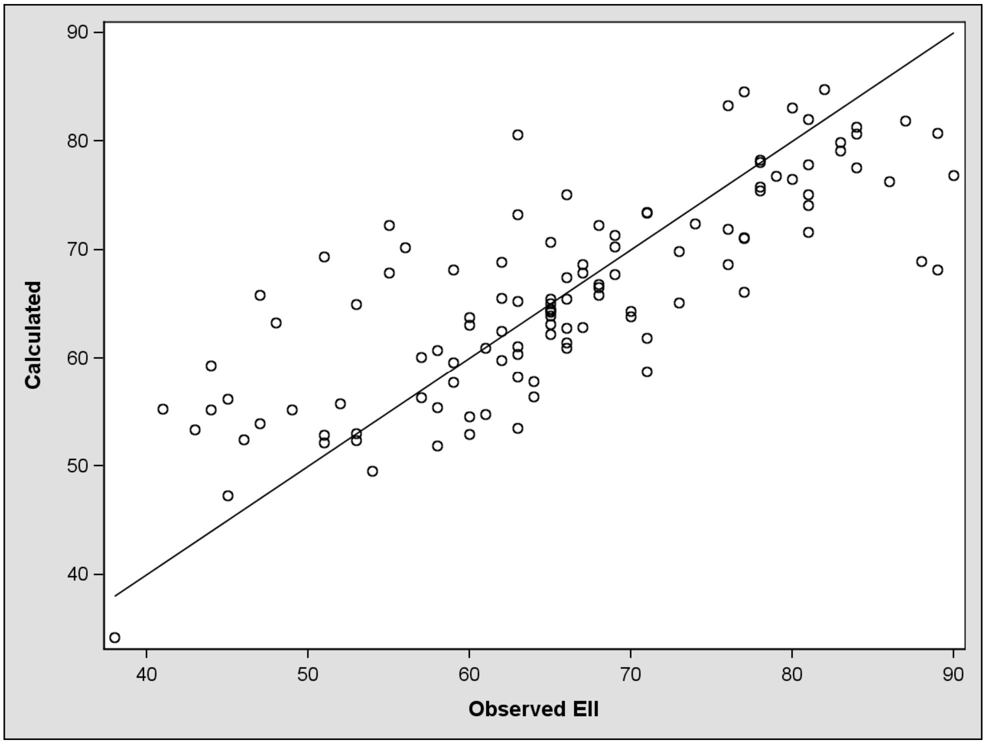

Figure 7: Selected model outputs (Calculated) plotted against the observed EII score for each reach.

Classifications were removed from the spatial term of the model if they were not significant. A-50-320-Sparse, A-400-320-Woody, and LU-400-64-Road remained in the model as spatial components which increased the model fit to an adjusted R^2 value of 0.6484. Visually this improved the fit of the extreme scores. Calculated values on the low and high end of the EII range were closer to the observed data (Figure 8). The spatial model represented the best estimate of environmental integrity based on the riparian buffer zone. Scores output by this tool were designated as the Index of Riparian Integrity (IRI). The actual equation to produce these scores will not be listed in this report because of the complexity of the equation. The spatial component of each equation was based on upstream reaches. As each reach has a different set of upstream reaches, the equation to compute the IRI was different for each reach. Raw data can be obtained by contacting the COA and the SAS code that computes the IRI scores can be viewed in Appendix E.

