GEOSPATIAL ANALYSIS OF RIPARIAN CONDITION IN LOCKHART, TEXAS: AN INVESTIGATION OF THE INDEX OF RIPARIAN INTEGRITY

by

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ABSTRACT

The City of Austin Watershed Protection Department has developed the Index of Riparian Integrity to assess the health of its environmental resources. The Index of Riparian Integrity uses a geographic information system and remotely sensed data to (1) calculate the relative amount of canopy cover, impervious cover, and pervious cover to estimate riparian health and floodplain function and (2) prioritize restoration efforts. The purpose of this study was to assess (1) the application of the Index of Riparian Integrity on a watershed outside of Austin's city limits and (2) the existing condition of the riparian area using the Index of Riparian Integrity in the Town Branch Watershed in Lockhart, Texas. The Index of Riparian Integrity, using the National Land Cover Database layers, gave a representative overview of Town Branch's riparian conditions when compared to the aerial imagery of the area with areas of greater development receiving lower scores and forested areas receiving higher scores. The Index of Riparian Integrity cannot identify more subtle differences between vegetation. All non-canopy vegetation is treated as the same quality, which means that invasive vegetation or mowed lawns receive the same score as high-quality wetland vegetation. This process also cannot capture erosion in a stretch of riparian area that might have otherwise "functional" land uses according to the Index of Riparian Integrity categorization. Due to the resolution of the National Land Cover Database layers used, certain features, like thinner railroads, are not captured in the analysis, which might lead to higher than appropriate Index of Riparian Integrity scores for certain areas of the watershed. While this methodology cannot replace *in situ* riparian assessments, the Index of Riparian Integrity allows decision makers to develop a watershed-wide assessment of its riparian condition in a fraction of the time that it would have taken to do the same in-person.

I. Introduction

Riparian areas are critically important for the health of streams and watersheds (Naiman et al., 1993; Goodwin et al., 1997; Naiman & Decamps, 1997; Poff et al., 1997; Walsh et al., 2005; Alldredge et al., 2014). A riparian area is, simply put, a transition zone between a stream or a lake and the surrounding upland area (Naiman et al., 1993; Naiman & Decamps, 1997). It includes the banks between the low flow elevation and the high flow elevation of the water body and the land between the high flow elevation and the uplands that are away from the influence of elevated water tables and flooding (Naiman & Decamps, 1997). These transition zones serve as habitat for sensitive species of flora and fauna, help to slow water draining to the stream and increase infiltration into soils, and help to filter out pollutants that may be in the water draining to the stream (Naiman et al., 1993; Naiman & Decamps, 1997; Goodwin et al., 1997).

Although riparian zones are critical to the proper functioning of streams and watersheds, they are often threatened and degraded by human activity (Gregory et al., 1991; Kauffman et al., 1997; Poff et al., 1997; Walsh et al., 2005; Alldredge et al., 2014). Deforestation, the increase of agricultural land, and the overgrazing of remaining riparian vegetation are just a few examples of human activities threatening riparian health. Increasing urbanization of previously open land introduces fertilizers, nutrients, and fecal coliform bacteria such as *E. coli* into stream systems and decreases the amount of time it takes for water to enter a stream system, leading to increased flows and erosion (Poff et al., 1997; Walsh et al., 2005; Alldredge et al., 2014).

Due to the critical and threatened nature of these areas, riparian restoration projects are conducted to mitigate the effects of human activity; improve or preserve aquatic habitat quality; and protect people, property, and the environment from any hazards that might occur as a result of impairment (Kauffman et al., 1997). Centuries of human development have fundamentally altered stream function in many areas, creating disordered systems that are unable to maintain the natural regimes that support the ecosystem services that they provide (Poff et al., 1997; Grayson et al., 1999; Walker et al., 2007; Wohl & Merritts, 2007; Rubin et al., 2017; Savopoulou et al., 2017; Wohl, 2019). Restoration projects have become a way for governments and practitioners to ameliorate this manufactured disequilibrium to encourage the development of healthier, safer, more resilient streams in the face of increased development (Kondolf, 1995; Kondolf & Micheli, 1995; Alexander & Allan, 2007; Hobbs et al., 2007; Kondolf et al., 2007).

Restoration projects can take on many different forms. They can consist of stream reach-scale engineering projects that use heavy equipment to completely transform a dysfunctional stream into a reconstructed version of a "natural" stream, also known as active restoration (Kauffman et al., 1997, Palmer et al., 2005; Duncan, 2012). Restoration projects can also be lower impact projects such as passive restoration (Kauffman et al., 1997; Palmer et al., 2005; Duncan, 2012) which includes spreading native seeds or implementing livestock grazing management (Duncan, 2012; Alldredge et al., 2014). Riparian restoration projects are becoming increasingly popular in stream types ranging from agricultural (George et al. 2011; Alldredge et al., 2014) to highly urbanized (Grayson et al., 1999; Duncan, 2012). With the time and resources being devoted to identifying, designing, and implementing these projects, it is important for practitioners to know what their true goals are and to fully understand the consequences of their restoration activities are having on any given stream system.

The Central Texas region is no exception to human-caused degradation of riparian areas and consequent restoration activities. Austin-Round Rock-Georgetown and San Antonio-New Braunfels were the fourth and eighth metropolitan areas with the greatest numeric population growth in the country in 2021, respectively (U.S. Census Bureau, 2022a). This influx of people is coupled with increased commercial and residential development, which contribute to decreased infiltration into soils and increased stormwater runoff (Miller et al., 2014), which, in turn, lead to water quality degradation due to pollutants entering streams, increased flooding, and increased erosion (Lee et al., 2012).

An example of a Central Texas city's response to mitigate human impacts on the environment is the City of Austin's Watershed Protection Department. This organization, and others like it throughout the Central Texas region, help reduce the impacts of flooding, erosion, and water pollution by managing the creeks and drainage systems within their jurisdiction (City of Austin Watershed Protection Department, 2022). Many different programs operate within the Watershed Protection Department, including Creek Flooding, Local Flooding, Erosion Control and Stream Restoration, Field Operations, Stormwater Management, and Creekside Restoration (which deals specifically with restoring the health and function of riparian buffers) (City of Austin Watershed Protection Department, 2022).

The Watershed Protection Department has developed its own indices to assess the health of its environmental resources. One is the Index of Riparian Integrity by Scoggins et al. (2021). The Index of Riparian Integrity uses a geographic information system and remotely sensed data to (1) calculate the relative amount of canopy cover, impervious cover, and pervious cover to estimate riparian health and floodplain function and (2) prioritize restoration efforts (Scoggins et al., 2021). By using this index to estimate the function of Austin's riparian zones, the Watershed Protection Department is able to target the areas that have the greatest need for restoration and will generate the greatest amount of benefit for their respective watersheds. Although the Index of Riparian Integrity has apparently served Austin well, no one to my knowledge has applied the methodology outside of Austin. Accordingly, no one to my knowledge has evaluated whether or not the methodology could be applied outside Austin.

One Central Texas community that is currently experiencing the effects of increased population and development is Lockhart in Caldwell County. Originally known for its prolific barbecue culture, Lockhart has seen unprecedented population growth in the last decade thanks to the opening of the Texas 130 tollway in 2012 (Wear, 2012) and the city's business-friendly nature that has attracted people looking to escape a traffic-congested Austin (Ellis & Hughes, 2021). Because of Lockhart's "moderately priced housing market," (Novak, 2022) homebuyers fleeing Austin's high cost of living can "get more for their money" (Novak, 2022). This increase in demand for housing has put a strain on Town Branch, the stream that flows through the town (City of Lockhart and Nueces River Authority, 2018). Coupled with existing widespread agricultural land use, this increase in development has contributed to the elevated levels of *E. coli* and nitrate and low levels of dissolved oxygen in the Town Branch Watershed (City of Lockhart and Nueces River Authority, 2018). Even though the Plum Creek Watershed Partnership publishes a biennial update to its Plum Creek Watershed Protection Plan, no additional reporting or monitoring has been published on the status of the restoration project or the grow zones.

The purpose of this study is to assess (1) the application of the Index of Riparian Integrity on a watershed outside of Austin's city limits and (2) the existing condition of Town Branch's riparian area using the Index of Riparian Integrity. My hypotheses are (1) that the Index of Riparian Integrity can provide an accurate overview of the riparian health of Town Branch since it is located in a similar ecoregion for Austin and (2) that, given the presence of agriculture and development in the watershed, more than 50 percent of the existing riparian buffer in Town Branch watershed will have “Very Bad” to “Marginal” Index Riparian Integrity scores.

By examining the current condition of the riparian area throughout the Town Branch watershed using the Index of Riparian Integrity, I also highlight areas of the stream that would benefit from riparian restoration. Developing a database of riparian conditions throughout the entire watershed will identify opportunities to guide riparian restoration projects in the future.

II. Background

The Town Branch Riparian Restoration Project is located on the Town Branch tributary in Lockhart, Texas. Lockhart is the county seat of Caldwell County in Central Texas (~48 kilometers [30 miles] south of Austin) and has an estimated population of 14,379 (U.S. Census Bureau, 2022b).

The city of Lockhart is in the Northern Blackland Prairie Ecoregion (Ecoregion 32a), which is a tallgrass prairie characterized by dark, fine clay soils that are known for being incredibly fertile (Griffith et al., 2007). The ecoregion was historically dominated by little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), yellow Indiangrass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*), but, presently, large areas are used for cropland and pasture and forage area for livestock, while areas of the ecoregion are becoming increasingly urbanized.

The region's riparian areas are characterized by forests dominated by bur oak (*Quercus macrocarpa*), Shumard oak (*Quercus shumardii*), sugar hackberry (*Celtis occidentalis*), elm (*Ulmus spp.),* ash (*Fraxinus spp*.), eastern cottonwood (*Populus deltoides*), and pecan trees (*Carya illinoinensis*) (Griffith et al., 2007). The Northern Blackland Prairie was historically dependent on wildfires and bison herbivory, but with the extirpation of bison from the region and the modern suppression of wildfires, the encroachment of woody vegetation is increasingly common in the ecoregion (Griffith et al., 2007).

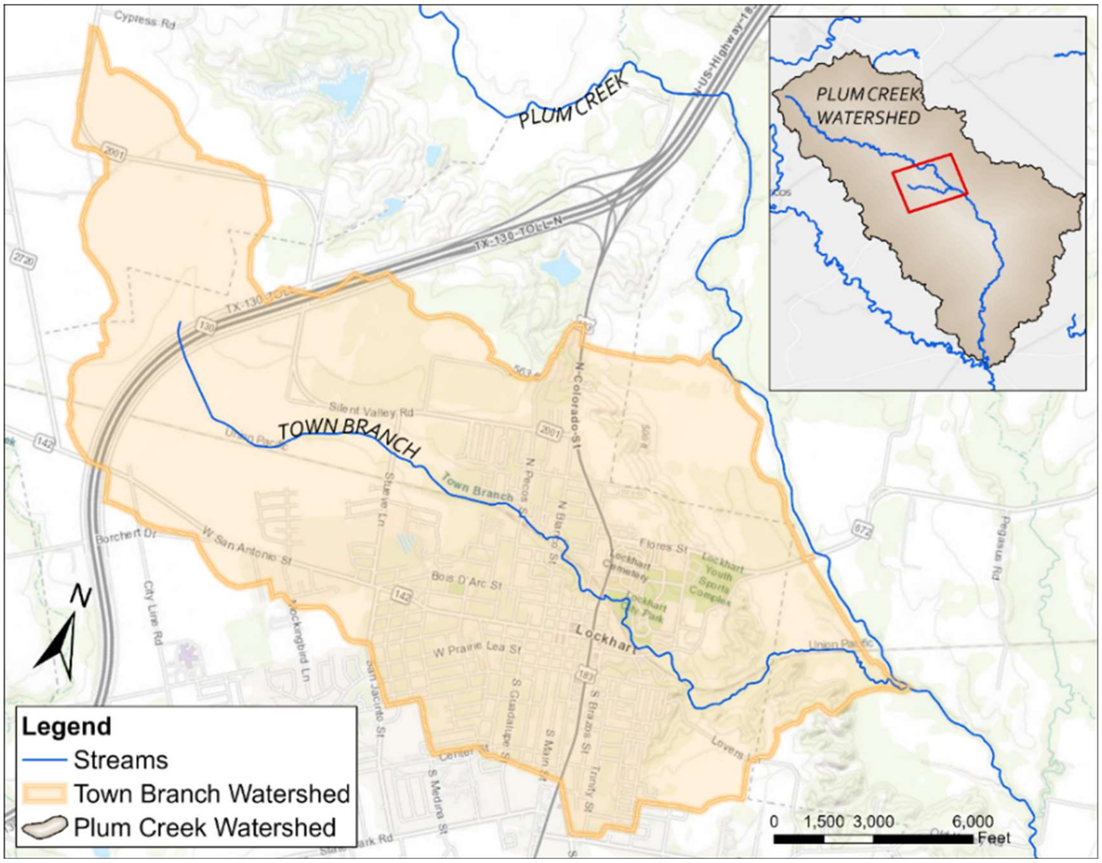


Figure 1. Town Branch Watershed and its location within Plum Creek Watershed.

The Town Branch Riparian Restoration Project is located on Town Branch, a tributary to Plum Creek, which drains into the San Marcos River and eventually to the Guadalupe River (Figure 1). Plum Creek has a drainage area of approximately 1,208 square kilometers (397 square miles), with its headwaters near Kyle and Buda and its confluence with the San Marcos River north of Palmetto State Park. Town Branch has a drainage area of approximately 16.2 square kilometers (6.25 square miles) and has its headwaters northwest of Lockhart, just north of State Highway 130 (Figure 1). The creek then flows southeast for approximately 8.45 kilometers (5.25 miles) through Lockhart to its confluence with Plum Creek.

