

## **An index of riparian integrity: A GIS-based tool for assessing city-wide riparian function.**

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### **Abstract**

*After 20 years, and three different iterations, the City of Austin has settled on a GIS/remote sensing-based tool for assessing general riparian cover that can be easily calculated and allows for city-wide comparison of floodplain function and prioritization of restoration efforts. The algorithm used in the updated Index of Riparian Integrity breaks the stream network into 10,000 sq ft grid units and incorporates tree canopy, impervious cover, and pervious cover to calculate a qualitative score of basic riparian function at a scale that is practical for understanding how development, the regulatory environment, and resources can be optimized toward healthy urban buffers.*

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### **Introduction**

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 (Groffman et al. 2003; Opperman et al. 2010). Riparian vegetation can reduce erosion by stabilizing bank material or reducing the velocity of water in the channel (Hawley and MacMannis 2019; Hupp and Osterkamp 1996). 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 (Barbour et al. 1999; Stacey et al. 2006; Del Tánago and De Jalón 2011).

The City of Austin (COA) developed the Environmental Integrity Index (EII) methodology to assess stream integrity for all streams in the City's jurisdiction (City of Austin 2002). This EII procedure has been used since 1996 and provides comprehensive biological, physical, and chemical data that includes a visually-based assessment of riparian health at a site-scale, as part of habitat assessment (City of Austin 2002). The COA developed a more robust Riparian Functional Assessment (RFA) procedure in order to

provide a detailed assessment of the riparian zone along creeks (Gonzalez and Richter 2015). While the RFA procedure assesses with high level of detail the riparian function available at a site, it represents a small spatial scale and does not incorporate riparian function throughout a watershed, similar to the EII habitat assessment. Riparian zones can vary greatly within a watershed and many assessments using the RFA methodology would be needed to represent the function of all riparian areas in the city, which would be time consuming, expensive, and impractical since access is limited to most of our stream network due to property being private. Thus, a large-scale planning-level tool was needed to efficiently quantify riparian integrity throughout the city, using available GIS resources.

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). 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). The COA previously created the Index of Riparian Integrity (IRI) as a combination of land use (vector-based polygons or planimetrics) and land cover (grid or pixel-based raster data from aerial photography) which was used to assess basic riparian cover in the Austin area in the past (Scoggins et al. 2013), but it was very time intensive and difficult to reproduce for comparability. The IRI was updated with a new approach to GIS-based riparian assessment which has been developed and tested using a simplified version of the previous approach, where buildings and paved surfaces are represented as impervious cover (IC), tree cover over pervious surfaces is represented by tree canopy (TC), and pervious surfaces without trees (only herbaceous vegetation or bare soil) is represented as pervious cover (PC) A grid-based analysis was done looking at distribution of these 3 types of cover (IC, TC, PC) in the Critical Water Quality Zone (CWQZ) of all of Austin's creeks and applying a scoring criterion that qualitatively assesses each grid. This method is presented along with examples of how it can be applied for prioritization of riparian restoration activities as well as spatial comparisons of riparian quality in Austin's stream network.

## Methods

The methods developed for this approach to riparian resource assessment are based heavily on locally available GIS data and on previous work done looking at City of Austin CWQZs and Floodplains (City of Austin 2013b; Porras et al. 2016; Scoggins 2002, 2005; Scoggins et al. 2013). The process can be broken down into four basic components, which are further detailed below:

1. GIS processing of land cover within a specific buffer area.
2. Creation of hexagon grids that break down branched buffer network into fixed comparable units.
3. Calculation and display of a scoring criteria for each hexagon grid.

### *GIS Processing of layers of land cover and land use (LU/LC) data:*

The GIS processing for the IRI analysis was completed in the ArcGIS Pro environment using the tools provided within the software. The COA maintains three layers used in this analysis. The Impervious Cover layer, the Tree Canopy layer, and a Creek Centerline layer (Figure 1). The Impervious Cover, Canopy, and Creek Centerline layers are based on aerial photography (supplement with LIDAR) and updated and quality checked approximately every 3 years. This is a crucial element for the IRI project as it allows for consistent, comparable monitoring of riparian condition over time. In this report, the 2017 Impervious Cover and the 2014 Canopy layers were used.