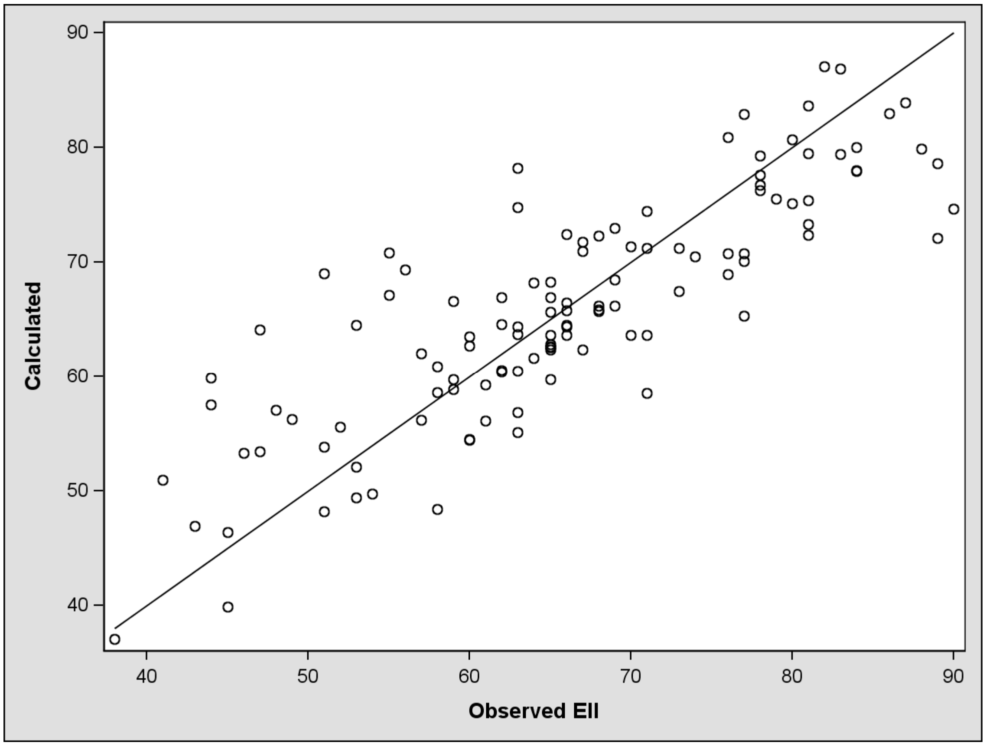

Figure 8: Spatial cross-regressive model outputs (Calculated) plotted against the observed EII score for each reach.

Reaches were numbered with consecutive integers starting with one at the mouth of a watershed and increasing in number with increasing distance from the mouth. Thus each watershed had at least a Reach 1 with the possibility of more reaches depending on the size of the watershed. IRI scores were calculated for each watershed broken up by reach (Figure 9). Reaches that do not have an IRI score include Barton Creek Reach 5 and Reach 6; Bear Creek Reach 3; Decker Creek Reach 2; Dry Creek North Reach 1; Eanes Creek Reach 1; Onion Creek Reach 4, Reach 5, and Reach 6; and Slaughter Creek Reach 2. These reaches were excluded from the analysis for various reasons. Barton, Onion, Bear, and Dry Creek reaches were left out of analysis because the planimetrics were incomplete for these reaches and could skew the analysis results. Decker, Eanes, and Slaughter Creek reaches were excluded from analysis because they did not have EII scores for the 2009 – 2010 sampling period. Decker Creek Reach 2 is actually Lake Walter E. Long and as such, is not hydrologically appropriate for inclusion in EII assessments. Slaughter Creek Reach 2 is located in aquifer recharge and has been consistently dry, while Eanes Creek Reach 1 was dry in this sampling period thus neither reach had an EII score for this period. Post analysis calculation of these reaches was considered, but the calculation would involve changing the spatial matrix thus changing the IRI scores of other reaches in these watersheds. The benefit of having scores for these reaches was not worth the lost accuracy.