Plum Creek has been listed as impaired due to *E. coli* concentrations since 2004 (Berg et al., 2008). In 2008, the Plum Creek Watershed Partnership, in collaboration with Texas A&M AgriLife Extension Service, the Guadalupe-Blanco River Authority, the Texas State Soil and

Water Conservation Board, the Texas Commission on Environmental Quality, and the United States Environmental Protection Agency, published the Plum Creek Watershed Protection Plan (Plan) with the purpose of improving the water quality of Plum Creek and its tributary reaches (Berg et al., 2008). The Plan, along with its biennial updates, serves as a “stream restoration guidebook,” that will help stakeholders achieve long-term goals in the Plum Creek Watershed, such as the reduction of fecal coliform bacteria and nutrient concentrations throughout the watershed (Dornak 2014).

The Plan and its updates serve as progress reports on the implementation efforts, analyses of any water quality data that were collected to determine any progress made towards water quality goals, and to communicate any modification to the Plan’s goals and strategies that might have developed (Berg et al., 2008; Dictson and McFarland 2012; Dornak 2014; Plum Creek Watershed Partnership 2018, 2020, 2022).

The Plan identified *E. coli*, phosphorus, and nitrate level reduction targets for the upper, middle, and lower Plum Creek watershed (Berg et al., 2008). Strategies discussed to meet these reduction targets consist of urban stormwater and nonpoint source pollution reduction through the implementation of stormwater control measures and public outreach, wastewater and industry-based pollution mitigation through upgrades to sewer systems and overflow management systems throughout the watershed, and agricultural nonpoint source pollution reductions through the implementation of voluntary water quality management plans with site-specific goals for each participating farm (Berg et al., 2008). Other strategies discussed in the Plan include feral hog management, public education and outreach in both rural and urban communities, and regular water quality testing throughout the watershed (Berg et al., 2008). The Plan was recently updated in 2020 and showed elevated levels of *E. coli*, nitrogen nitrate, and phosphorus at all monitoring locations in Lockhart (Figure 2; Plum Creek Watershed Partnership, 2020).

Figure 2. Sign posted along Town Branch warning of increased risk of illness due to increased fecal coliform bacteria.

The Town Branch Riparian Restoration Project began in 2018 with a Texas Commission on Environmental Quality and U.S. Environmental Protection Agency funded riparian evaluation to document existing riparian conditions and identify opportunities for improvement in riparian health and condition (City of Lockhart and Nueces River Authority, 2018). The riparian evaluation study area consisted of a ~91.4-meter (300-foot) buffer on each side of Town Branch and a ~45.7-meter (150-foot) buffer on each side of an unnamed tributary to Town Branch, totaling approximately 716,300 square meters (177 acres). The study area, including the unnamed tributary, was divided into five separate reaches: Headwater Reach, Conservation Reach, Urban Trail Reach, City Park Reach, and Union Pacific Reach (Figure 3). The reaches were evaluated using a bull's eye riparian evaluation method, which considers ten factors on a qualitative basis (City of Lockhart and Nueces River Authority, 2018). These factors are indicators of riparian function and include active floodplain, energy dissipation, new plant colonization, stabilizing vegetation, age diversity, species diversity, plant vigor, water storage, bank and channel erosion, and sediment deposition.

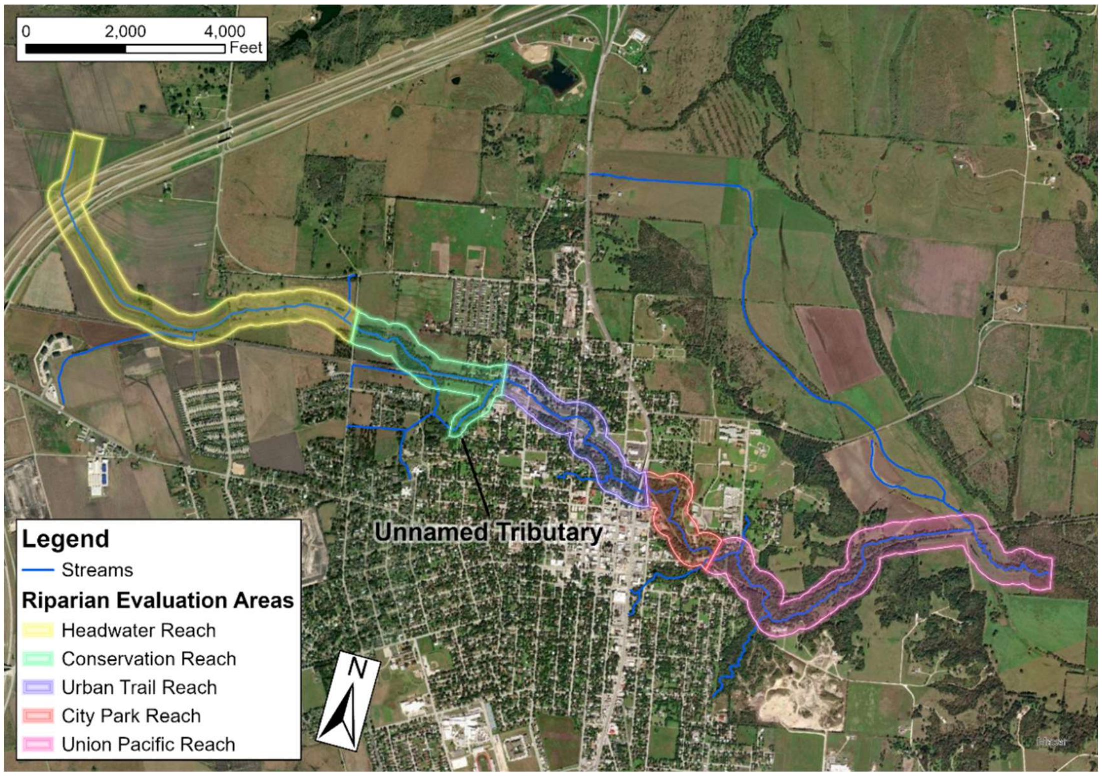


Figure 3. Location of the five study reaches included in the Town Branch riparian evaluation with streamlines based on contours and aerial imagery (adapted from City of Lockhart and Nueces River Authority, 2018).

In the Headwater Reach, identified riparian enhancement opportunities include incentivizing the growth of tall riparian vegetation along agricultural ‘drain-ways,’ establishing riparian grazing setbacks to encourage regrowth, preserving an off-channel pool that was identified during field observations, and replacing or repairing a crossing at Stueve Lane (City of Lockhart and Nueces River Authority, 2018; Figure 4; Table 1). Riparian enhancement opportunities within the Conservation Reach, which included the unnamed tributary, were establishing riparian grazing setbacks to encourage regrowth, encouraging creek-side residents to allow for sufficient riparian vegetation to re-establish, setting back mowing on city-owned or maintained property by creating “no mow” zones to encourage regrowth of riparian vegetation, and preserving a tributary head pool observed near Medina Street during field activities (City of Lockhart and Nueces River Authority, 2018; Table 1).

Figure 4. Under-sized culvert, debris caught in fence, and chute cut-off leading to off-channel pool at crossing at Stueve Lane.

Riparian enhancement opportunities identified within the Urban Trail Reach were setting back mowing on City-owned or maintained property by creating “no mow” zones to encourage regrowth of riparian vegetation, making improvements or corrections to a cemented drainage system tie-in with the reach in order to cease or slow erosion, adjusting stream crossings to allow for the conveyance of water and sediments, implementing an invasive vegetation control program, working with the railroad to establish a permanent silt-control structure, and reconstructing pedestrian recreational trails with a narrower footprint and/or pervious materials. In the Union Pacific Reach, identified riparian enhancement opportunities were incentivizing riparian management with landowners along an impaired section of the reach and encouraging nearby properties owners to continue responsible riparian stewardship (City of Lockhart and Nueces River Authority, 2018; Table 1).

Riparian enhancement opportunities along the City Park Reach include setting back mowing on City-owned or maintained property by creating "no mow" zones to encourage regrowth of riparian vegetation, allowing vegetation to grow between and around old concrete conduits that run throughout the pond and removing remnants of a concrete same and removing invasive vegetation in the area (Figure 5), reconstructing pedestrian recreational trails with a narrower footprint and/or pervious materials, and encouraging nearby properties owners to continue responsible riparian stewardship and engaging with the public during the riparian restoration and recovery process (City of Lockhart and Nueces River Authority, 2018; Table 1).

Figure 5. Algae, invasive plants, trash, and concrete-line channels result in impairments in Town Branch's Urban Trail Reach.

Table 1. Riparian Hindrances and Enhancement Opportunities Identified During the 2018 Riparian Assessment (City of Lockhart and Nueces River Authority, 2018).

Reach	Riparian Hindrances	Riparian Enhancement Opportunities
Headwaters Reach	• Mowing in the riparian area and creek channel. • Prolonged livestock grazing in the creek. • Poorly designed road crossing at Stueve Lane.	1. Work with landowners to incentivize growing tall riparian vegetation along existing "grassed drain-way" above and immediately below Hwy 130 and along other observed drainage courses. 2. Work with and incentivize owners/operators of the grazing lands above Stueve Lane to temporarily restrict livestock access to the creek and riparian area, allowing it to recover. 3. Consider ways to ensure preservation of the off-channel pool at the corner of Stueve Lane and the railroad. 4. Consider the replacement and/or repair of Stueve Lane crossing.
Conservation Reach	• Mowing and farming too close to the creek. • Prolonged grazing concentrations in the creek. • Artificial manipulation of banks, channels, or sediments. • Physical alteration of floodplain.	1. Work with landowners to incentivize an increase in the setback of farming and temporarily restrict livestock access to the creek while the riparian area is allowed to recover. 2. Educate and encourage the creek-front residential property owners along Tanks Street to give the creek as much flood-room as possible and allow riparian vegetation to grow. 3. On City-owned or controlled lands along the tributary drainage channel, set back mowing to the extent tolerable by the public and provide public education for the change. 5. Consider ways to preserve the tributary head pool near Medina Street.
Urban Trail Reach	• Manicured and altered residential or park landscapes nest to the waterway. • Mowing too close to the creek. • Artificial manipulation of banks, channel, or sediments. • Poorly designed road crossing and drainage facilities. • Physical alteration of floodplain.	1. On City-owned or controlled lands along the creek, set back moving to the extent tolerable by the public. Provide public explanations for the change via signage, kiosks, news stories, etc. 2. Take steps to stop or slow erosion and to avoid an extreme and widespread condition. 3. Reconstruct or adjust stream crossings to allow for sufficient passage of sediment and water and align culverts directly in the stream channel at the grade of the channel. 4. Consider implementing a thoughtful and [through] *Arundo donax* (and possibly Elephant ear) control program beginning with the uppermost section of the urban trail reach. 5. Work with the railroad to secure a permanent vegetative, silt-control structure to slow, spread, and filter runoff from their material storage yard before it enters to creek, or relocate storage site away from the creek. 6. When possible, reconstruct pedestrian trails in a narrower footprint using previous material and a meandering pattern. 7. Educate, encourage, and validate the creek-front residential property owners between Commerce St and the railroad for their continued good riparian stewardship. 6. Find ways to engage the public, especially the youth, in the riparian recovery process along the urban trail reach of Town Branch.
Union Pacific Reach	• Farming too close to the creek. • Prolonged livestock grazing in the creek area. • Artificial manipulation of banks, channel, or sediments.	1. Work with landowners to incentivize a riparian management area along 0.6-kilometer (0.4-mile) segment where function is impaired. 8. Educate, encourage, and validate the riparian property owners and the railroad company for their continued good riparian stewardship.

Table 1 (cont.) Riparian Hindrances and Enhancement Opportunities Identified During the 2018 Riparian Assessment (City of Lockhart and Nueces River Authority, 2018).

Reach	Riparian Hindrances	Riparian Enhancement Opportunities
City Park Reach	• Manicured and altered residential or park landscapes next to the waterway. • Mowing too close to the creek. • Artificial manipulation of bank, channel, or sediments. • Poorly designed road crossing and drainage facilities.	1. On City-owned or controlled lands along the creek, set back moving to the maximum extent tolerable by the public. Provide public explanations for the change via signage, kiosks, news stories, etc. 2. The old concrete conduits that run across the park may be treated by allowing riparian vegetation to grow up between and around them, thus helping to slow and clean runoff before it enters the creek. 3. Remove remnants of the concrete dam from the channel and treat Arundo at the dam location with herbicide, being careful not to disturb and spread the invasive plant further. 4. When possible, reconstruct pedestrian trails in a narrower footprint using previous material and a meandering pattern. 5. Educate, encourage, and validate the creek-front residential property owners encouraging them to preserve the natural condition of their creek-front lots. 6. Find ways to engage the public, especially the youth, in the riparian recovery process along the City Park reach of Town Branch.