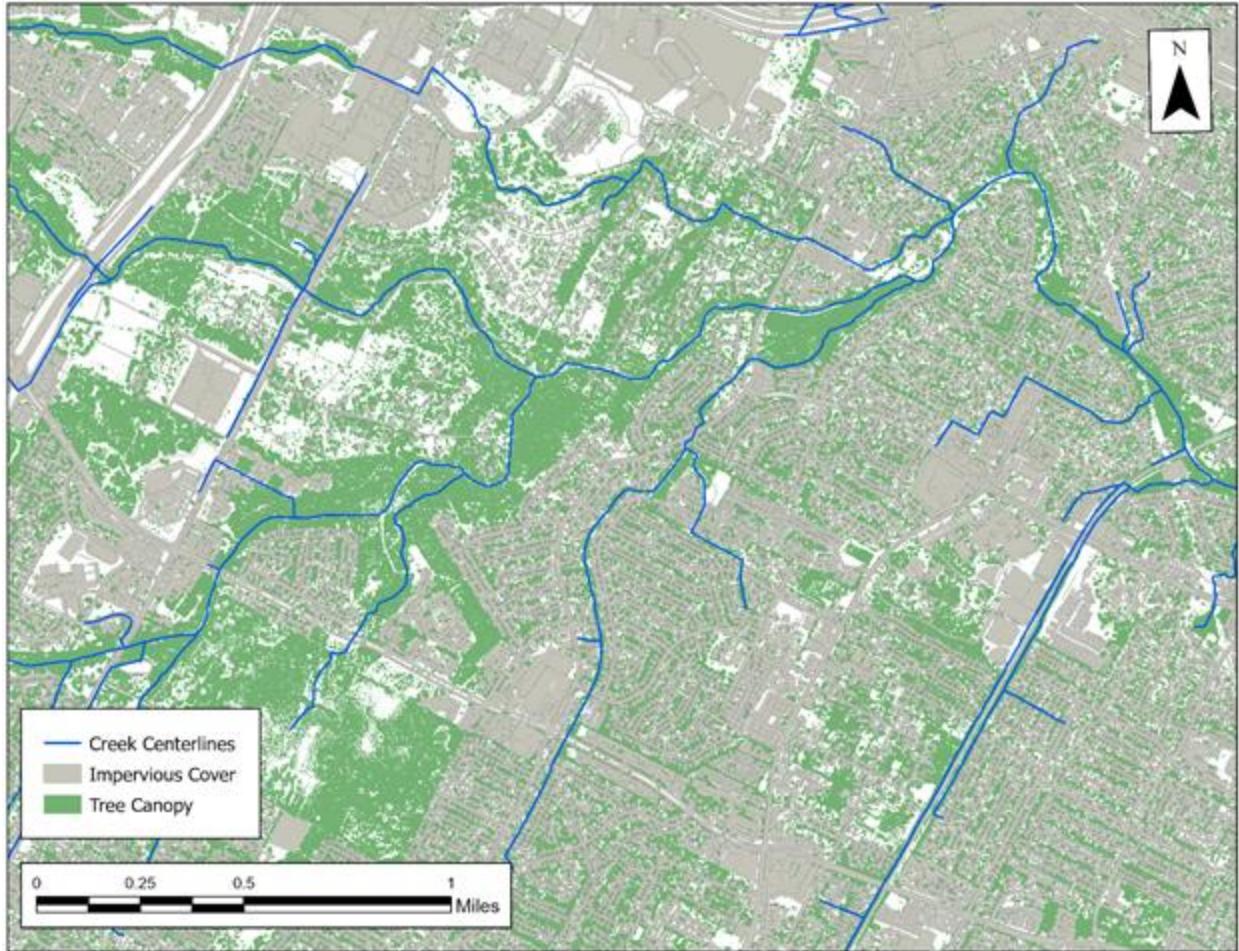


Figure 1. Example map in Austin, TX, showing Creek Centerlines (blue), Impervious Cover (grey) and Tree Canopy generated from aerial photography (green).

Using the Buffer Tool in ArcGIS Pro, each creek centerline was buffered according to the drainage area threshold:

- 0 - 320 AC of Drainage = 100ft Buffer
- 320 - 640 AC of Drainage = 200ft Buffer
- > 640 AC of Drainage = 300ft Buffer

The buffers were dissolved with the Dissolve Tool into 1 polygon (Figure 2).