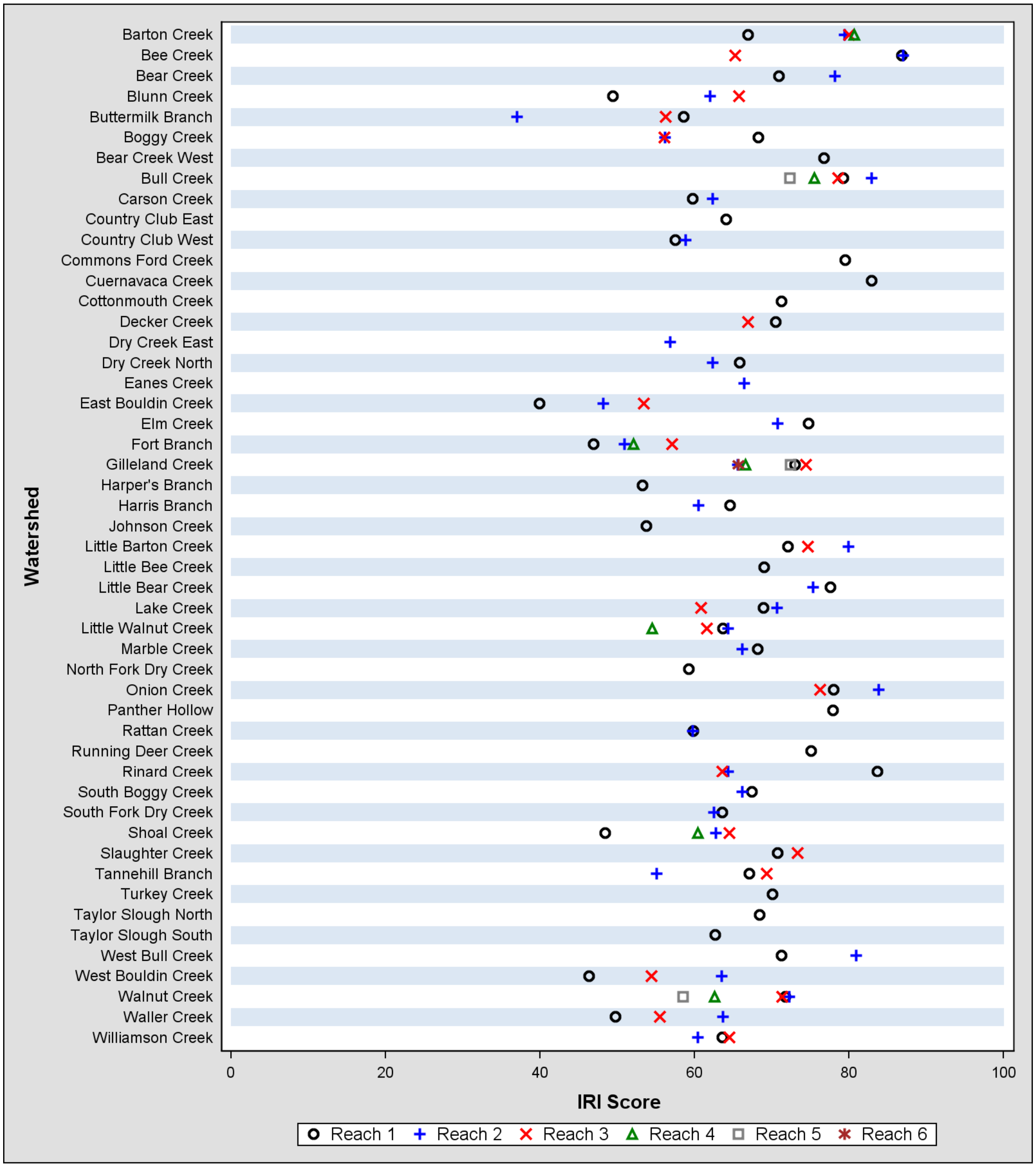

Figure 9: Index of Riparian Integrity (IRI) scores for each watershed reach. Reach 1 was closest to the mouth of the watershed and reach number increased as distance from the mouth increased.

Index of Riparian Integrity scores ranged from 37 in Buttermilk Branch Reach 2 to 87 in Bee Creek Reach 2. Buttermilk Branch Reach 2 is a highly urbanized reach with very little vegetation along the creek and a large proportion of impervious cover while Bee Creek Reach 2 (along with some of Bee Creek Reach 1) is part of the Wild Basin Wilderness Preserve with large amounts of protected vegetation and very little impervious cover.

For a quality control check of the model, IRI scores for the reaches designated as degraded or reference were compared to the full range of IRI scores (Table 5). Degraded reaches were expected to have low IRI scores while reference reaches were expected to have high scores. With the exception of Tannehill Reach

3 (TAN3) and Fort Branch Reach 1 (FOR1), the model seemed to accurately predict the riparian condition in the selected degraded or reference reaches. Blunn Reach 1 (BLU1), Marble Reach 1 (MAR1), Tannehill Reach 2 (TAN2), and West Bouldin Reach 1 (WBO1) had similar characteristics to Fort Branch Reach 1, so the model did not accurately predict the riparian condition in these reaches.

Table 5: Index of Riparian Integrity scores for designated degraded and reference sites along with the overall IRI ranking for each reach.

DEGRADED			REFERENCE		
REACH	**IRI SCORE**	**RANK**	**REACH**	**IRI SCORE**	**RANK**
ELM1	75	24	BEE2	87	1
GIL1	73	28	BEE1	87	2
WLN3	71	34	BUL2	83	5
TAN3	69	43	BAR4	81	8
BOG1	68	47	BAR3	80	9
DKR3	67	51	CMF1	79	11
GIL4	67	53	BUL3	79	14
GIL6	66	59	BER2	78	15
SHL3	65	63	BRW1	77	19
LWA2	64	65	BUL4	76	21
CAR2	62	79	TRK1	70	42
LWA3	62	81	BAR1	67	52
HRS2	61	83	FOR1	47	112
SHL4	60	84			
FOR3	57	94			
BOG2	56	97			
JOH1	54	103			
EBO2	48	111			
BMK2	37	115			

Conclusions/Recommendations

A spatial cross-regressive model was developed using aerial vegetative cover, land use and planimetric data to measure riparian integrity on a large spatial scale across Austin, TX. Aerial imagery vegetative cover classifications evaluated in the model included impervious cover, woody vegetation, and sparse vegetation in the 50 ft buffer with a 64 acre drainage threshold; sparse vegetation in the 50 ft buffer up to a 320 acre drainage area; robust vegetation in the 400 ft buffer up to a 64 acre drainage area; and woody vegetation in the 400 ft buffer up to a 320 acre drainage area. Land use data included in the model included apartments and single family residential in the 50 ft buffer up to a 64 acre drainage area; single family residential in the 50 ft buffer up to a 640 acre drainage area; road coverage in the 400 ft buffer up to a 64 acre drainage area; and duplex homes in the 400 ft buffer up to a 640 acre drainage area. These classifications explained the most variation in environmental integrity and did not introduce multicollinearity into the model. Thus, the 11 variable model based on these classifications produced the best representation of riparian integrity for Austin area streams, and is the basis of the Index of Riparian Integrity (Table 6). It is important to note that of the 11 variables selected, seven are in the 50-foot buffer vs. four the 400 foot buffer, seven are in the headwaters vs 4 in the farther downstream reaches, and six are taken from aerial imagery vs. five from land use classification.