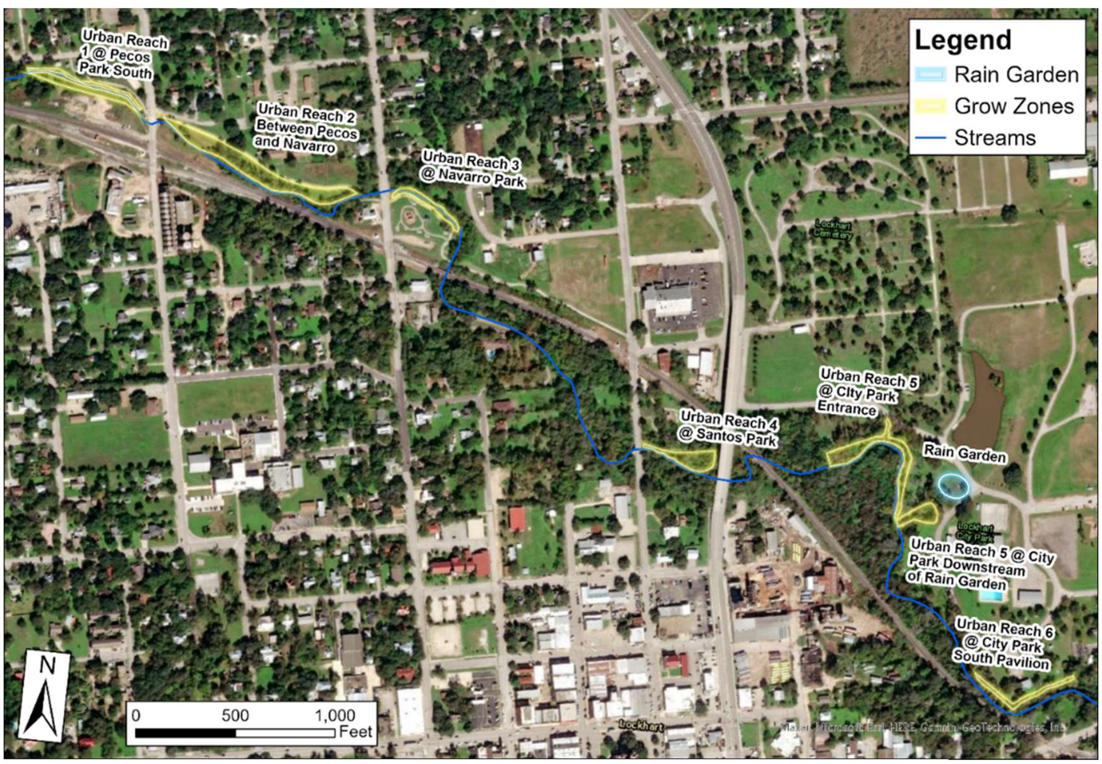


Figure 6. Map of the Town Branch Riparian Restoration Project area in Lockhart, TX.

Construction of the Town Branch Riparian Restoration Project took place from May 4–6, 2020 (City of Lockhart and Nueces River Authority, 2020a, b). The project consisted of the construction of a ~370-square meter (~4,000-square foot) raingarden in City Park (City of

Lockhart and Nueces River Authority, 2020a) and the establishment of six riparian best management practices known as grow zones along the Urban Trail and City Park reaches of Town Branch, totaling about 9,834 square meters (2.43 acres) (Figure 6; Figure 7; City of Lockhart and Nueces River Authority, 2020b). The purpose of these grow zones is to ameliorate effects of manicured and mowed residential landscapes, mowing too close to creek, and the artificial manipulation of the channel and its banks by establishing a mowing setback to restore and retain a buffer with natural vegetation to maintain a degree of riparian function. Eastern gamma grass (*Tripsacum dactyloides*) and switchgrass (*Panicum virgatum*) seedlings were planted in the grow zones because of their ability to withstand floods and promote stability (City of Lockhart and Nueces River Authority, 2020b).

Figure 7. Urban Reach 4 at Santos Park grow zone (left, right) with signage posted at each grow zone area (middle).

As of February 2023, no additional riparian restoration improvements have been planned or completed and no additional projects have been announced publicly. Even though the Plum Creek Watershed Partnership publishes a biennial update to its Plum Creek Watershed Protection Plan, no additional reporting or monitoring has been published on the status of the restoration project or the grow zones.

III. Literature Review

This project draws on and contributes to two bodies of literature: (1) riparian buffers' importance to the functioning of streams and (2) methodological approaches for assessing riparian condition and restoration opportunities.

III.I. Riparian Buffers' Importance to the Functioning of Streams

It is well-established in the literature that human modifications to the landscape have had negative effects on the condition of streams and rivers (Naiman & Decamps, 1997; Poff et al., 1997; Walsh et al., 2005; Bêche et al., 2009; Franklin et al., 2009; Allred & Gary, 2019). The literature shows just how crucial the existence of a robust riparian buffer is to the health of a watershed. Deforestation of riparian areas and/or reduction of wetland ecosystems related to human land use change have been shown to decrease water quality (Sweeney et al., 2004) and reduce a system's ability to withstand large volumes of water as readily (Franklin et al., 2009; Allred & Gary, 2019). Even human responses to natural hazards like floods (Allred & Gary, 2019) or droughts (Bêche et al., 2009) can affect the form and function of stream systems. It has been shown that engineered responses to flooding, such as dams and levees, alter the natural flow regime and habitat of streams (Franklin et al., 2009) and human responses to drought conditions, like increased withdrawal of surface water for agricultural use, can result in habitat loss and flow reductions, which affect the health of the streams and the aquatic species that call them home (Naiman & Decamps, 1997; Poff et al., 1997; Bêche et al., 2009).

Walsh et al. (2005) introduced the concept of the "urban stream syndrome" to describe the widespread systemic issues exhibited by many urban streams, including a flashier hydrograph, elevated concentrations of nutrients and contaminants, altered channel morphology and stability, reduced biotic richness with the increased dominance of more tolerant species, and reduced baseflow and increased suspended sediment (Figure 8), both of which might not always be present.

Figure 8. Examples of impairments characteristic "urban stream syndrome" (Walsh et al., 2005) throughout Town Branch.

Climate change-related phenomena such as more severe droughts and floods also threaten the condition of modern stream systems. Bêche et al. (2009) discuss the impacts that drought has on the habitat and water quality in freshwater systems. Refugia for fish and invertebrate species are likely to be reduced or eliminated during periods of drought, and systems can see a marked reduction in flow and an increase in conductivity, which is used as an analog to measure the concentration of dissolved solids or metals in a body of water (Ahmad et al., 2021). This reduction in habitat and colonization opportunities for species that rely on higher, colder flows and a decrease in water quality can affect the abundance of sensitive aquatic species and even result in the disappearance of certain local species from a system during periods of drought (Poff et al., 1997; Bêche et al., 2009).

III.II. Methodological Approaches for Assessing Riparian Health and Restoration Goals

The analysis of riparian function and riparian restoration projects encourages a wide array of approaches. Many studies assessing riparian restoration rely heavily on quantitative methods for their analysis (Purcell et al., 2007; Alberts et al., 2018; Hausner et al., 2018). Quantitative methods used in the field include taking measurements of site characteristics, such as vegetation type and cover or canopy cover (Purcell et al., 2007; Alberts et al., 2018). These techniques require certain tools, such as quadrats for measuring vegetation (Purcell et al., 2007) or densiometers for measuring percent canopy cover (Alberts et al., 2018). Other methods used in the field involve gathering samples to analyze in a laboratory setting. Alberts et al. (2018) provided excellent examples of collecting benthic organic matter and macroinvertebrates, as well as water samples, to measure pH, conductivity, and nutrient concentrations.

While riparian assessments have historically been restricted to measurements taken in the field, Hausner et al. (2018) introduced a novel and completely remote method of riparian restoration assessment by comparing publicly available Landsat Normalized Difference Vegetation Index (NDVI) datasets and total water year precipitation data for pre- and post-restoration. Using qualitative methods in riparian restoration assessment can also produce valuable information for consideration.

Using geographic information systems (GIS) to assess riparian area conditions is becoming increasingly common. Many of these geospatial riparian assessment protocols employ land use and land cover datasets and some form of imagery (such as National Agriculture Imagery Program [NAIP], Landsat, satellite images, and Google Earth) in their analyses as an analog for riparian condition assessments conducted *in situ* (Guida-Johnson & Zuleta, 2017; Brogna et al., 2018; Batbayar et al., 2019; Akturk et al., 2020). Most examples for geospatial riparian assessments used metrics that were applied to environmental or ecological condition or restoration potential of a given riparian area (Brogna et al., 2018; Batbayar et al., 2019; Akturk et al., 2020), while one novel example employed both ecological and socio-environmental criteria to allow for the "consideration of citizens, both as beneficiaries and potential impacts to rehabilitation," (Guida-Johnson & Zuleta, 2017) in their GIS-based riparian restoration planning tool.

A common feature of most of these geospatial riparian assessment tools is their focus on vegetation type, specifically tree canopy (Brogna et al., 2018: Batbayar et al., 2019; Akturk et al., 2020). These studies all cite the importance of a healthy, intact tree buffer in determining riparian health and water quality. In addition to forest cover within the riparian buffer zone and throughout the watershed, these geospatial studies highlight the influence of other land use land cover types on riparian buffer condition. A study modeling riparian buffer zones in South Carolina used a ratio of tree cover compared with "shrubs" and "other" land uses, which consists of every land use land cover type that is neither trees nor shrubs. They cited the reason for this method is that forest buffers have been found to be more effective at filtering nutrients than grass buffers or buffers of other land use land covers, such as impervious cover or agricultural land (Akturk et al., 2020). Other studies found that presence of settlements, or developed land use land cover, is another dominant predictor of riparian condition and water quality (Batbayar et al., 2019) and that cropland and cattle grazing land were both high predictors of poor water quality (Brogna et al., 2018).

The City of Austin Watershed Protection Department's Index of Riparian Integrity features many of these same aspects. The Index of Riparian Integrity is a grid-based analysis using the proportion of impervious cover in the form of building footprints and paved surfaces, tree canopy over pervious surfaces, and pervious surfaces without tree cover, mostly consisting of bare soil and herbaceous cover (Scoggins et al., 2021). A scoring criterion is applied to the amount of impervious cover, tree canopy, and pervious cover for each grid to calculate a numerical score for riparian integrity (Scoggins et al., 2021). The Index of Riparian Integrity was designed to be used as a large-scale planning tool to help identify and prioritize reaches or tributaries that are "in need of further riparian support" (Scoggins et al., 2021) across the City of Austin's jurisdiction.

I have chosen to use the City of Austin's Index of Riparian Integrity to assess the condition of Town Branch's riparian area for several reasons. I can imagine that having a relatively straightforward and simple to use desktop riparian assessment procedure is appealing to environmental and water resources stewards and managers. Identifying areas that would benefit from riparian restoration activities in-office will help practitioners prioritize which areas should be assessed in greater detail through field work. This will not only save time and money for field work but will develop, essentially, a database of riparian area condition for any area of interest. Because of Lockhart's proximity to Austin, Texas and the similarities between their landscapes (especially in east Austin), I wanted to perform the Index of Riparian Integrity in Town Branch Watershed. My assumption is that the scoring thresholds developed for the City of Austin will be suitable for analysis in Lockhart, Texas. There are several questions that arise regarding the application of the Index of Riparian Integrity to Town Branch Watershed: (1) How successful will the Index of Riparian Integrity analysis be when applied to a watershed outside of the City of Austin's jurisdiction? (2) Since the study area does not have similar tree canopy and impervious surface geospatial datasets, how will the application of the Index of Riparian Integrity be when it utilizes National Land Cover Database land use, tree canopy, and percent imperviousness layers, instead? These questions will be examined throughout this research study.

IV. Methodology

This research employed quantitative methods and geospatial analysis using the City of Austin Watershed Protection Department's Index of Riparian Integrity. This tool requires certain geographic data on the watershed and geographic processing of that data.

IV.I. Data Collection

The City of Austin Watershed Protection Department's Index of Riparian Integrity is a GIS-based protocol that uses easily downloadable, publicly available data to assess the condition of a given riparian zone, which helps to identify areas that would derive the greatest benefit from riparian enhancement or restoration (Scoggins et al., 2021). The protocol requires information on the watershed boundaries, stream centerlines, land cover, imperviousness, and tree cover.

I created watershed boundaries by downloading and using the United States Geological Survey National Hydrography Dataset Best Resolution (NHD) for Hydrological Unit (HU) 8 – 12100203 (USGS, 2022) and the 2016 Central Texas Lidar elevation data from the Texas Natural Resources Information System Strategic Mapping Program (Strategic Mapping Program, 2017). I downloaded land cover, imperviousness, and tree cover data from the National Land Cover Database (Dewitz & USGS, 2021) provided by the Multi-Resolution Land Characteristics Consortium. To determine stream centerlines, I used the previously downloaded 2016 Central Texas Lidar elevation data from the Texas Natural Resources Information System Strategic Mapping Program (Strategic Mapping Program, 2017).

IV.II. Data Preparation

In order to begin data preparation, I needed to define my watershed boundaries and stream centerlines. To do this, I downloaded the United States Geological Survey National Hydrography Dataset Best Resolution (NHD) for Hydrological Unit (HU) 8 – 12100203 (USGS, 2022), which contains a geospatial dataset with HUC12 subwatersheds for this region of Texas.

Once this subwatershed file was added to my ArcGIS file, I located the HUC12 subwatershed in which Town Branch Watershed is located. I selected that subwatershed and exported it as a separate dataset. Then I took the 2016 Central Texas Lidar elevation dataset (Strategic Mapping Program, 2017) and used the Contour tool to convert the elevation raster into two-foot contours across the extent of the elevation dataset. Then, using this contour dataset, I edited the newly exported watershed file by identifying and following the ridgelines in the contours (Figure 9). This process gave me an accurate representation of the Town Branch Watershed boundary in which to perform analysis.

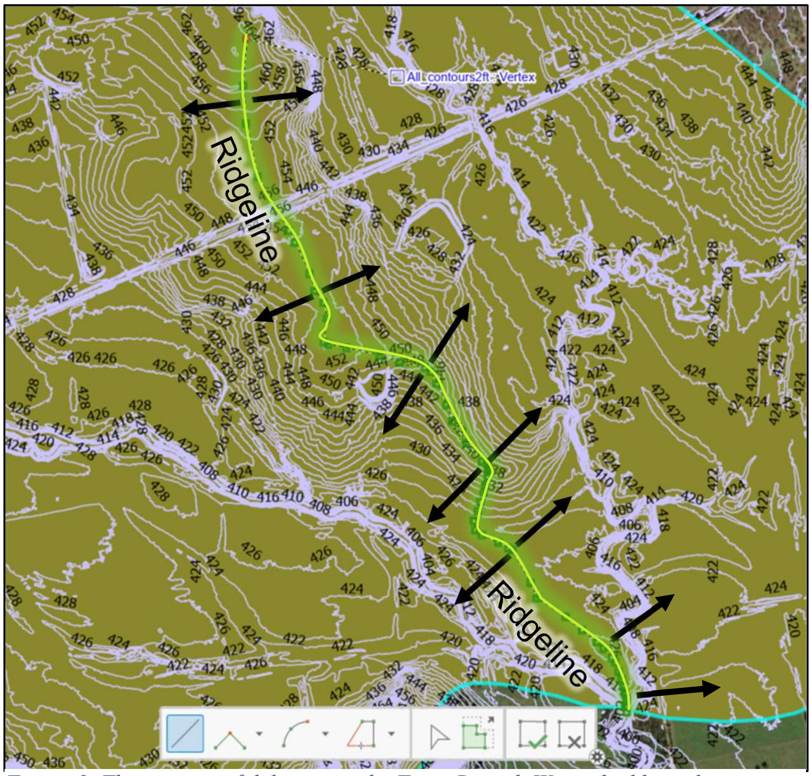


Figure 9. The process of delineating the Town Branch Watershed boundaries involved identifying and following ridgelines in the contours.