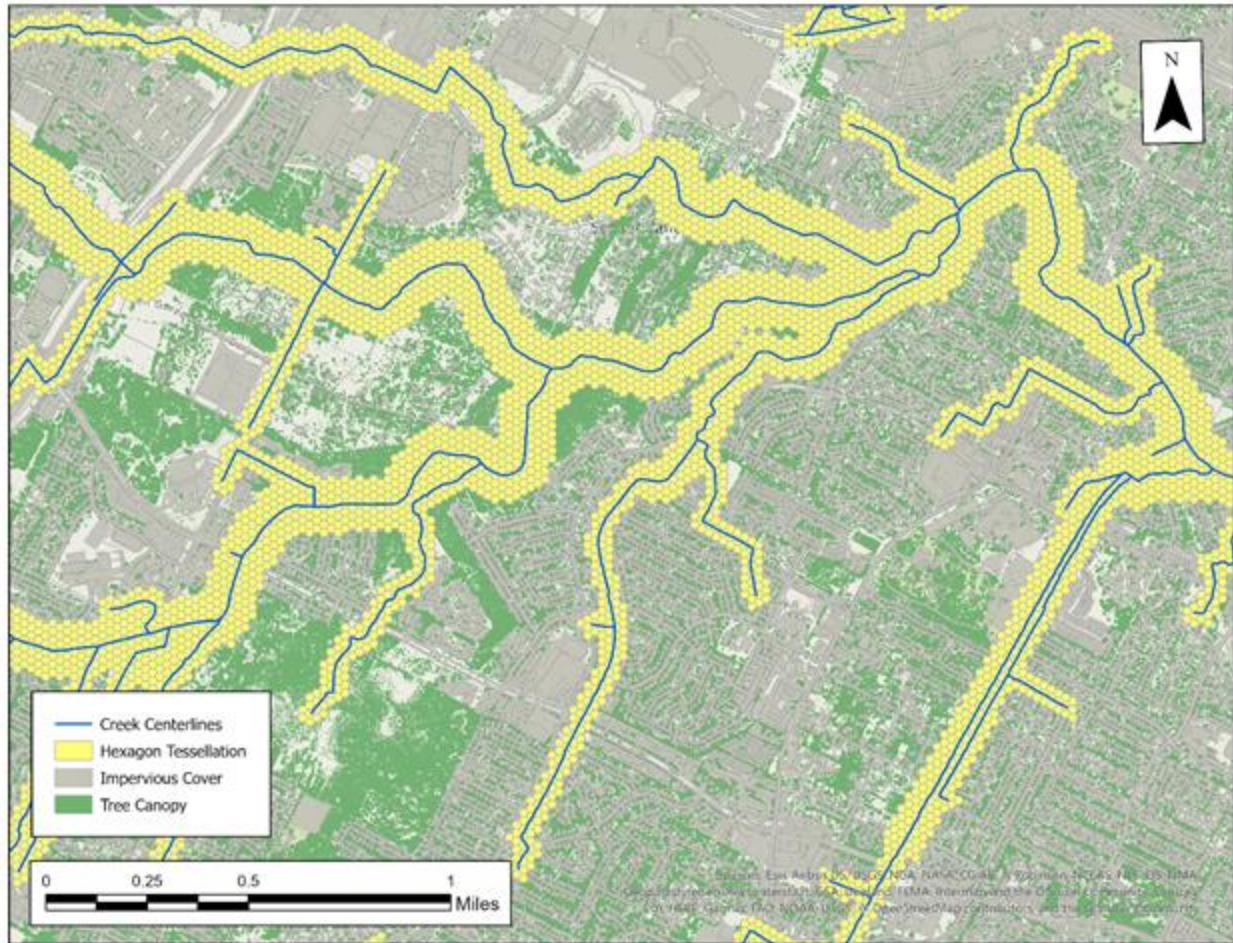
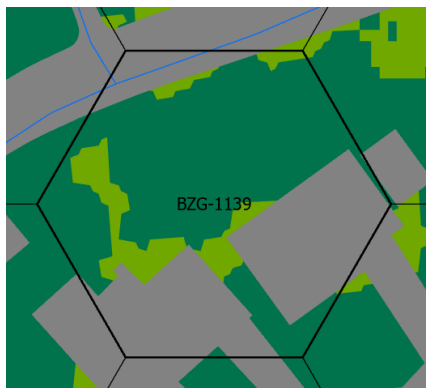


Figure 3. Example map showing 10,000 sq ft hexagonal grid distributed throughout the stream buffer network.

Any hexagons that overlapped waterbodies were erased from the dataset using the Erase Tool. The grid was clipped to the extent of the buffers to match the geometries. Due to the size of the datasets and the processing time, the assumption was made that if land cover was not impervious cover or tree canopy, then it was pervious cover and assumed to be the delta of the area that was not the other two. The land cover of impervious and tree canopy were clipped to the buffers. A union of impervious cover with the buffer was made and a further union of that output was made. This allowed any overlap of impervious and canopy to be privileged as impervious. The remaining area not impervious or tree canopy was coded as pervious. This layer was then intersected using the Tabulate Intersection Tool (Figure 4). This approach resulted in each hexagon containing the three cover categories and associated areas for each (Figure 5).



Figure 4. Example map showing the individual categories of canopy (dark green), impervious cover (grey), and pervious cover (light green) distributed throughout the entire buffer/hexagon network.



Grid ID	Land Cover	Area (sq ft)	%
BZG-1139	Impervious	1994.722	0.20
BZG-1139	Canopy	5031.178	0.50
BZG-1139	Pervious	2974.076	0.30
Sum		9999.976	1

Figure 5. Example grid, BZG-1139, with relative distribution of impervious (grey), canopy (dark green), and pervious (light green) and tabular data output.

*Calculation and display of scoring criteria:*

The IRI aims to characterize any buffer area of land along a water feature for assessment of riparian integrity using compositional analysis. Compositional analysis is useful when the variables in a data set are proportions of a whole and their sum is one (Pawlowsky-Glahn and

Buccianti 2011). Thus, for application to compositional analysis, the IRI components of IC, TC, and PC need to be converted to a proportion by dividing the area of each component in every grid by the total area of that grid. This results in an ordered triple of components for each grid, which can be transformed to a single score. This transformation from a triple of components to a single score is analogous to mapping the triple on a 2-simplex<sup>1</sup> onto a surface (See Figure 6 below). This analogue is helpful for developing the intuition behind the mathematical transformation to a single score.