Table 6. Index of Riparian Integrity model that best predicted EII stream health scores. Each variable is either in the Headwaters, mid-stream or downstream in the watershed, relative to the bottom of the reach, and either in the 50 or 400 foot buffer areas. These 11 variables are what will be used in assessing riparian health in Austin area streams.

Headwater Variables (64-320 acres)		Mid stream variables (320-640 acres)		Down Stream Variables (>640 acres)	
50-ft Buffer	**400-ft Buffer**	**50-ft Buffer**	**400-ft Buffer**	**50-ft Buffer**	**400-ft Buffer**
Imp. Cover	Robust Veg	Sparse Veg	Woody Veg	Single Family	Duplex
Sparse Veg	Roads				
Woody Veg					
Apartments					
Single Family					

The riparian integrity for Tannehill Creek Reach 3 was not predicted well by the model. Land use in the reach was mainly commercial development and the land classification in the 400 ft buffer was impervious cover; however, the land classification in the 50 ft buffer was woody and sparse vegetation. The model scored this reach higher because of the vegetation found only in the 50 ft buffer. This is a failing of the model to distinguish between the 50 ft buffer and the 400 ft buffer where large differences are detected between the vegetative and land use class percentages. In most reaches, the 50 ft buffer vegetative coverage and land use were positively correlated with the 400 ft buffer vegetative coverage and land use. Thus only small differences in explanatory value of the model existed when using 50 ft buffer parameters versus 400 ft buffer parameters. Currently, TAN3 is an outlier. Other reaches were not misrepresented by the model based on a difference in vegetative cover or land use between the 50 ft and 400 ft buffer. In the future, if percentages of vegetative cover or land use change and are shown to be different between the 50 ft buffer and the 400 ft buffer, the current model should be checked for errors and the data possibly reanalyzed.

It is important to note the ecological impact of the correlation between the 50 ft buffer vegetative coverages/land uses and the 400 ft buffer vegetative coverages/land uses. As the selected model for the IRI involved 7 factors in the 50 ft buffer and 4 factors in the 400 ft buffer, one conclusion could be that the 50 ft buffer is more important to the ecological integrity of the riparian zone although this is not supported by current scientific literature. The strong correlations that exist in most reaches show that reaches with good riparian integrity in the 50 ft buffer also have good riparian integrity in the 400 ft buffer. Thus the 400 ft buffer has been contributing to the environmental integrity of the buffer zone. Parameters selected from the 50 ft buffer explain only slightly more variation in the environmental integrity based on the EII scores of these reaches. The model should not be used to determine an optimal width (50 ft or 400 ft) for a riparian zone to protect water quality in adjacent water bodies. However, it can and should be used to score and rank the riparian integrity in reaches around Austin, TX.

Blunn Creek Reach 1, Fort Branch Reach 1, Marble Creek Reach 1, Tannehill Creek Reach 2, and West Bouldin Creek Reach 1 were scored artificially low in the IRI because they did not contain 64 acre or 320 acre drainage areas. Each of these are the most downstream reaches of the creek (except Tannehill 2) , and have simplified drainage networks, either due to mapping limitations or to urbanization of stormwater infrastructure. There are a few parameters in the model relevant to the 640 acre drainage area, but the lack of data from the other drainage areas caused the IRI scores for the above reaches to be low. The vegetative cover and land use of Blunn Reach 1, Fort Branch Reach 1, and Tannehill Reach 2 were indicative of reaches that would have a low IRI score, but the scores were still artificially lowered by the lack of smaller drainage areas. West Bouldin Reach 1 and Marble Creek Reach 1 had high amounts of woody vegetation in both the 50 ft and 400 ft buffer zones with high amounts of park land use. The riparian integrity of West Bouldin Reach 1 and Marble Creek Reach 1 is justifiably higher than the calculated IRI scores. When prioritizing reaches for riparian restoration, these 5 reaches may need to be investigated more closely prior to final decisions. An interesting result of this analysis showed that reaches with only a 640 acre drainage area had low EII scores and poor water quality. One possible explanation is the upstream reaches are heavily impacting the water in downstream reaches. As most of the reaches with only a 640 acre drainage area are at the mouth of the creek, it is very likely that the upstream reaches are having an impact on the water quality within these sites. In fact, each of these reaches is downstream of a reach that scored mediocre to poor in the IRI. This reinforces the notion that the riparian buffer zone along an entire watershed is important to the water quality at the mouth of the watershed. Another possibility is that systems where drainage areas have been simplified or truncated have water quality problems that can't be explained by the riparian zone. In urban systems with only large drainage areas there are likely to be hydrology issues that cannot be addressed by riparian buffers. For West Bouldin Creek Reach 1 hydrology has been altered in various ways and is dry most of the time. Water quality in this reach has continuously been bad in the EII monitoring system. When prioritizing riparian restoration projects for these five reaches it may be warranted to look at the upstream reaches and other environmental factors such as hydrology before making final decisions about restoration efforts.