I derived stream centerlines using surface hydrology tools in ArcGIS Pro. First, I took the Lidar elevation datasets and ran the Mosaic to New Raster tool to create one continuous raster on which to do analysis. Next, I ran the Fill tool to fill any holes or imperfections in the elevation raster to ready it for surface hydrology analysis. Then I ran Flow Direction with the filled elevation raster as the input, then used the resulting Flow Direction raster as the input raster for the Flow Accumulation Tool. Next, I used the Reclassify tool on the Flow Accumulation raster to identify areas of the greatest flow accumulation, which I later converted into stream centerlines. I ran this tool several times using different flow accumulation thresholds—50,000, 500,000, and 400,000—until the output raster resembled my preferred level of detail for the streamlines.

I based my stream centerlines on the reclassified raster with the flow accumulation threshold of 400,000 or greater. After I decided on which reclassified raster to use, I ran the Stream Link tool with the reclassified flow accumulation raster and the flow direction raster from earlier in the analysis as inputs. The Stream Link tool assigns values to sections of a linear raster network (such as streams) between intersections and is a necessary step in creating streamlines from an elevation raster using Surface Hydrology tools. Next, I used the Stream to Feature tool to convert the output raster from the Stream Link tool to create the streamline feature class. Finally, I exported the stream centerline feature dataset to a new file and performed final edits to ensure that the alignment of the stream centerlines matched sufficiently with aerial imagery of Town Branch and its tributaries (Figure 10).

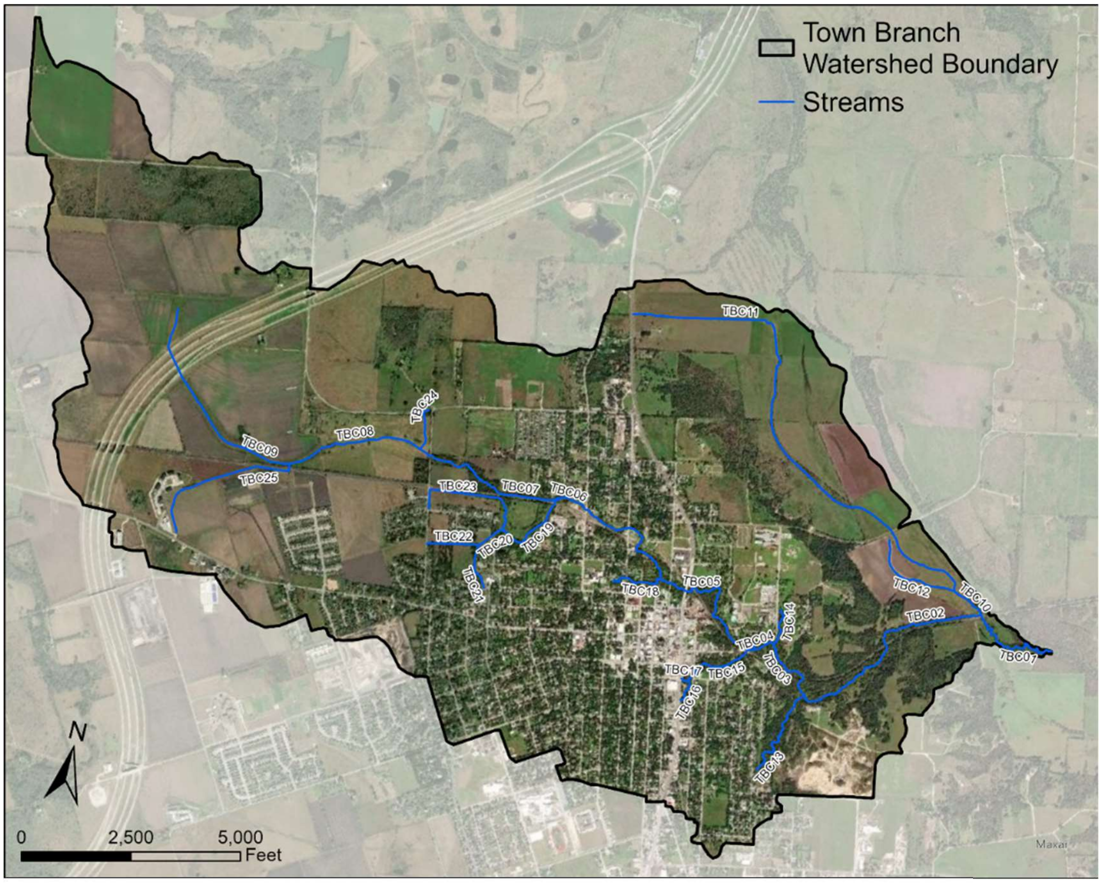


Figure 10. Stream reaches and their unique IDs for analysis.

I divided the stream centerlines into separate reaches at intersections and assigned them each a unique code by which to identify them. I then created a copy of the Town Branch watershed boundary by exporting the dataset as a new file. Then, using the same contour dataset that I used to create the Town Branch watershed boundary dataset, I drew individual drainage areas for each of the stream reaches using the newly exported Town Branch watershed boundary dataset (Figure 11). I created two versions of the subwatersheds dataset: a “local” drainage area dataset that represents the area draining to a reach excluding the upstream drainage areas, and a “global” drainage area dataset that includes the entire upstream area draining to that specific reach.

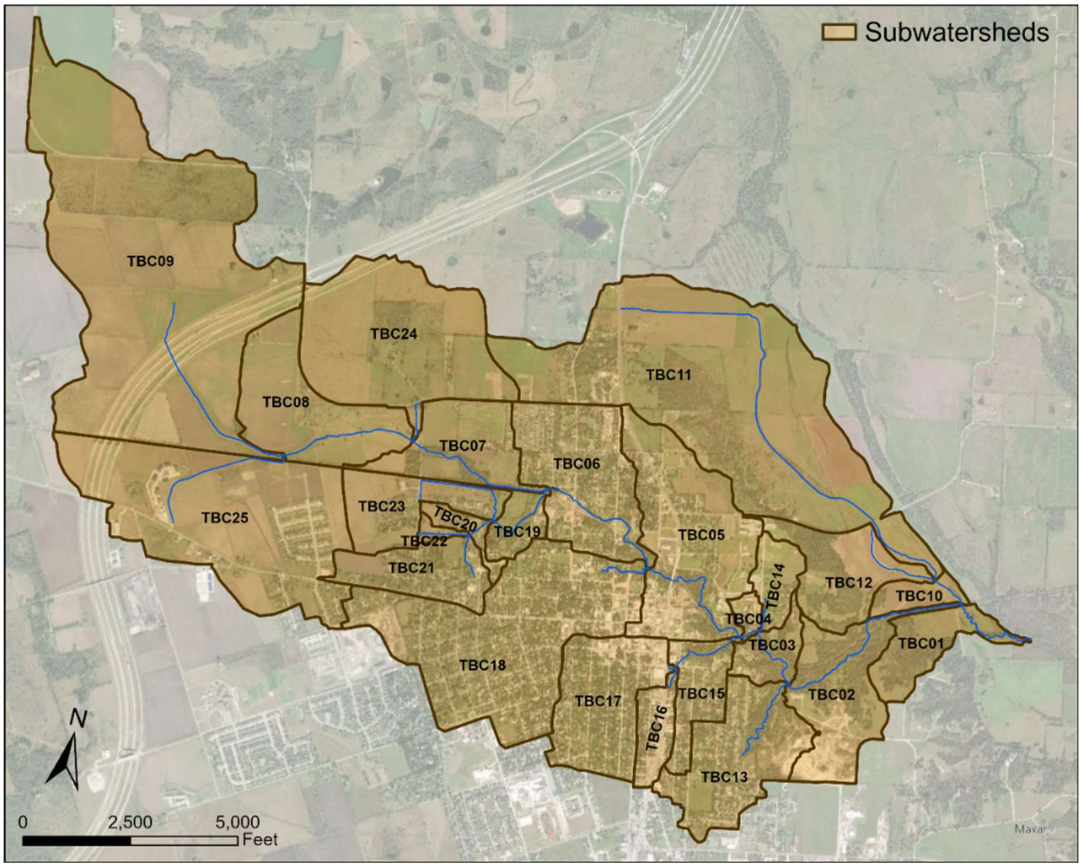


Figure 11. Map of local drainage areas.

I clipped the Land Cover dataset to the same extent as the Town Branch watershed boundaries with the Clip Raster tool. After clipping the raster, I converted the raster later into a polygon vector file using the Raster to Polygon tool, with the Town Branch watershed boundary as the masking polygon so that the output dataset was limited to the watershed boundary. Next, I added a new attribute to the dataset called "type" and populated the field so that land uses with values of 41, 42, 43, and 90 were classified as "forest," land uses with values of 22, 23, 24, and 31 were classified as "impervious," and land uses with values of 11, 21, 52, 71, 81, 82, and 95 were classified as "other (pervious)" (Table 2). After the new attribute was added and populated for each land use category, I used the Dissolve tool on the dataset, using the "type" attribute as the Dissolve Field, so that the resulting dataset consisted of only three large polygons representing forest cover, impervious cover, and other (pervious) cover instead of the more specific National Land Cover Database land use categories.

Table 2. How National Land Cover Database land uses translate to Index of Riparian Integrity land uses.

Index of Riparian Integrity Land Use	National Land Cover Database Land Use	
Forest	41	Deciduous Forest
	42	Evergreen Forest
	43	Mixed Forest
	90	Woody Wetlands
Other (Pervious)	11	Open Water
	21	Developed, Open Space
	52	Shrub/Scrub
	71	Grassland/Herbaceous
	81	Pasture/Hay
	82	Cultivated Crops
	95	Emergent Herbaceous Wetlands
Impervious	22	Developed, Low Intensity
	23	Developed, Medium Intensity
	24	Developed, High Intensity
	31	Barren Land

Using ESRI ArcGIS Pro, I used the Clip Raster tool to cut the Tree Canopy Cover coverage to Town Branch watershed boundaries. I then used the Reclassify tool to reclassify the clipped raster so that all the cells that had a value of 60 or greater (representing 60 percent or greater tree canopy cover) were assigned a value of 1 and cells with all other values were assigned no value. This resulted in one continuous layer representing areas of sufficient canopy cover. I based the threshold of 60 percent canopy cover or greater on the Bureau of Land Management's *Riparian Area Management: Inventory and Monitoring of Riparian Areas* (Myers, 1989). Myers (1989) classified the Forest Phase of Riparian Forest Formations as greater than 60 percent tree canopy cover.

After reclassification, I converted the raster into a polygon vector file, using the Raster to Polygon tool, with the Town Branch watershed boundary as the masking polygon so that the output dataset was only limited to the watershed boundary. To create a single tree canopy layer, I selected the “forest” polygon from the previously dissolved land use dataset and merged it with the reclassified tree canopy layer. This ensured that both the “forest” from the National Land Cover Database Land Use Land Cover dataset and all cells representing 60 percent or greater cover from the Tree Canopy Cover were represented in the Index of Riparian Integrity tree canopy layer.

I performed a similar process to prepare the Percent Developed Impervious raster for analysis. I clipped Percent Developed Impervious dataset’s extent to the Town Branch Watershed boundary with the Clip Raster tool. Next, I used the Reclassify tool to reclassify the clipped raster so that all cells that had a value of 20 or greater (representing 20 percent or greater impervious cover) were assigned a value of 1 and cells with all other values assigned no value. I based the threshold of 20 percent impervious cover or greater on the National Land Cover Database Land Use Land Cover dataset’s classification legend and descriptions which stated that the threshold for Developed, Low Intensity land cover was 20 percent impervious cover (Dewitz & USGS, 2021). Because I treated the Developed, Low Intensity; Developed, Medium Intensity; and Developed, High Intensity land covers (as well as Barren Land) (Table 2) as impervious in this analysis, I chose the same threshold used for those land covers to reclassify the Percent Developed Impervious raster dataset.

After reclassification, I converted the raster into a polygon vector file using the Raster to Polygon tool, with the Town Branch Watershed boundary as the masking polygon so that the output dataset was limited to the watershed boundary to make analysis simpler. To create a single impervious cover layer, I selected the “impervious” polygon from the previously dissolved land use dataset and merged it with the reclassified impervious cover layer. This ensured that both the “impervious” cover from the National Land Cover Database Land Use Land Cover dataset and all cells representing 20 percent or greater cover from the Percent Developed Impervious were represented in the Index of Riparian Integrity impervious cover layer.