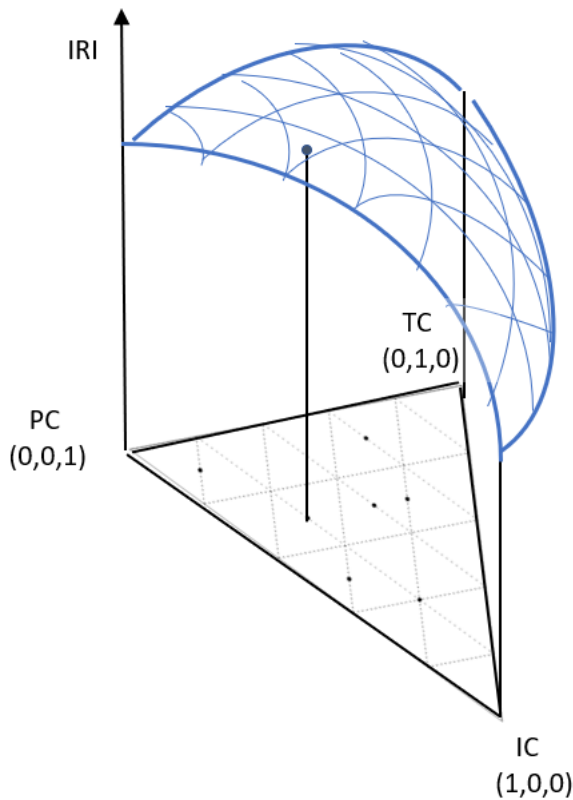


Figure 6. A graphic representation of the triangular simplex mapped onto a surface whose elevation represents the IRI score.

To develop this mathematical transformation, an equation is needed to fit known points on the simplex onto the surface. To start, for the vertex (1,0,0), which indicates a grid with an area of land that is 100% impervious cover, an IRI score of 0 was selected, since this area would have no riparian function. Any grid of land with less than 100% impervious cover would then have a proportionally greater IRI score. Thus, the transformation should be of the form:

$$IRI = X * (1-IC) \tag{Equation 1}$$

In Equation 1, IRI is the score from 0 to 100, IC is the percent impervious cover and X is the remaining unknown coefficients and their corresponding proportions.

<sup>1</sup> A simplex is a generalization of a triangle or tetrahedron into arbitrary dimensions. A 2-simplex denotes a triangle; that is, a simplex in 2 dimensions.

To find X, then, consider the vertices (0,1,0) and (0,0,1), which correspond to grids with areas of land for 100% tree canopy and 100% pervious cover, respectively. IRI scores were assigned per their theoretical functional assessment scores in the COA Environmental Criteria Manual (City of Austin 2013a). Following the functional assessment, an area of land with 100% tree canopy would be given the highest functional assessment score of 100. For an area of land with 100% pervious cover (no tree canopy), a functional assessment score of 55 was assigned. Thus, along the line connecting TC and PC, the IRI score should be proportionally increasing from 55 to 100 as one moves from the PC vertex to the TC vertex. This equation takes the form of:

$$IRI(\text{along TC and PC}) = 100*TC + 55*PC \quad \text{Equation 2}$$

Note that areas where canopy was over the top of impervious cover were recorded as IC within the hexagon grids since impervious cover essentially negates the effect of trees on riparian function. Also note that percent impervious cover is 0 along the line connecting TC and PC.

Given scores for the three vertices in the simplex and combining Equations 1 and 2, an equation can be fit that maps the triple (% cover for TC, IC, and PC) to an IRI score. This equation was determined to be:

$$IRI = (100*TC + 55*PC) * (1 - IC) \quad \text{Equation 3}$$

A representation of this IRI scoring surface, when superimposed on a simplex, is displayed in Figure 7, showing 10-point contours going from light bands on the right with higher scores to dark bands on the left with lower scores. Any triple can be located within the simplex using Equation 3, and thus, be given an IRI score.

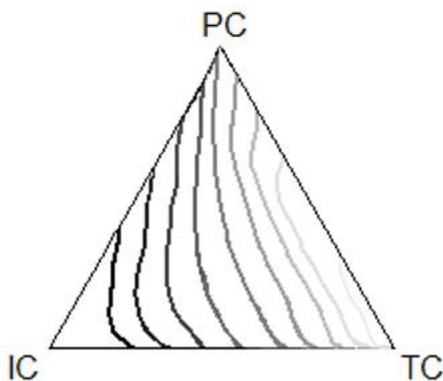


Figure 7. Representation of IRI scoring surface on a simplex, or simplified triangle. Contours display IRI scores on 10-point increments with darker contours signifying lower IRI scores.