It is recommended that the model output proposed here be used to measure riparian integrity in Austin on a large spatial scale. Blunn Reach 1, Fort Branch Reach 1, Marble Reach 1, Tannehill Reach 2, Tannehill Reach 3, and West Bouldin Reach1 should be assessed separately in more detail when prioritizing the reach for a riparian project. Otherwise, the IRI scores should be used by policy makers and project managers to prioritize riparian restoration locations.

REFERENCES

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. Pages 267-281 in B.N. Petrov and F. Czaki, eds. *Information Theory*. Academia Kiado, Budapest.

Akaike, H. 1974. A new look at the statistical model identification. *IEEE Transaction on Automatic Control* AC **19**: 716-723.

Alexander, R. B., E.W. Boyer, R.A. Smith, G.A. Schwarz, and R.B. Moore. 2007. The Role of Headwater Streams in Downstream Water Quality. Journal of the American Water Resources Association **43**(1): 41-59.

Anderson J.R, E.E. Hardy, J.T. Roach and R. E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. USGS Professional Paper 964; U.S. Government Printing Office, Washington D.C.

Anderson, N.H. and J.R. Sedell. 1979. Detritus processing by macroinvertebrates in stream ecosystems. Annual Review of Entomology. **24**: 351-377.

Anselin, L. 2002. Under the hood: Issues in the specification and interpretation of spatial regression models. Agricultural Economics **27**: 247-267.

Barrett, M.E., A.M. Quenzer, and D.R. Maidment. 1998. Water Quality and Quantity Inputs for the Urban Creeks: Future Needs Assessment. Center for Research in Water Resources, University of Texas at Austin.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for use in streams and wadeable rivers, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Booth, D.B, J.R. Karr, S. Schauman, C.P. Konrad, S.A. Morley, M.G. Larson, P.C. Henshaw, E.J. Nelson and S.J. Burges. 2001. Urban Stream Rehabilitation in the Pacific Northwest: Physical, Biological and Social Considerations. Final Report, EPA Grant Number R82-5284-010. University of Washington. Seattle, Washington. 78 pp.

City of Austin (COA). 2001. Watershed Protection Master Plan Phase 1 Watersheds Report. City of Austin, Watershed Protection Department.

City of Austin (COA). 2002. Environmental Integrity Index Water Quality Technical Assessment Methodology. City of Austin, Watershed Protection Department, Environmental Resources Management Division, Water Resource Evaluation Section: CM-02-01.

City of Austin (COA). 2011. City of Austin Neighborhood Planning Guide to Land Use Standards. City of Austin Neighborhood Planning and Zoning Department, July 2011.

Correll, D. 1999. Vegetated Stream Riparian Zones Their Effects on Stream Nutrients, Sediments, and Toxic Substances: An Annotated and Indexed Bibliography of the world literature including buffer strips, and interactions with hyporheic zones and floodplains, 8th Ed. Smithsonian Environmental Research Center Edgewater, Maryland, USA .

Fischer, R.A. and J.C. Fischenich. 2000. Design recommendations for riparian corridors and vegetated buffer strips. EMRRP Technical Notes Collection (ERDC TN-EMRRP-SR-24), U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Florax, R. and H. Folmer. 1992. Specification and estimation of spatial linear regression models: Monte Carlo evaluation of pre-test estimators. Regional Science and Urban Economics **22**: 405-432.

Groffman P.M., D.J. Bain, L.E. Band, K.T. Belt, G.S. Brush, J.M. Grove, R.V. Pouyat, I.C. Yesilonis, and W.C. Zipperer. 2003. Down by the riverside: urban riparian ecology. Frontiers in Ecology and Environment **1**(6**)**: 315–321.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, and S.V. Gregory. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research **15**: 133-302.