IV.III. Data Analysis

I used ArcGIS Pro to complete the geospatial analysis to calculate Index of Riparian Integrity scores for Town Branch watershed as laid out in the Scoggins et al. (2021) report. Using the Buffer Tool, I assigned a buffer to each stream centerline according to the following drainage area threshold:

- < 1.3 square kilometers (320 acres) – 30.5-meter (100-foot) buffer width
- 1.3 – 2.6 square kilometer (320 – 640 acres) – 61-meter (200-foot) buffer width
- > 2.6 square kilometers (640 acres) – 91.5-meter (300-foot) buffer width

Once completed, I dissolved the buffers into one polygon using the Dissolve tool. Next, I created a 30.5-meter by 30.5-meter (100-foot by 100-foot) hexagonal grid using the Tessellation tool across the Town Branch watershed. With the Select by Location tool, I selected the hexagons that intersected with the stream buffers and saved them as a new polygon feature dataset. Next, I clipped the hexagonal grid to match the geometry of the stream buffer using the Clip tool. I clipped both the impervious cover and tree canopy datasets to match the geometry of the stream buffers using the Clip tool. Using the Union tool, I performed two unions, the first was with the clipped impervious cover layer and the stream buffer layer as inputs and the second union was with the output file of the first union and the clipped tree canopy layer. This allowed for “any overlap of impervious and canopy to be privileged as impervious” (Scoggins et al., 2021).

Scoggins et al. (2021) assumed that any land use that was classified as neither impervious cover nor tree canopy would be classified as pervious cover—I made this same assumption. Next, I used the Tabulate Intersection tool with the output of the second union (the dataset that now contains impervious cover, tree canopy, and pervious cover for all stream buffers in Town Branch watershed) and the hexagonal grid. The result was a table containing the percent area of each land use classification for every hexagon contained in the grid.

The next step was to convert the table representing the geospatial data into numerical Index of Riparian Integrity scores. To do this, I used same process detailed in Scoggins et al. (2021).

The Index of Riparian Integrity scores are based on

$$IRI = (100*TC + 55*PC) * (1 - IC)$$

where *IRI* is the numerical score of the Index of Riparian Integrity, *TC* is the fraction of tree canopy, *PC* is the fraction of pervious cover, and *IC* is the fraction of impervious cover. I then assigned the resultant numerical values a descriptive score and a corresponding color symbology (Table 3).

After Tabulate Intersection was complete, I created a pivot table using the Pivot Table tool with the Tabulate Intersection output table as the input table, the unique code assigned to each hexagon, GRID_ID, as the input field, Land Cover as the Pivot Field, and PERCENTAGE as the Value Field. Whereas the tabulate intersection table had multiple entries for each hexagon for each land use type that fell within it, the pivot table allowed the percentages of canopy, impervious cover, and pervious cover to be listed for each hexagon in a single entry. This allowed for simpler Index of Riparian Integrity calculations.

Table 3. Index of Riparian Integrity score ranges and associated narrative scores and color codes (from Scoggins et al. 2021).

Index of Riparian Integrity 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

After creating the pivoted table, I added two new attributes, "IRI score" and "IRI_Rubric", to the table. "IRI score" is the numerical score while "IRI_Rubric" is the narrative, descriptive score. Next, I joined the pivoted table with newly added attributed to the hexagonal grid geospatial dataset and exported the output as a new feature class. I then used the Calculate Field tool the "IRI_Score" attribute, using a version of the above equation that accounts for percentages of each land use type, to calculate the numerical IRI score for each hexagon in the hexagonal grid:

(((100!Canopy!)+(55*!Pervious!))/100)*((100-!Impervious!)/100)*

To calculate the narrative scores for each hexagon in the grid, I ran the Calculate Field tool for the "IRI_Rubric" attribute. After entering the Reclassify function, this code is entered into the dialog box:

```
def Reclass(arg):
    if (arg >= 0 and arg <=12.5):
        return "Very Bad"
    elif (arg > 12.5 and arg <= 25):
        return "Bad"
    elif (arg > 25 and arg <= 37.5):
        return "Poor"
    elif (arg > 37.5 and arg <= 50):
        return "Marginal"
    elif (arg > 50 and arg <= 62.5):
        return "Fair"
    elif (arg > 62.5 and arg <= 75):
        return "Good"
    elif (arg > 75 and arg <= 87.5):
        return "Very Good"
    elif (arg > 87.5 and arg <= 100):
        return "Excellent"
```

In order to estimate the impact that the Town Branch Watershed Riparian Restoration Project grow zones on the condition of the Town Branch riparian area, I created a grow zone dataset by georeferencing a map of the grow zones including the operation and maintenance plan for the Town Branch Watershed Riparian Restoration Project grow zones and rain garden (City of Lockhart, 2020) and tracing over the polygons representing the grow zones in ArcGIS Pro. Next, I combined the grow zone dataset with the output of the second union performed during the baseline Index of Riparian Integrity analysis union (the dataset that contains impervious cover, tree canopy, and pervious cover for all stream buffers in Town Branch watershed) using the Union tool. The resultant dataset contains impervious cover, pervious cover, and tree canopy with the grow zone polygons added in to represent the fully grown conditions that the grow zones will eventually achieve. I then followed the same methodology I followed when calculating the baseline Index of Riparian Integrity scores earlier in the analysis. The output of this analysis was the Index of Riparian Integrity scores across the Town Branch watershed riparian area with the grow zones represented as added canopy cover.

Next, I calculated the average Index of Riparian Integrity score for each reach drainage area by using the Intersect tool to divide the hexagonal bins with the scores by drainage area, multiplying the Index of Riparian Integrity for each hexagonal bin by its area, adding this value up for each drainage area, and dividing by the total area of each drainage area. This was performed for both the baseline riparian conditions and those that factor in the grow zone canopy area. Then, to estimate the impact that the grow zones have on the Index of Riparian Integrity scores, I subtracted the average Index of Riparian Integrity score for the grow zone conditions from those of the baseline conditions.

V. Results

The approximate riparian zone area for the Town Branch Watershed, using the City of Austin Index of Riparian Integrity methodology, is 663.5 acres or 1.02 square miles (Figure 12).

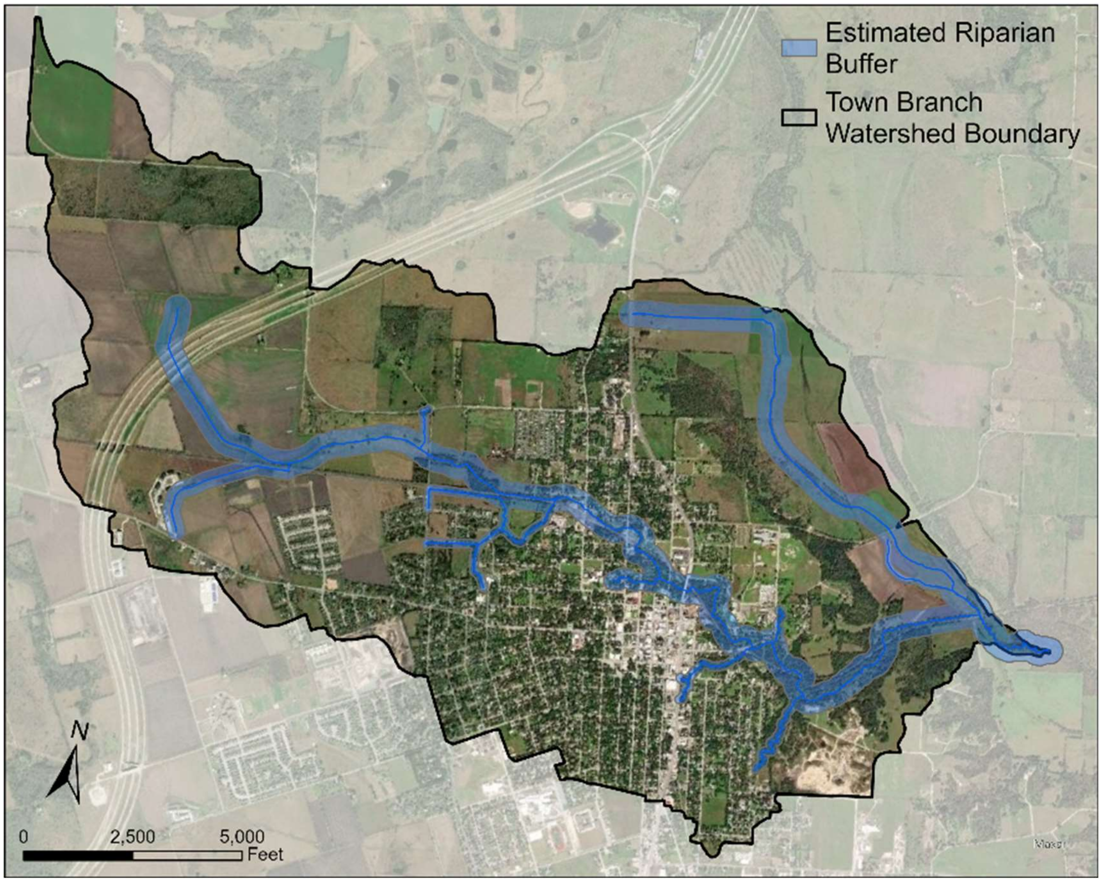


Figure 12. Riparian zone for analysis in Town Branch Watershed.

Table 4. The percentage of Town Branch Watershed's riparian area that falls within each Index of Riparian Integrity narrative score categories.

Color Code	Narrative Score	Percent of Total Riparian Area
	Excellent	18.5%
	Very Good	3.4%
	Good	3.6%
	Fair	57.2%
	Marginal	2.1%
	Poor	2.9%
	Bad	2.7%
	Very Bad	9.6%

The average Index of Riparian Integrity score of the entire riparian zone is approximately 56.8, while the median score is 55.0, both of which equate to a "Fair" narrative score. Contrary to my hypothesis that more than 50 percent of the study area would receive "Very Bad" to "Marginal" narrative scores (18% of the total area; Table 4) due to widespread agricultural areas, much of the riparian zone (57 percent of the total area; Table 4) received a "Fair" Index of Riparian Integrity score (Figure 13). The largely agricultural nature of the upper reaches of the watershed accounts for the large proportion of "Fair" scores in the study area.

The lower scoring areas, those that received "Poor" (3 percent of the total area; Table 4), "Bad" (3 percent; Table 4), and "Very Bad" (10 percent; Table 4) narrative scores, coincide with areas of increased development and, therefore, increased impervious cover.

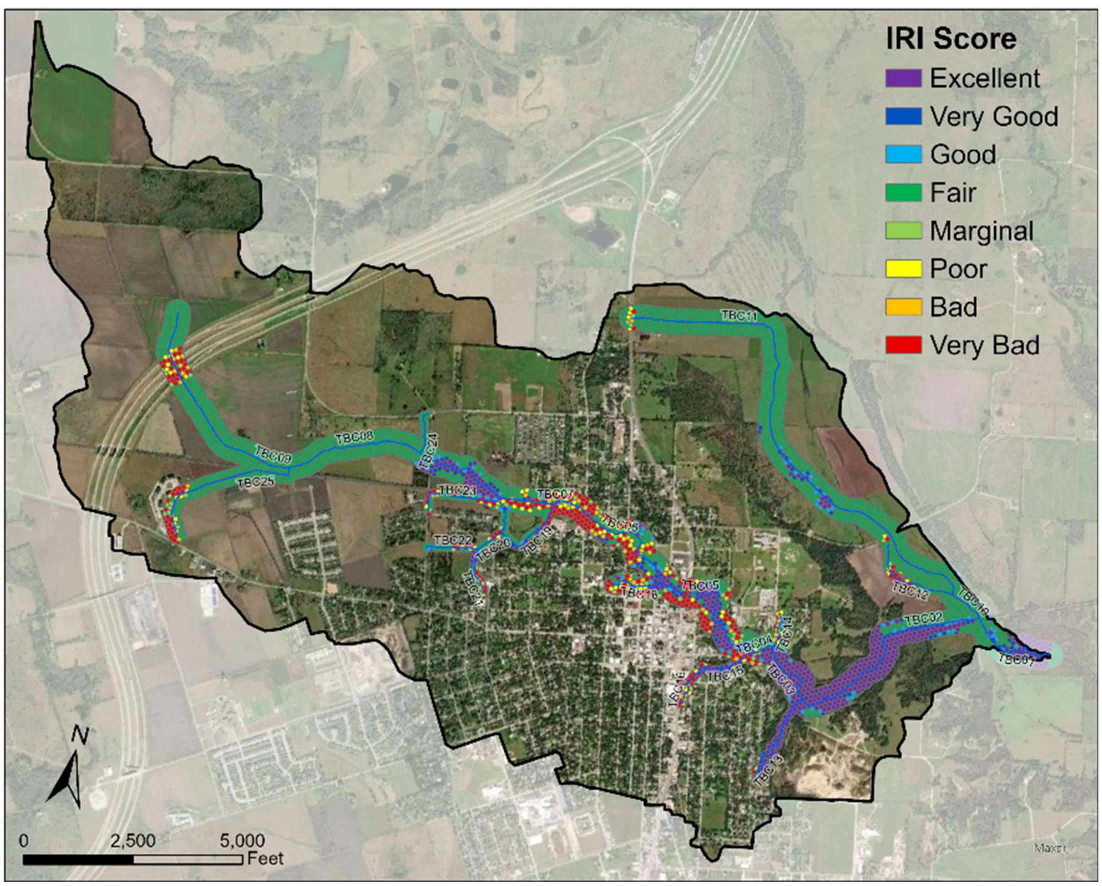


Figure 13. Baseline Index of Riparian Integrity scores for Town Branch riparian zones (IRI = Index of Riparian Integrity).

Notable examples of these areas include where the Headwater Reach of Town Branch crosses under TX-130 (TBC09), the upstream-most portion of TBC25 that flows through a field next to a recently constructed apartment complex off West San Antonio Street, and where Town Branch flows through Lockhart, especially in the Urban Trail Reach (TBC06), City Park Reach (TBC05), and their tributaries (TBC15-TBC23) (Figure 13).