Once proportions for the type of cover are calculated for each grid of land in GIS, Equation 3 can be applied within GIS to produce an IRI score. To better visualize the numerical results, a narrative categorical scoring system is assigned to all the grids, grouping the grids into a category according to its value (from Very Bad to Excellent), corresponding to the same system

used for the Environmental Integrity Index (EII) (Table 1). In this way, a triple can be transformed to an IRI score for a grid and then be displayed categorically on a map of the entire buffer network.

Table 1. Coding system applied to IRI results across grids.

IRI Scoring System			
Color Code	Narrative Score	Lower Range	Upper Range
	Excellent	87.5	100
	Very Good	75.0	87.5
	Good	62.5	75.0
	Fair	50.0	62.5
	Marginal	37.5	50.0
	Poor	25.0	37.5
	Bad	12.5	25.0
	Very Bad	0.0	12.5

## Results

Aggregation of hexagon grid scores can be generalized at any larger spatial scale desired. An individual 10,000 sq ft grid with spatially explicit categories is the initial building block (Figure 8).

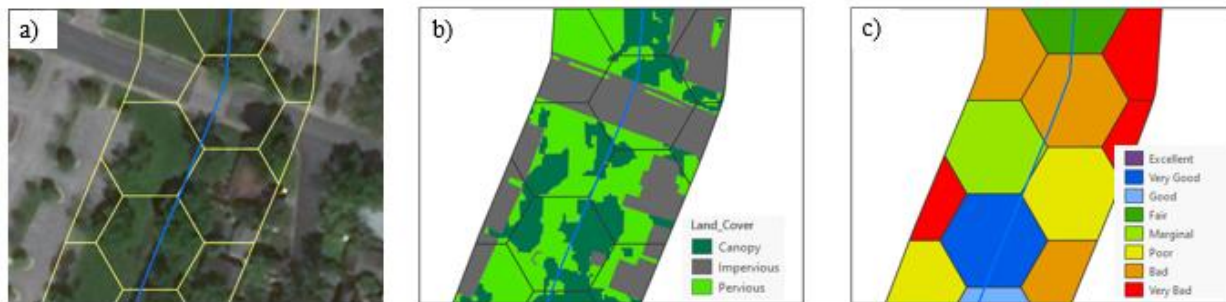
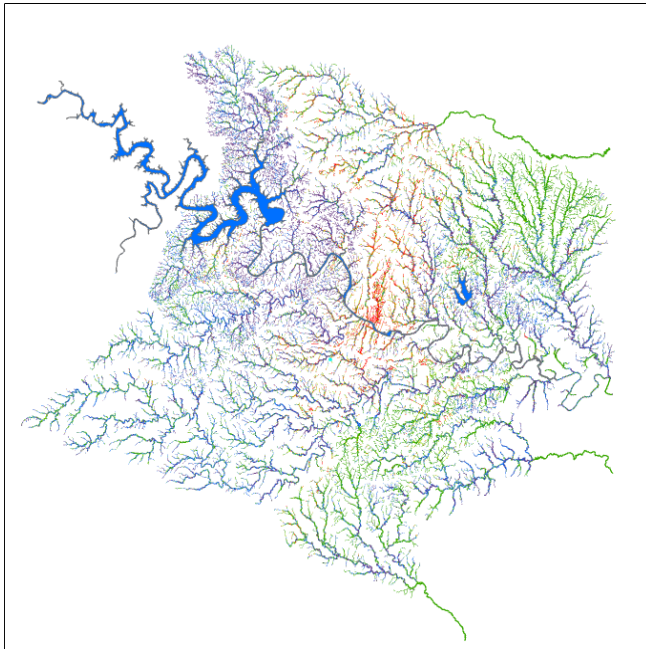


Figure 8. An example stream reach, showing the creek in blue, the CWQZ buffer which in this case is 100 ft on both sides of the creek, and a) the hexagon grids over the aerial imagery, b) the 3 converted components of the IRI (IC, TC, PC) and c) how each grid would be scored using the simplex equation and the narrative EII categories.

With each hexagon's cover data in the buffer network, the IRI score can be calculated for any spatial scale; from the hexagon to the full extent of the network. This is done by simply selecting the applicable hexagons and converting the proportions to an IRI score using Equation 3 above. For example, the IRI scores from this analysis can be calculated at a watershed scale for all Austin jurisdictional watersheds (Table 2). In addition, for planning purposes, summary data can easily be calculated with respect to restoration gaps and goals (Figure 9). For example, total impervious cover area within the CWQZ can be calculated (13,398 acres, 7.20%), as well as total canopy in the CWQZ (82,539 acres, 44.37%) or total number of grids that have an IRI score of Good or better (613,744 grids, 109,430 acres, 58.78 %).

Table 2. The IRI scores can be calculated at any area where land cover is available. This table summarizes the overall scores for all Austin jurisdictional watersheds.