Horner, R.R. and C.W. May. 1999. Regional Study Supports Natural Land Cover Protection as Leading best Management Practice for Maintaining Stream Ecological Integrity. Pp. 233-247 *In:* Comprehensive Stormwater and Aquatic Ecosystem Management. First South Pacific Conference, Auckland, New Zealand.

Jacobs, T.C. and J.W. Gilliam. 1985. Riparian losses of nitrate from agricultural drainage waters. Journal of Environmental Quality **14**: 472-478.

Johnson, D.E. 1998. Applied Multivariate Methods for Data Analysts. Duxbury Press. Pacific Grove, CA.

King, R. S., M. E. Baker, D. F.Whigham, D. E. Weller, T. E. Jordan, P. F. Kazyak, and M. K. Hurd. 2005. Spatial considerations for linking watershed land cover to ecological indicators in streams. Ecological Applications **15**:137–153.

Kutner, M.H., C.J. Nachtsheim, J. Neter, and W. Li. 2005. Applied Linear Statistical Models – 5th edition. McGraw-Hill/Irwin. New York, NY.

Lowrance, R., R.L. Todd, and L.E. Asmussen. 1983. Waterborne nutrient budgets for the riparian zone of an agricultural watershed. Agriculture, Ecosystems & Environment **10**: 371-384.

Lowrance, R., R. Leonard, and J. Sheridan. 1985. Managing riparian ecosystems to control nonpoint pollution. Journal of Soil & Water Conservation **40**: 87-97.

May, C.W and R.R. Horner. 2000. The cumulative impacts of watershed urbanization on stream-riparian ecosystems. Pp. 281-286 *In:* P. J. Wigington, Jr. and R. L. Beschta, eds. Proceedings of the American Water Resources Association International Conference on riparian ecology and management in multi-land use watersheds, Portland, Oregon.

Naiman, R.J. and H. Decamps. 1997. The Ecology of Interfaces: Riparian Zones. Annual Review of Ecology and Systematics. **28**: 621-658.

Peterjohn, W.T. and D.L. Correll. 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest. Ecology **65**: 1466-1475.

Richardson, M.D., P.M. Holmes, K.J. Esler, S.M. Galatowitsch, J.C. Stromberg, S.P. Kirkman, P. Pysek, and R.J. Hobbs. 2007. Riparian vegetation: degradation, alien plant invasion, and restoration prospects. Diversity and Distributions **13**: 126-139.

Richter, F.A. and A. Duncan. 2012. Riparian Functional Assessment: Choosing Metrics that Quantify Restoration Success in Austin, Texas. City of Austin, Watershed Protection Department, Environmental Resource Management. SR-12-12.

Sanborn. 2003. *City of Austin, Travis County ARC/INFO Database Design for Planimetric & Topographic Information*. Sanborn Colorado, LLC., GIS Technical Services.

Silva, L. and D.D. Williams. 2001. Buffer zones versus whole catchment approaches to studying land use impact on river water quality. Water Research **35**(14): 3462-3472.

Stacey, P. B., A. Jones, J.C. Catlin, D.A. Duff, L.E. Stevens, and C. Gourley. 2006. User's Guide for the Rapid Assessment of the Functional Condition of Stream Riparian Ecosystems in the American Southwest. Wild Utah Project.

TaxNetUSA. 2013. "Texas State Codes." TaxNetUSA, Inc. Web Accessed April 4, 2013. http://www.taxnetusa.com/research/texas/sptb.php

Tong, S.T.Y. and W. Chen. 2002. Modeling the relationship between land use and surface water quality. Journal of Environmental Management **66**: 377-393.

Walsh, C.J., A.H. Roy, J.W. Feminella, P.D. Cottingham, P.M. Groffman, and R.P. Morgan II. 2005. The urban stream syndrome: current knowledge and the search for a cure. Journal of the North American Benthological Society **24**(3): 706-723.

Weng, Q. 2012. Remote sensing of impervious surfaces in the urban areas: Requirements, methods and trends. Remote Sensing of Environment **117**: 34-49.

Wicklin, R. 2010. Statistical Programming with SAS/IML Software. SAS Institute Inc. Cary, NC.

Wissmar, R.C and R.L. Beschta. 1998. Restoration and management of riparian ecosystems: a catchment perspective. Freshwater Biology **40**: 571-585.

Woolsey, S., F. Capelli, T. Gonser, E. Hoehn, M. Hostmann, B. Junker, A. Paetzold, C. Roulier, S. Schweizer, S.D. Tiegs, K. Tockner, C. Webber, and A. Peter. 2007. A strategy to assess river restoration success. Freshwater Biology **52**(4): 752-769.

Appendix A: Specific & General Land Use Categories, associated city reference codes (COA 2011).