Areas with “Excellent” narrative scores (18 percent of the total area, Table 4) coincide with areas of dense canopy cover. Examples of these areas include the aptly named Conservation Reach (TBC07) east of Stueve Lane and north of Union Pacific Railroad; the immediate area surrounding the confluence of TBC05, TBC06, and TBC18 west of North Commerce Street; a narrow section of City Park Reach (TBC05) that lies between Union Pacific Railroad and East City Park Road; the section of TBC15 that flows south of East Market Street between South Brazos Street and Kennedy Street; and TBC03, TBC13, TBC02, and the downstream end of TBC01 at its confluence with Plum Creek (Figure 13).

The construction of the Town Branch Restoration Project's grow zones did not appreciably increase the condition of Town Branch's riparian zones. When you add the grow zones in as areas of 100 percent canopy cover, the greatest amount of ecological lift (quantified by the Index of Riparian Integrity) takes place in subwatershed TBC06 where the baseline index is approximately 33.5 and the grow zones' index is approximately 35.1 (Figure 14). This 1.6-

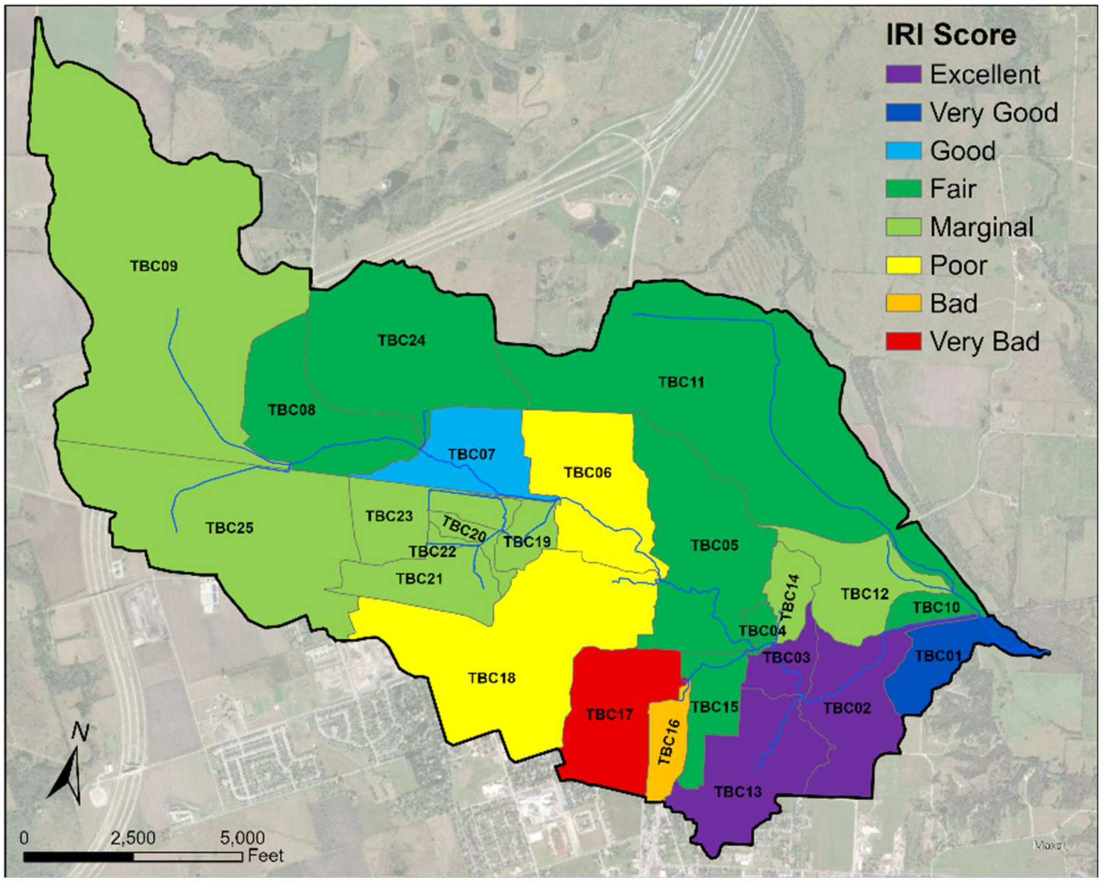


Figure 14. The Index of Riparian Integrity (IRI) scores for the Town Branch subwatersheds were essentially unchanged after the grow zones were added to the analysis.

point increase does not increase the narrative score (Figure 15). The localized nature of these grow zones limits their ability to increase the condition of large portions of riparian area in the watershed. Also, the reaches downstream of these grow zones—TBC03, TBC02, and TBC01—contain some of the highest quality riparian zones in Town Branch watershed, featuring little development and widespread, dense canopy cover. As a result, the reaches with the most impaired riparian areas might not experience sufficient environmental benefit from the grow zones' implementation.

The small amount of ecological lift achieved by these grow zones, as quantified by the Index of Riparian Integrity, demonstrates their limitations. Representing the grow zones as areas of 100 percent canopy cover in the geospatial analysis, which is the best-case scenario for these features, only amounts to minimal increases in Index of Riparian Integrity in two subwatersheds

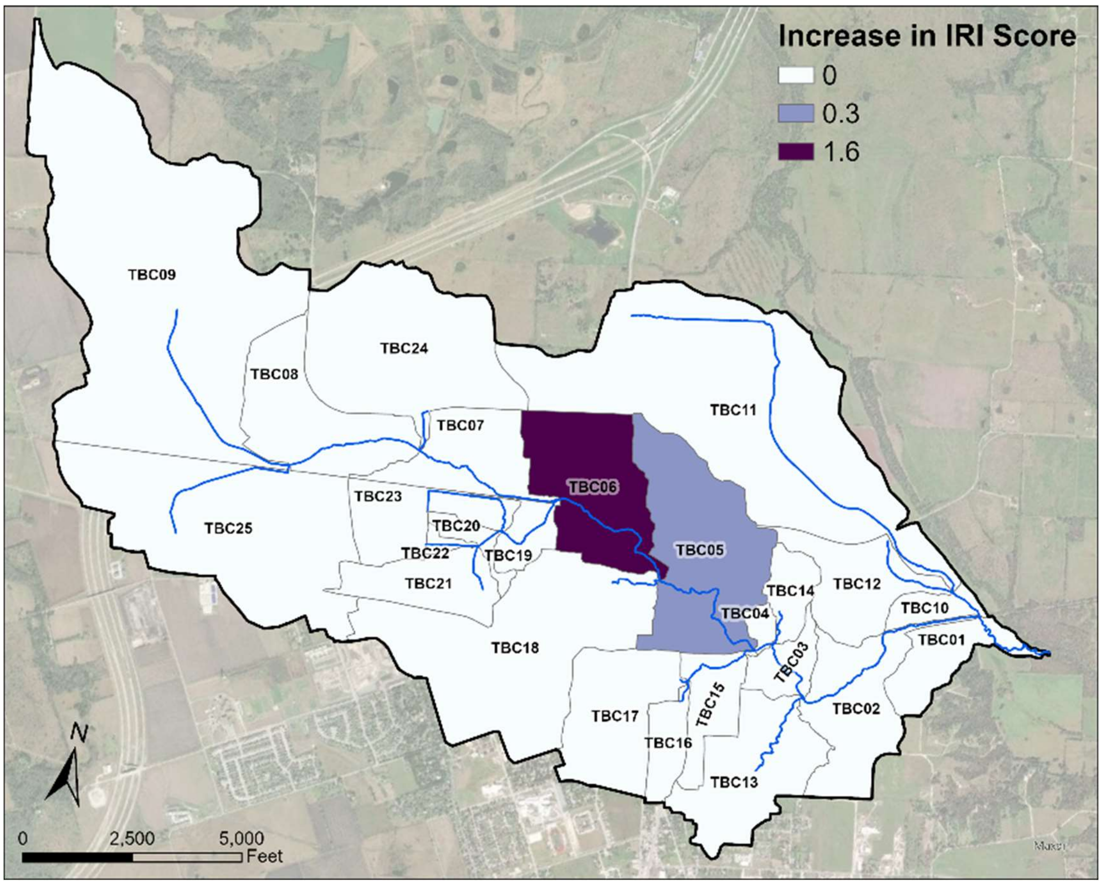


Figure 15. Increase in Index of Riparian Integrity scores from baseline to established grow zone conditions.

out of the whole Town Branch Watershed. While these grow zones may provide benefits that are not quantified by Index of Riparian Integrity, such as water quality or aquatic and riparian habitat, their presence, even when represented as fully grown-out, dense canopy cover, offers little to no impact on Index of Riparian Integrity scores.

The Index of Riparian Integrity analysis results allow us to identify areas of Town Branch's riparian zone that could benefit from restoration or mitigation and other high-quality areas that could benefit from preservation. Much of the riparian zone consists of agricultural land that features neither impervious cover nor tree canopy, which results in its "Fair" narrative Index of Riparian Integrity score. Caldwell County, the City of Lockhart, or other practitioners could use these Index of Riparian Integrity score data to prioritize potential project opportunities and identify property owners with whom they might be able to partner.

If managers want to find areas in which they can implement riparian restoration activities, they may consider identifying current landowners and/or future developers for potential opportunities for public/private partnership. Potential solutions could include working with landowners to establish riparian grazing setbacks or conservation easements on parcels that abut Town Branch and its tributaries. In instances of new development, managers may be able to work with developers to establish stormwater control features of nature-based solutions, like rain gardens or green roofs.

Overall, the Index of Riparian Integrity analysis results for Town Branch watershed appear to be in line with the assessment included in the Riparian Evaluation Report (Figure 16; City of Lockhart, Texas and Nueces River Authority, 2018). While the Index of Riparian Integrity analysis scores reflect the impaired nature of the Headwater Reach of Town Branch, with its mowed and agricultural sections, it does not capture the severe erosion near the crossing at Stueve Lane. Also, the Riparian Evaluation Report mentions the impaired function of riparian and floodplain vegetation, but, since this vegetation is classified as pervious cover in the Index of Riparian Integrity, this area still receives "Fair" narrative scores. Perhaps "Fair" is an appropriate score for this area, but it does seem generous when you compare the Riparian Evaluation Report's description of a riparian area that is "restricted by both the type of vegetation and the mowing program" (City of Lockhart, Texas and Nueces River Authority, 2018).

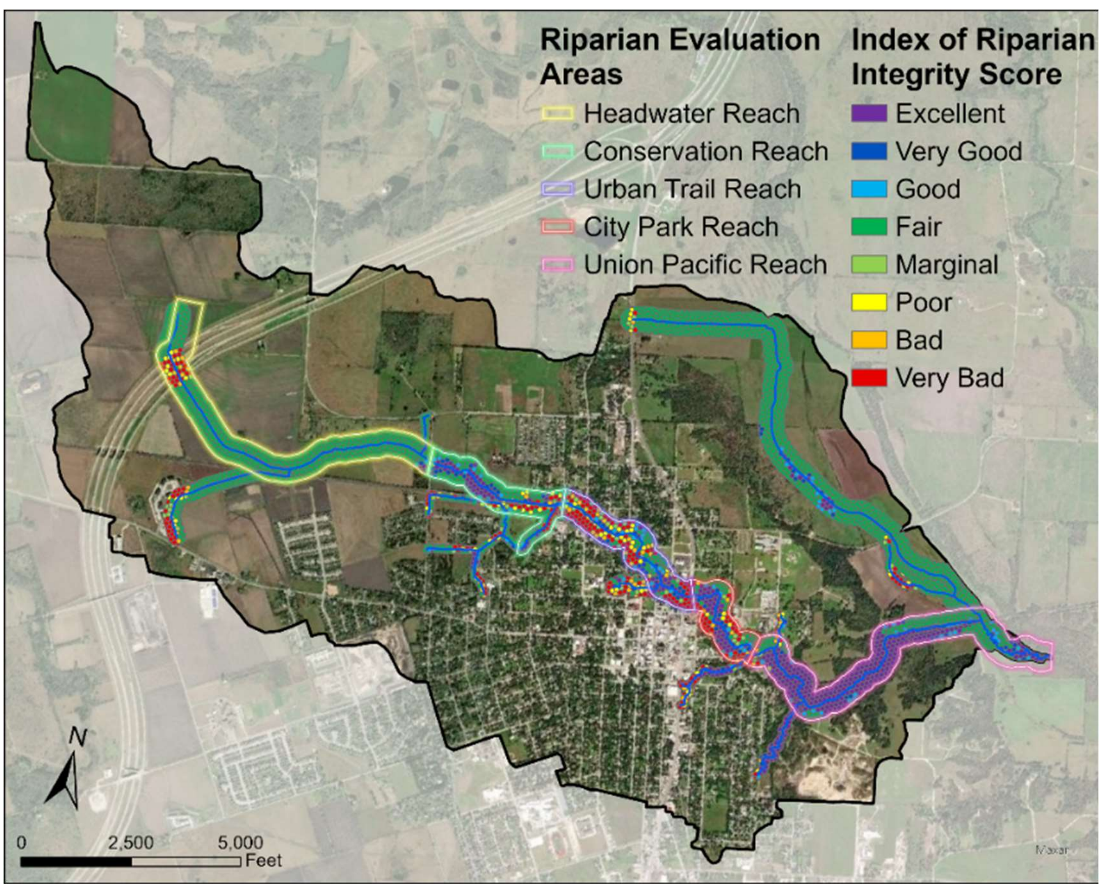


Figure 16. Index of Riparian Integrity results with the Riparian Evaluation Report evaluation areas overlaid.

The Index of Riparian Integrity scores appear to represent the wooded nature of the upper section of the Conservation Reach with “Excellent” narrative scores, while also capturing the impairment of the lower section and confluence with the Unnamed Tributary where the presence of homes and the railroad constrict the floodplain with lower Index of Riparian Integrity scores. The impairment of the Urban Trail Reach is captured quite well with the Index of Riparian Integrity scores. This is the reach with the largest proportion of “Very Bad” narrative scores, which reflects the riparian impairment caused by mowing and large amounts of impervious cover.