Watershed Name	IRI Score	Description	Watershed Name	IRI Score	Description
Barton Creek	76	Very Good	Huck's Slough	56	Fair
Buttercup Creek	54	Fair	Johnson Creek	27	Poor
Bee Creek	80	Very Good	Little Barton Creek	67	Good
Bear Creek	71	Good	Little Bee Creek	76	Very Good
Blunn Creek	41	Marginal	Lady Bird Lake	28	Poor
Buttermilk Branch	23	Bad	Little Bear Creek	76	Very Good
Boggy Creek	34	Poor	Lake Austin	79	Very Good
Bohls Hollow	88	Excellent	Lake Creek	46	Marginal
Brushy Creek	55	Fair	Lake Travis	79	Very Good
Bear Creek West	85	Very Good	Lockwood Creek	74	Good
Bull Creek	80	Very Good	Little Walnut Creek	37	Poor
Carson Creek	50	Marginal	Maha Creek	64	Good
Country Club East	61	Fair	Marble Creek	66	Good
Country Club West	46	Marginal	North Fork Dry Creek	53	Fair
Cedar Creek	72	Good	Onion Creek	70	Good
Cedar Hollow	92	Excellent	Panther Hollow	86	Very Good
Commons Ford Creek	86	Very Good	Plum Creek	64	Good
Connors Creek	92	Excellent	Rattan Creek	54	Fair
Colorado River	69	Good	Running Deer Creek	74	Good
Cuernavaca Creek	80	Very Good	Rinard Creek	57	Fair
Cottonmouth Creek	64	Good	South Boggy Creek	58	Fair
Cottonwood Creek	58	Fair	South Brushy Creek	57	Fair
Coldwater Creek	94	Excellent	South Fork Dry Creek	59	Fair
Decker Creek	63	Good	Shoal Creek	25	Poor
Dry Creek NE	66	Good	Slaughter Creek	69	Good
Dry Creek East	65	Good	Steiner Creek	86	Very Good
Dry Creek North	65	Good	St. Stephens Creek	58	Fair
Eanes Creek	49	Marginal	Tannehill Branch	38	Marginal
East Bouldin Creek	17	Bad	Turkey Creek	85	Very Good
Elm Creek	63	Good	Taylor Slough North	59	Fair
Elm Creek South	67	Good	Taylor Slough South	50	Marginal
Fort Branch	49	Marginal	West Bull Creek	83	Very Good
Gilleland Creek	64	Good	West Bouldin Creek	34	Poor
Honey Creek	87	Very Good	Wilbarger Creek	67	Good
Hog Pen Creek	86	Very Good	Walnut Creek	57	Fair
Harrison Hollow	87	Very Good	Waller Creek	12	Very Bad
Harper's Branch	18	Bad	Willow Creek	57	Fair
Harris Branch	59	Fair	Williamson Creek	54	Fair



Land Cover	Area acres	%
Canopy	82,539.37	44.34
Impervious	13,398.37	7.20
Pervious	90,218.85	48.46
Total	186,156.60	100
<b>Grids scored Good or better</b>		
Number	613,744	
Area acres	109,430	
%	58.78	

Figure 9. Distribution of the three IRI land covers (Canopy, Impervious, Pervious) and areas that score Good or better for the entire buffer network in all Austin-area watersheds.

At smaller scales, say within a tributary or at a reach scale, IRI scores can assist decision makers prioritize among various units in need of further riparian support. For example, Austin watersheds are often broken into monitoring reaches for our Environmental Integrity Index, and those reaches can easily be scored by applying the scoring equation to the scale desired. The IRI scores for the EII reaches for the upper portions of the Boggy Creek watershed in Central East Austin demonstrate a diversity of riparian condition even within a similar development area, showing conditions of Bad, Poor, Marginal, and Fair (Figure 10a). And at even smaller scales, individual development parcels for example, actual grid scores can illuminate local opportunities for restoration or conservation. The location of a soccer stadium in North Austin sits directly on the headwaters of Little Walnut Creek and demonstrates a diversity of buffer conditions, from Very Bad to Very Good, that could be prioritized to help mitigate the development that occurs (Figure 10b).