General LU	Specific LU	Description
100	113	Mobile Home
100	120	High Density Single Family (<=0.51 acres)
100	130	Medium Density Single Family (<=2.1 acres)
100	140	Low Density Single Family (<=10.1 acres)
100	150	Duplex
100	160	Large-lot Single Family (>10 acres)
200	210	Three/Fourplex
200	220	Apartments/Condos
200	230	Group Quarters
200	240	Nursing Home
300	300	Commercial
400	400	Office
500	510	Manufacturing
500	520	Warehouses (excludes ministorage)
500	530	Heavy Equipment Sales, Service or Repair
500	550	Animal Related Services
500	560	Mining
500	570	Landfill/Salvage Yard
600	610	Semi-institutional Housing
600	620	Hospitals
600	630	Government Services
600	640	Education
600	650	Meeting and Assembly
600	670	Cemetery
600	680	Cultural facilities
700	710	Parks & Recreation
700	720	Golf Course
700	730	Camp Grounds
700	750	Open Space, protected
700	760	Sport fields
800	810	Railroad facilities
800	820	Transportation terminal
800	830	Aviation facilities
800	840	Marina
800	850	Parking Lot/Vehicle Storage
800	860	Streets and Roads
800	870	Utilities
900	900	Undeveloped
900	910	Agriculture
900	940	Water
999	999	Unknown

Appendix B: State Property Tax Board Codes used by County Central Appraisal Districts (TaxNetUSA 2013).

State Category ID	Texas State Codes Description
A1	Real, Residential, Single-Family
A2	Real, Residential, Mobile Homes
B1	Real, Residential, Multi-Family
B2	Real, Residential, Two-Family
B3	Real, Residential, Three-Family
B4	Real, Residential, Four- or More-Family
C1	Real, Vacant Lots/Tracts
C2	Real, Vacant Commercial
C3	Real, Vacant
D1	Real, Qualified Agricultural Land
D2	Real, Unqualified Agricultural Land
E1	Real, Farm & Ranch Improved
F1	Real, Commercial
F2	Real, Industrial
J1	Real & Tangible Personal, Utility Water
J2	Gas Companies
J3	Electric Companies
J4	Telephone Companies
J5	Railroads
J6	Pipelines
O1	Inventory
PT	Subdivision Header
T	Temporary
U0	Unknown
X0	Primarily Charitable Organization
X1	Governmental Exempt
X2	Charitable Exempt
X3	Religious Exempt
X4	Cemetery Exempt
X5	Private School Exempt
X6	Youth Development Exempt
X7	Historical Exempt
X8	Miscellaneous Exempt
X9	Low-Moderate Income Housing

Appendix C: City of Austin Planimetric Categories and Codes (Sanborn 2003).

Feature	**Code**
Building polygons	
Building (100 - 4000 sq. ft.)	30
Large Building (>4,000 sq. ft.)	31
Courtyard	32
Landmark polygons	
Recreation Court/Ball Field	140
Golf Course	141
Airport Runway/Taxiway	142
Quarry	143
Landfill	144
Gravel/Sand Pit	145
Transportation polygons	
Edge of Paved Roads	210
Edge of Unpaved Roads	211
Paved Parking (10 or more cars)	213
Paved Driveway (>150 ft)	214
Bridge	215
Median (>10 ft)	218
Ege of Paved Alleys	219
Edge of Unpaved Alleys	220
Unpaved Driveway (>150 ft)	221
Open Storage	222

Appendix D: List of classification and land use metrics. Naming is based on the following convention: Area/Length/Land Use-Buffer Width-Drainage Acreage-Classification. Apt = Apartment, Comm = Commercial, IC = Impervious Cover, SF = Single Family Residential, Undev = Undeveloped.