The City Park Reach is also reflected quite well in the Index of Riparian Integrity analysis results. The Riparian Evaluation Report mentions that the riparian area in this reach is heavily wooded in the upper sections, while the floodplain remains relatively undisturbed while being manicured on the side of the bank where City Park is (City of Lockhart, Texas and Nueces River Authority, 2018). The heavily wooded nature of the upper section of the City Park Reach as well as the floodplain in the section of the reach within City Park is reflected in the Index of Riparian Integrity scores with “Excellent” narrative scores. The more lateral areas of the riparian buffer in this reach have “Very Bad” narrative scores, which corresponds with the descriptions of heavily manicured areas in the park.

The Union Pacific Reach at the downstream end of the watershed contains, overwhelmingly, the highest quality riparian area, which is reflected in the large proportion of “Excellent” narrative scores. If it is not apparent by its name, the Union Pacific Reach coincides with a long segment of railroad that runs roughly parallel to the stream in this section. The Riparian Evaluation Report notes that the presence of the railroad has limited the extent of the floodplain, which results in hindered floodplain function (City of Lockhart, Texas and Nueces

River Authority, 2018). Because of the density of tree cover in this area and the thinness of the railroad line, the railroad is not actually captured in the Index of Riparian Integrity scores. This means that the pinched nature of the floodplain in this area is not fully represented by the analysis because the presence of the railroad was overwhelmed by the dense canopy cover in the area, or the National Land Cover Database land use and percent impervious layers were not granular enough to capture the railroad sufficiently.

VI. Discussion

Converting the original City of Austin methodology for the Index of Riparian Integrity into one that uses publicly available National Landcover Database layers added additional complexity to the analysis of Town Branch's riparian area. Lockhart does not have geospatial datasets like the city-wide tree canopy and impervious surfaces that the City of Austin used in its original analysis, which means that I had to use tree canopy, percent imperviousness, and land cover data from the National Land Cover Database instead. While data like those used by the City of Austin Watershed Protection Department would have provided a greater level of precision, the Index of Riparian Integrity scores developed for Town Branch seem to correspond well with the aerial imagery of the area. More developed areas with higher amount of impervious cover have lower Index of Riparian Integrity scores, while areas with more dense canopy cover received higher Index of Riparian Integrity scores. This was the goal of this analysis, and it appears to have been achieved.

These data required additional preprocessing that datasets like the City of Austin's tree canopy and impervious surface layers would not have required. Geospatial datasets similar to the City of Austin's tree canopy and impervious surface layers could be developed for any area of interest with access to recently developed Lidar point clouds, but I wanted to examine whether using National Land Cover Database land use, tree canopy, and percent impervious layers would result in a similar product. These publicly available layers are developed roughly every three years for the contiguous United States, Hawaii, Alaska, and Puerto Rico, so they could, ostensibly, be used to quantify the riparian area condition in any study area for which these layers are developed.

Translating the National Land Cover Database layers into layers that were useful for this analysis required several judgement calls on my part. I had to make decisions about which land cover categories in the National Land Cover Database 2019 Land Cover would be converted to tree canopy, impervious cover, and pervious cover and at what percentage cover of tree canopy and impervious cover would the thresholds for reclassifying the National Land Cover Database tree canopy and percent impervious be set. If I had made different decisions, such as choosing 50 percent tree canopy instead of 60 percent as the reclassification threshold, the results of this analysis would have turned out differently. I believe that this will be the main challenge for other analysts when applying the Index of Riparian Integrity process to other watersheds. Depending on the climate and ecoregion in which the analysis is taking place, there might be different standards for what percentage of tree canopy cover is considered ideal for a healthy riparian area. It is important to be able to make these decisions using resources that are relevant to and appropriate for the contexts in which the analysis is being conducted.

VI.I. Limitations

There are both benefits and shortcomings of the Index of Riparian Integrity analysis process using National Land Cover Database layers. Overall, the condition of the riparian area in the Town Branch Watershed is represented well by the scores, but there are many things that could have a large influence of the health of the riparian area that are lost in translation of the

Index of Riparian Integrity. The Index of Riparian Integrity is a geospatial analysis that uses land cover data to estimate the condition of riparian areas. This process cannot capture erosion in a stretch of riparian area that might have otherwise “functional” land uses according to the Index of Riparian Integrity categorization. Apart from tree cover, the Index of Riparian Integrity does little to differentiate between vegetation types, which can be important for riparian and floodplain health and function. Wetland vegetation is much more functional than a mowed Bermuda grass lawn, but, based on the Index of Riparian Integrity categories, they received the same scores.

This is not a comprehensive analysis of all types of riparian restoration projects across the state of Texas but rather an investigation of the condition of the existing riparian area of a small watershed in Central Texas. There is no replacement for a “boots-on-the-ground” riparian assessment where one can truly capture and understand the health and functionality of the area. The Index of Riparian Integrity should be seen not as an exhaustive tool that replaces in-person evaluations but as a decision-making tool that can be used to help guide practitioners to high-priority or high-need areas in which to target riparian restoration activities.

VI.II. Future Work

There are many opportunities for future work using the Index of Riparian Integrity as a geospatial methodology for assessing the condition of a watershed’s riparian area. A straightforward way to tell whether this translation of the City of Austin Watershed Protection Department's Index of Riparian Integrity is truly successful would be to perform this analysis, using the same procedure and National Land Cover Database layers, on the watersheds analyzed in the original City of Austin’s Index of Riparian Integrity study. By comparing the results from the original analysis and the one performed in this study, you would be able to determine the relative success of analysis that used National Land Cover Database layers in achieving similar Index of Riparian Integrity scores to the original study. Alternatively, investigators could perform both versions of the Index of Riparian Integrity analysis (City of Austin and the one studied in this report) in a new watershed and compare the results of the two methods.

While I did not conduct these analyses, they are ideas that could be explored in future studies. It would be an important step in vetting the veracity of the Index of Riparian Integrity analysis using the National Land Cover Database layers.

VII. Conclusion

The purpose of this study was to assess (1) the application of the Index of Riparian Integrity on a watershed outside of Austin's city limits and (2) the existing condition of Town Branch's riparian area using the Index of Riparian Integrity. My hypotheses were (1) that the Index of Riparian Integrity can provide an accurate overview of the riparian health of Town Branch since it is located in a similar ecoregion as Austin and (2) that, given the presence of agriculture and development in the watershed, more than 50 percent of the existing riparian buffer in Town Branch Watershed will have "Very Bad" to "Marginal" riparian integrity scores.

The Index of Riparian Integrity, using the National Land Cover Database layers, gave a representative overview of Town Branch's riparian conditions when compared to the 2018 Riparian Evaluation Report (City of Lockhart, Texas and Nueces River Authority, 2018) and aerial imagery of the area. The Index of Riparian Integrity methodology allowed me to develop a watershed-wide assessment of its riparian condition in a fraction of the time that it would have taken to do the same in-person. Areas of dense development, like downtown Lockhart were given lower Index of Riparian Integrity scores, while areas that have dense canopy cover were given higher scores. There are shortcomings to using this methodology, such as not capturing areas of erosion or the fact that all vegetation that is not tree canopy is given the same scores, but I believe that the Index of Riparian Integrity process produced an inventory of riparian condition throughout the watershed that will help guide and prioritize restoration activities.

I underestimated the Index of Riparian Integrity scores for Town Branch Watershed in my original hypothesis. "Very Bad" to "Marginal" Index of Riparian Integrity scores only accounted for 18% of the total riparian area, while Fair scores dominated with 57% of the total riparian area. This is because of the large areas of agricultural land that manifest as pervious cover in the Index of Riparian Integrity workflow and, therefore, receive a score of 55.

Geospatial datasets similar to the City of Austin's tree canopy and impervious surface layers could be developed for any area of interest with access to recently developed Lidar point clouds, but I wanted to examine whether using National Land Cover Database land use, tree canopy, and percent impervious layers would result in a similar product. These publicly available layers are developed roughly every three years for the contiguous United States, Hawaii, Alaska, and Puerto Rico, so they could, ostensibly, be used to quantify the riparian area condition in any study area for which these layers are developed. While many municipalities and environmental management bodies use geospatial analysis, many of these entities might not have the technical abilities to develop tree canopy and impervious surface layers from a Lidar point cloud to precisely recreate the original City of Austin Index of Riparian Integrity workflow. Developing a process that uses easy to find datasets will provide opportunities to an even greater number of environmental managers and practitioners to be able to use this desktop workflow to assess the quality of their respective riparian areas.

To truly test the accuracy of using the National Land Cover Database land use, tree canopy, and percent developed impervious layers for the Index of Riparian Integrity, this same process should be carried out for the watersheds in which the original City of Austin Index of Riparian Integrity study was conducted. By doing this, you would be able to compare the Index of Riparian Integrity scores calculated with both processes for all watersheds in the original study area. This would allow you to further refine the process developed for this research project, resulting in greater precision and accuracy for Index of Riparian Integrity analysis in the future.

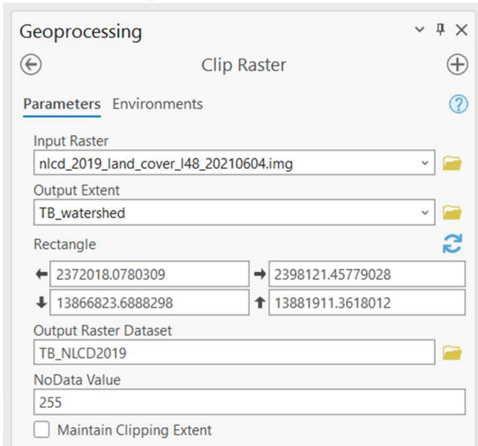
This research is important to the field of riparian restoration for several reasons. By quantifying riparian area condition using a geospatial process, this project will help develop a means of creating a deeper understanding of the total existing riparian condition within watersheds across Central Texas. Using the Index of Riparian Integrity in watersheds outside of Austin will allow municipalities that lack the monetary and technological resources of cities like Austin to create inventories of riparian health for all watersheds within their respective jurisdictions. Especially in rapidly developing watersheds, such as Town Branch, being able to quickly and easily calculate riparian condition and identify potential riparian restoration opportunities is important for identifying and developing strategies to mitigate the deleterious effects of that development. By allowing practitioners to understand the restoration needs more fully of a certain project area, they will be better able to identify shortfalls sooner and work to develop decision-making tools to create more thorough, effective, and self-sustaining restoration projects in the future.

APPENDIX A

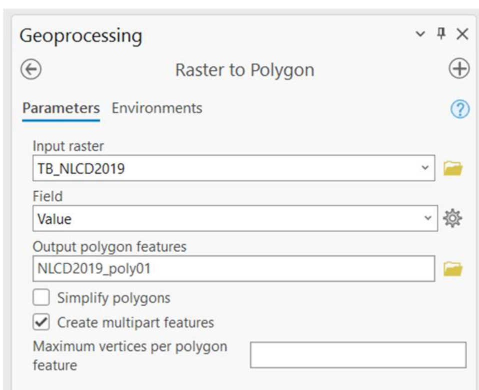
Index of Riparian Integrity Workflow

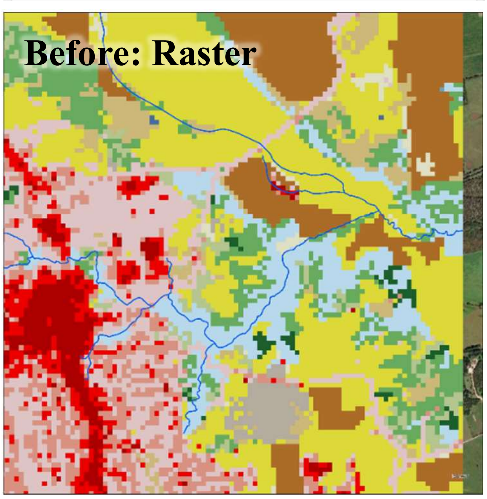
Appendix A: Index of Riparian Integrity Workflow

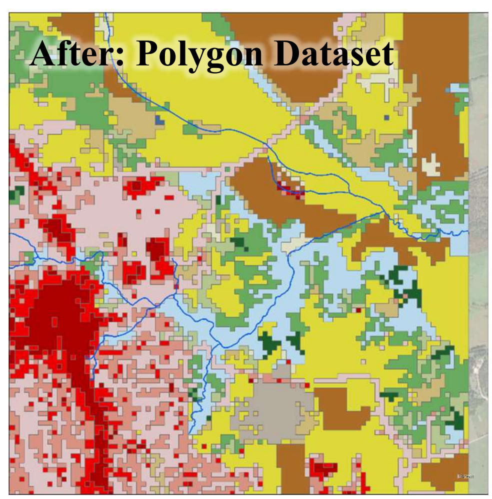
- Clip Land Use raster to project area with **Clip Raster** tool.
    - Input Raster: National Land Cover Database Land Cover
    - Output Extent: Watershed Drainage Area



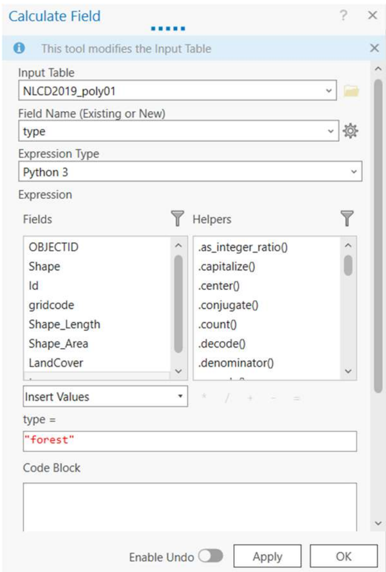
- Convert Land Use with **Raster to Polygon** tool.
    - Input Raster: Clipped Land Cover Raster
    - Field: Value