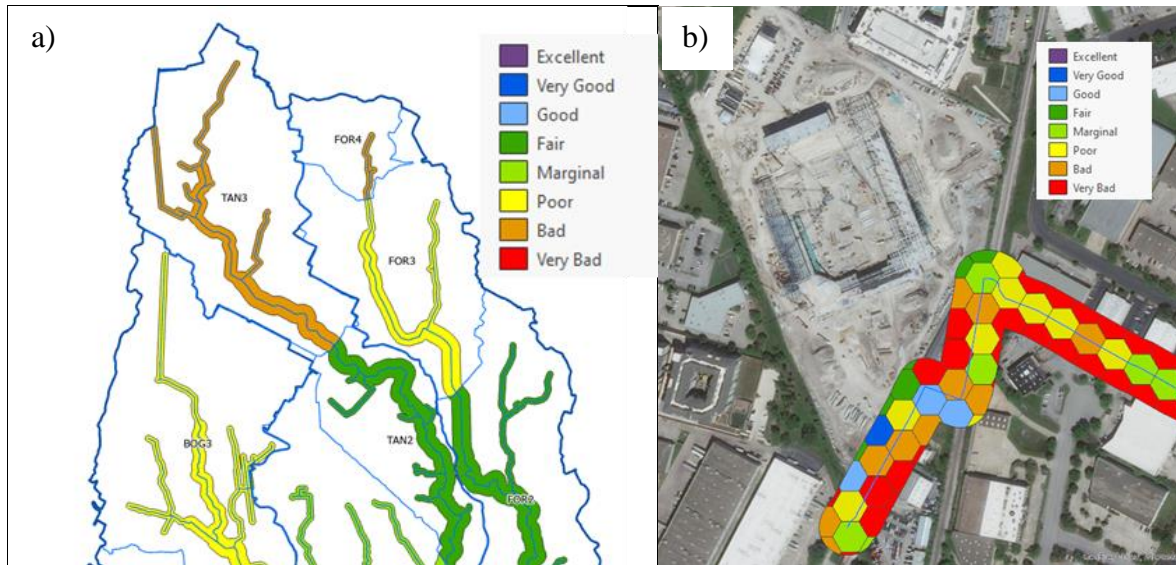


Figure 10. IRI scores distributed at the reach scale at the top of the Boggy Creek watershed (a) and at the parcel and grid scale near a proposed soccer stadium and the headwaters of Little Walnut Creek (b).

## Discussion

This analysis tool has a variety of advantages and limits due primarily to its basis in GIS-generated spatial data. The Watershed Protection Department (WPD) is moving away from reach-based management units, toward grid-based approaches that are much better for modeling and higher-resolution monitoring and prioritization. This IRI tool allows resource managers to look at the entire stream and buffer network with non-biased spatial data at a fairly granular scale (10,000 sq ft grids). This allows for more quantitatively based prioritization systems, better understanding of gaps, both spatially and temporally. For example, WPD has a goal of Good or better EII condition for all of Austin's water resources. With this tool, we can explicitly identify what percent of our stream network meets that criteria for the riparian component (59 percent), and even more importantly, exactly where those grids are located. We can even also develop screening level cost estimates for the different types of restoration that might be necessary. For example, removing impervious cover from the CWQZ (7% of total network) is considered active restoration, and is more costly than restoring pervious cover (48% of total network) that requires passive methods to get to a canopied, functional riparian area.

The City of Austin is currently looking at adopting a 50% canopy goal for the whole city by 2050 with a focus on areas which have lower than average canopy coverage ([Climate Equity Plan](#), in draft). Overall, the CWQZ citywide currently has an average of 44% canopy. The CWQZ can support the Climate Equity plan goal by supporting higher canopy cover with a goal of 100%, given the more hospitable habitat and protected buffer status creek corridors represent for tree establishment and growth. If applied citywide, beyond the creek buffer network, a grid-based approach like the IRI could help more strategically target lower coverage areas or more accurately apply equity-based filters. In addition, because this method is simple and the data very reproducible and comparable, temporal changes can be more accurately tracked, including changes canopy cover over time both within the creek buffer network and also citywide. This

type of approach can be applied to a wide range of scales and costs and benefits more accurately estimated to achieve targeted WPD goals, or broader, city-wide goals.

Limits of this tool are significant, since it is assuming that total canopy is a functioning riparian buffer, which is not always the case. Riparian function is a complex mix of vegetation density, structure, and diversity as well as soil, slope, and hydrologic character. This tool doesn't include any of these measures and is simply a screening level assessment of riparian potential. Especially at the parcel and grid scales, further riparian assessment work would need to be done before restoration or conservation projects were initiated. Other limitations are the quality and frequency of spatial data, especially the impervious cover values and canopy coverage. These values both change with time and with method of assessment, so keeping consistency when calculating IRI scores both spatially and temporally is critical. For example, if aerial photography methods change due to technology or just contractor variability, results in canopy classification methods can result in significant variability (Parmehr et al. 2016).

## **Recommendations**

- Make sure the quality assured IRI data is available and understood by the wide range of potential users, including WPD review staff, DSD review staff, and the development community.
- Include the IRI as a riparian component to the EII program, with an overall goal of 100% canopy cover for the entire CWQZ buffer.
- Review and recalculate IRI every 3 years, based on availability of new aerial photography and derived Canopy Cover layer as well as updated Impervious Cover.
- Analyze for temporal patterns approximately every 6-10 years using consistent comparison methods that will illuminate potential improvements and/or losses in riparian health.
- Utilize the IRI data in a SMART (specific, measurable, achievable, relevant and timely) objective that will help assess progress and more effectively direct resources.
- Incorporate the IRI tool in assessing riparian restoration opportunities, ecological uplift goals to enhance benefits for individual WPD projects (e.g. stream stabilization, water quality retrofits, etc.). For example, depavement options as part of the scope of work, or tree planting beyond the original limits of construction.