Area Classification	Length Classification	Land Use	
A-50-64-Bare	LEN-64-Bare	LU-50-64-Apt	LU-400-64-Apt
A-50-64-IC	LEN-64-IC	LU-50-64-Civic	LU-400-64-Civic
A-50-64-Robust	LEN-64-Robust	LU-50-64-Comm	LU-400-64-Comm
A-50-64-Sparse	LEN-64-Sparse	LU-50-64-Duplex	LU-400-64-Duplex
A-50-64-Water	LEN-64-Water	LU-50-64-Office	LU-400-64-Office
A-50-64-Woody	LEN-64-Woody	LU-50-64-Park	LU-400-64-Park
A-50-320-Bare	LEN-320-Bare	LU-50-64-Road	LU-400-64-Road
A-50-320-IC	LEN-320-IC	LU-50-64-SF	LU-400-64-SF
A-50-320-Robust	LEN-320-Robust	LU-50-64-Undev	LU-400-64-Undev
A-50-320-Sparse	LEN-320-Sparse	LU-50-64-Utility	LU-400-64-Utility
A-50-320-Water	LEN-320-Water	LU-50-320-Apt	LU-400-320-Apt
A-50-320-Woody	LEN-320-Woody	LU-50-320-Civic	LU-400-320-Civic
A-50-640-Bare	LEN-640-Bare	LU-50-320-Comm	LU-400-320-Comm
A-50-640-IC	LEN-640-IC	LU-50-320-Duplex	LU-400-320-Duplex
A-50-640-Robust	LEN-640-Robust	LU-50-320-Office	LU-400-320-Office
A-50-640-Sparse	LEN-640-Sparse	LU-50-320-Park	LU-400-320-Park
A-50-640-Water	LEN-640-Water	LU-50-320-Road	LU-400-320-Road
A-50-640-Woody	LEN-640-Woody	LU-50-320-SF	LU-400-320-SF
A-400-64-Bare		LU-50-320-Undev	LU-400-320-Undev
A-400-64-IC		LU-50-320-Utility	LU-400-320-Utility
A-400-64-Robust		LU-50-640-Apt	LU-400-640-Apt
A-400-64-Sparse		LU-50-640-Civic	LU-400-640-Civic
A-400-64-Water		LU-50-640-Comm	LU-400-640-Comm
A-400-64-Woody		LU-50-640-Duplex	LU-400-640-Duplex
A-400-320-Bare		LU-50-640-Office	LU-400-640-Office
A-400-320-IC		LU-50-640-Park	LU-400-640-Park
A-400-320-Robust		LU-50-640-Road	LU-400-640-Road
A-400-320-Sparse		LU-50-640-SF	LU-400-640-SF
A-400-320-Water		LU-50-640-Undev	LU-400-640-Undev
A-400-320-Woody		LU-50-640-Utility	LU-400-640-Utility
A-400-640-Bare			
A-400-640-IC			
A-400-640-Robust			
A-400-640-Sparse			
A-400-640-Water			
A-400-640-Woody			

Appendix E: SAS code used to compute the Index of Riparian Integrity (spatial cross-regressive model).

```
proc iml;
*Calculations;
WX = W*X2;
XWX = X||WX;
txwx = XWX`;
xpx = (XWX)` * (XWX);
xpy = XWX` * Y;
est = (inv(xpx)) * xpy;
rows = {1 2 3 4 5 6 7 8 9 10 11 12};
rowsg = {13 14 15};
beta = est[rows, ];
gamma = est[rowsg, ];
*Beta = non-spatial model coefficients, Gamma = spatial model coefficients;
print beta, gamma;
yhat = X*beta + WX*gamma;
*Yhat = model predictions (output);
print yhat;
res = y - yhat;
print res;
ymean = y[:,];
print ymean;
difymean = y - ymean;
SST = difymean[##,];
difyhat = yhat - ymean;
SSE = difyhat[##,];
SSR = SST - SSE;
e = res` * res;
print e;
resvar = sqrt((e)/ (115 - 15));
COV = (inv(XWX` * XWX));
print COV, resvar;
rsquare = SSE/SST;
adj_rsquare = 1 - (1 - rsquare)*(114/(115-15-1));
print rsquare, SST, SSE, difymean, difyhat, y, yhat, ymean;
tgamma1 = (gamma[1,1])/(resvar * sqrt(COV[13,13]));
tgamma2 = (gamma[2,1])/(resvar * sqrt(COV[14,14]));
tgamma3 = (gamma[3,1])/(resvar * sqrt(COV[15,15]));
print tgamma1 tgamma2 tgamma3;
tbeta0 = (beta[1,1])/(resvar * sqrt(COV[1,1]));
tbeta1 = (beta[2,1])/(resvar * sqrt(COV[2,2]));
tbeta2 = (beta[3,1])/(resvar * sqrt(COV[3,3]));
tbeta3 = (beta[4,1])/(resvar * sqrt(COV[4,4]));
tbeta4 = (beta[5,1])/(resvar * sqrt(COV[5,5]));
tbeta5 = (beta[6,1])/(resvar * sqrt(COV[6,6]));
tbeta6 = (beta[7,1])/(resvar * sqrt(COV[7,7]));
tbeta7 = (beta[8,1])/(resvar * sqrt(COV[8,8]));
tbeta8 = (beta[9,1])/(resvar * sqrt(COV[9,9]));
tbeta9 = (beta[10,1])/(resvar * sqrt(COV[10,10]));
```

```
tbeta10 = (beta[11,1])/(resvar * sqrt(COV[11,11]));
tbeta11 = (beta[12,1])/(resvar * sqrt(COV[12,12]));
print tbeta0 tbeta1 tbeta2 tbeta3 tbeta4 tbeta5;
print tbeta6 tbeta7 tbeta8 tbeta9 tbeta10 tbeta11;
*Model fit;
print adj_rsquare;
```