## References

- Barbour, M T, J Gerritsen, B D Snyder, and J B Stribling. 1999. 2nd US Environmental Protection Agency Office of Water Washington DC *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition*. U.S. Environmental Protection Agency; Office of Water.  
[http://www.lic.wisc.edu/glifwc/Polymet/SDEIS/references/USEPA\\_2012b.pdf](http://www.lic.wisc.edu/glifwc/Polymet/SDEIS/references/USEPA_2012b.pdf).
- City of Austin. 2002. *Environmental Integrity Index Methodology*. Austin.  
[http://www.austintexas.gov/watershed\\_protection/publications/document.cfm?id=186267](http://www.austintexas.gov/watershed_protection/publications/document.cfm?id=186267)  
(September 12, 2017).
- City of Austin. 2013a. Environmental Criteria Manual *APPENDIX X - FUNCTIONAL ASSESSMENT OF FLOODPLAIN HEALTH*.  
[https://library.municode.com/tx/austin/codes/environmental\\_criteria\\_manual?nodeId=APXXFUASF\\_LHE](https://library.municode.com/tx/austin/codes/environmental_criteria_manual?nodeId=APXXFUASF_LHE) (November 18, 2019).
- City of Austin, WPD. 2013b. *Watershed Protection Ordinance No. 20131017-046*. City of Austin, Watershed Protection Department.
- Gonzalez, Ana, and Aaron Richter. 2015. SR-15-10 *Updated Riparian Functional Assessment, 2014*.
- Groffman, Peter M. et al. 2003. "Down by the Riverside: Urban Riparian Ecology." *Frontiers in Ecology and the Environment*: 315–21.
- Hawley, Robert J., and Katherine R. MacMannis. 2019. "Tree Roots as a Dominant Agent of Streambed Habitat, Profile Pattern, and Grade Control." *Geomorphology* 343: 81–91.  
<https://doi.org/10.1016/j.geomorph.2019.06.021>.
- Hupp, Cliff R., and W. R. Osterkamp. 1996. "Riparian Vegetation and Fluvial Geomorphic Processes." *Geomorphology* 14: 277–95.
- Naiman, R J, and H Decamps. 1997. "The Ecology of Interfaces: Riparian Zones." *Annual Review of Ecology and Systematics* 28: 621–58.
- Opperman, Jeffrey J. et al. 2010. "Ecologically Functional Floodplains: Connectivity, Flow Regime, and Scale." *Journal of the American Water Resources Association* 46(2): 211–26.
- Parmehr, Ebadat G., Marco Amati, Elizabeth J. Taylor, and Stephen J. Livesley. 2016. "Estimation of Urban Tree Canopy Cover Using Random Point Sampling and Remote Sensing Methods." *Urban Forestry and Urban Greening* 20(April 2018): 160–71.  
<http://dx.doi.org/10.1016/j.ufug.2016.08.011>.
- Pawlowsky-Glahn, Vera, and Antonella Buccianti. 2011. *Compositional Data Analysis: Theory and Applications*. John Wiley & Sons.  
<https://pdfs.semanticscholar.org/794b/b9143e2577ce8a2c46e7ee2428240c1dfdac.pdf>.
- Porras, Abel et al. 2016. *Reclaimed Water Irrigation Water Quality Impact Assessment*.
- Richter, Aaron. 2011. *Creation of a Multi-Metric Index for Describing the Environmental Integrity of Austin-Area Lakes*.  
[http://www.austintexas.gov/watershed\\_protection/publications/document.cfm?id=196479](http://www.austintexas.gov/watershed_protection/publications/document.cfm?id=196479).
- Richter, Aaron, and Alex Duncan. 2012. SR-12-12 *Riparian Functional Assessment: Choosing Metrics That Quantify Restoration Success in Austin, TX*. Austin: Watershed Protection Department.
- Scoggins, Mateo. 2002. *Land Use and Land Cover Analysis for Variable Buffer Scales in the Canyon Tributaries*. Austin, Texas.
- . 2005. *An Index of Riparian Integrity for the Austin Area*.  
[http://www.austintexas.gov/watershed\\_protection/publications/document.cfm?id=186257](http://www.austintexas.gov/watershed_protection/publications/document.cfm?id=186257).
- Scoggins, Mateo, Aaron Richter, Jon Meade, and Kathryn Murray. 2013. *An Index of Riparian Integrity for the Austin Area*. Austin Texas.  
[http://www.austintexas.gov/watershed\\_protection/publications/document.cfm?id=206342](http://www.austintexas.gov/watershed_protection/publications/document.cfm?id=206342).
- Stacey, Peter B et al. 2006. *User's Guide for the Rapid Assessment of the Functional Condition of Stream Riparian Ecosystems in the American Southwest*. Wild Utah Project.

- Del Tánago, Marta González, and Diego García De Jalón. 2011. "Riparian Quality Index (RQI): A Methodology for Characterising and Assessing the Environmental Conditions of Riparian Zones." *Limnetica* 30(2): 235–54.
- Weng, Qihao. 2012. "Remote Sensing of Impervious Surfaces in the Urban Areas: Requirements, Methods, and Trends." *Remote Sensing of Environment* 117: 34–49.