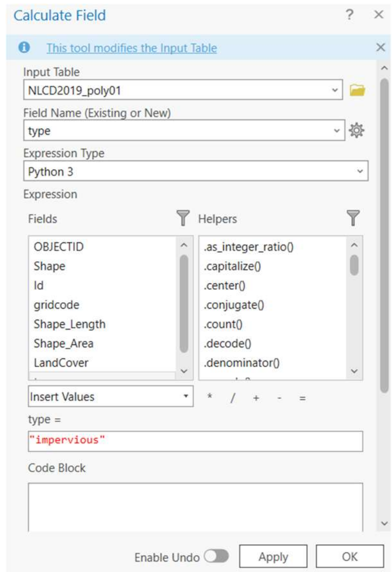


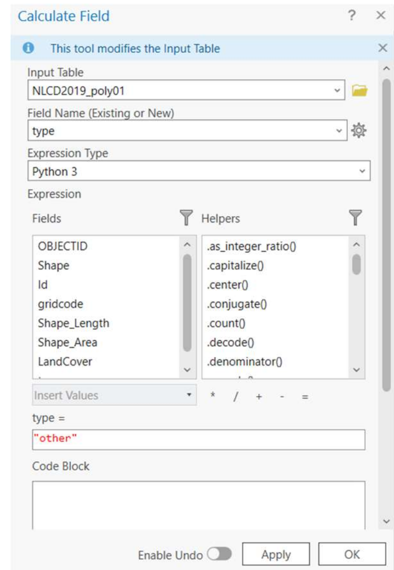




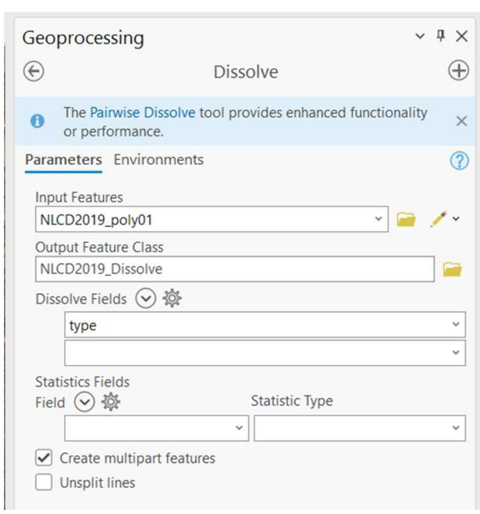
- Add new attribute for land use type and **Calculate Field**.
    - **Select By Attribute** where “gridcode” equals:
        - “forest” = 41, 42, 43, 90
        - “impervious” = 22, 23, 24, 31
        - “other” = 11, 21, 52, 71, 81, 82, 95
    - **Calculate Field** with respective land use type gridcodes are selected.

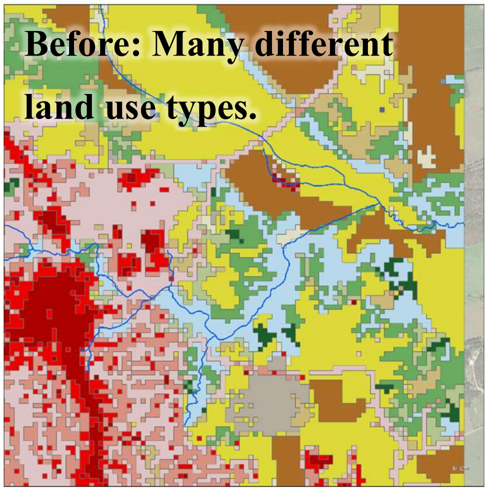


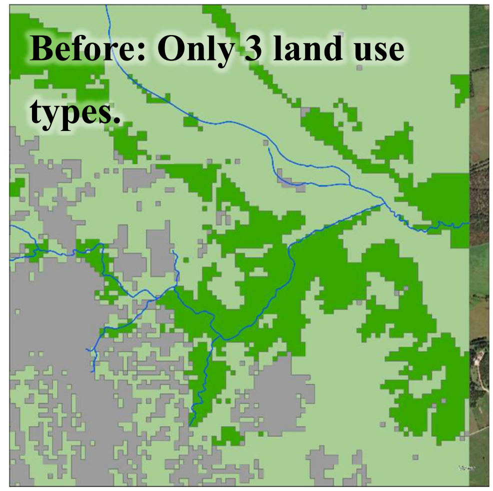




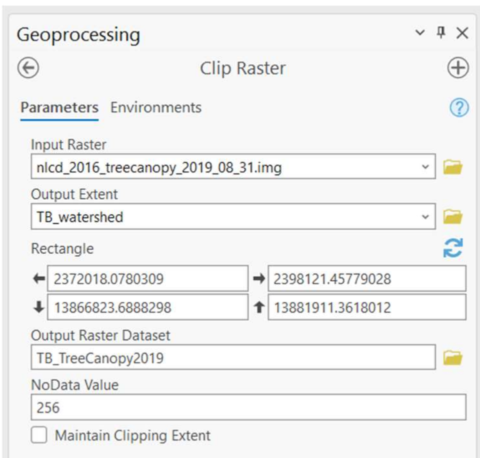
- **Dissolve** Land Use so that there are only 3 polygons representing forest, impervious, and other.
    - Input: Land Cover polygon dataset
    - Dissolve Field: type



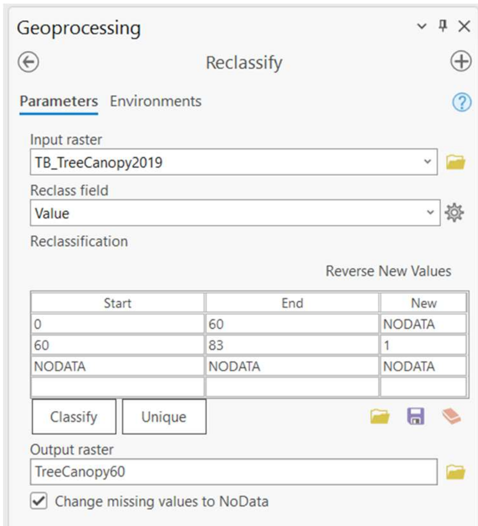


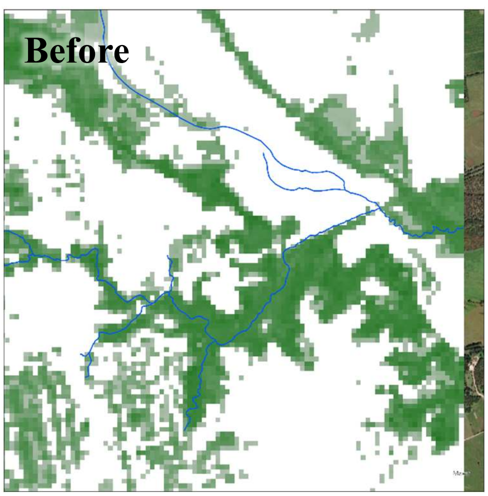


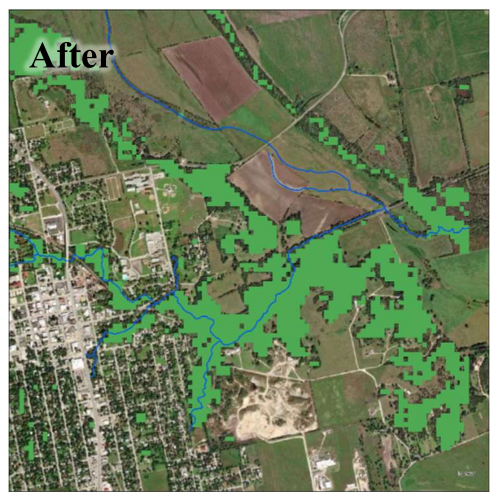
- Clip Tree Canopy raster to project area with **Clip Raster**.
    - Input Raster: National Land Cover Database Tree Canopy Cover
    - Output Extent: Watershed Drainage Area



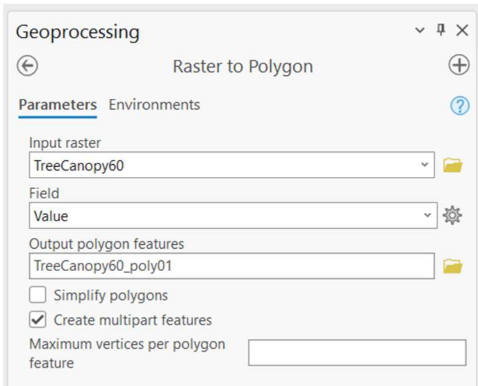
- **Reclassify** clipped raster so that canopy cover of 60% or greater receives a new value of 1 and all other canopy cover percentages are assigned a NODATA value.
    - Input Raster: Clipped Tree Canopy
    - Reclass Field: Value



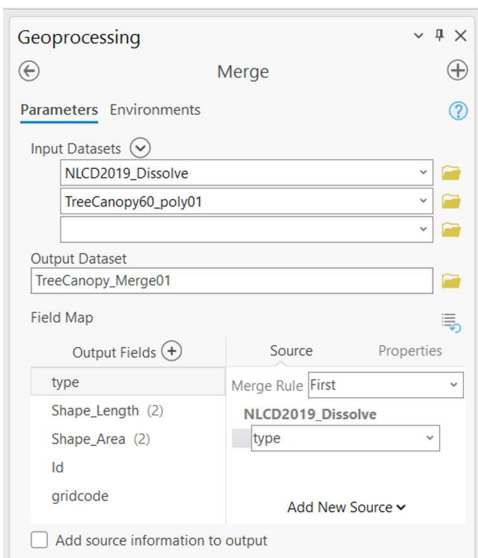




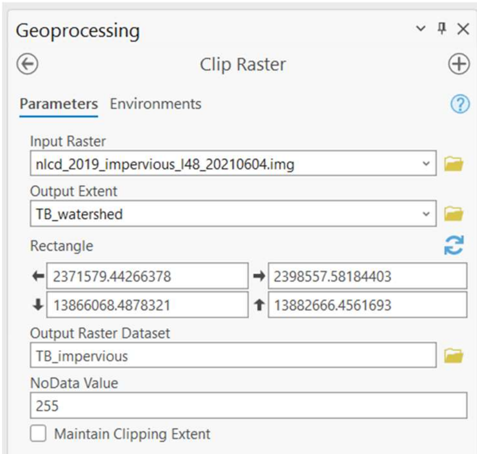
- Convert Tree canopy with **Raster to Polygon** tool.
  - Reclassified Tree Canopy
  - Field: Value



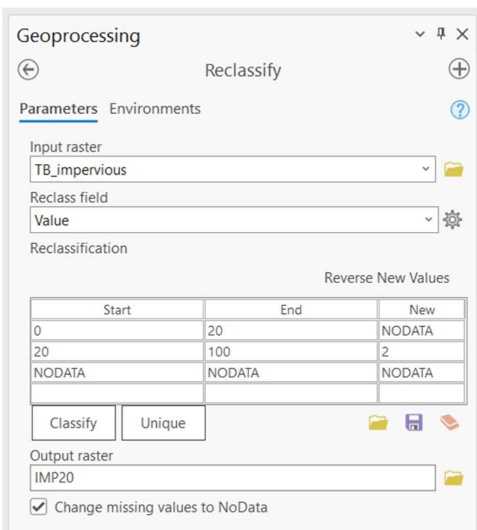
- **Merge** Tree canopy layer with the forest polygon from Land Use dataset.
  - Input Datasets: Dissolved Land Cover (with "forest" land use type selected), Tree Canopy polygon.

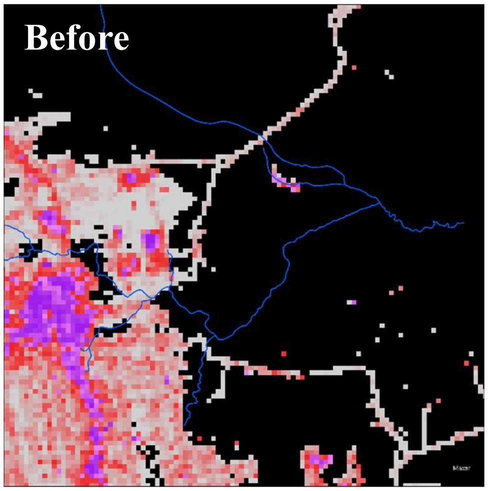


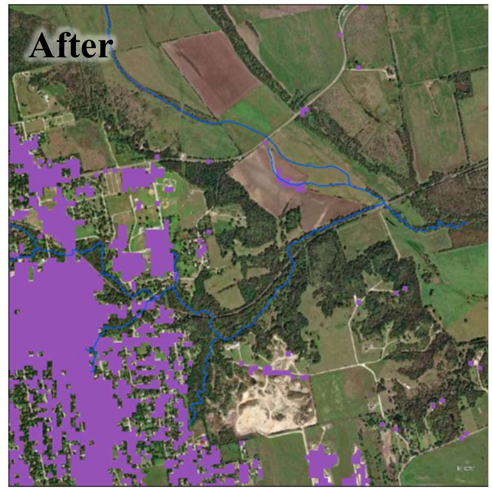
- Clip Impervious raster to project area with **Clip Raster** tool.
    - Input Raster: National Land Cover Database Impervious Cover
    - Output Extent: Watershed Drainage Area



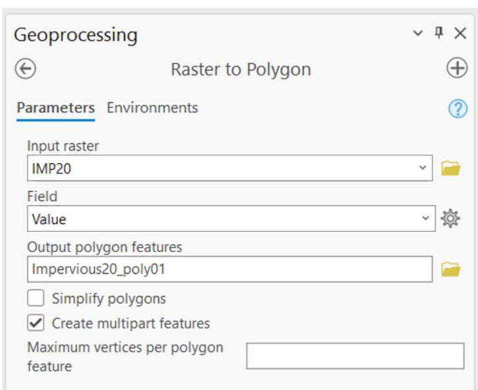
- **Reclassify** raster so that impervious cover of 20% or greater receives a new value of 1 and all other impervious cover percentages are assigned a NODATA value.
    - Input Raster: Clipped Impervious Cover
    - Reclass Field: Value



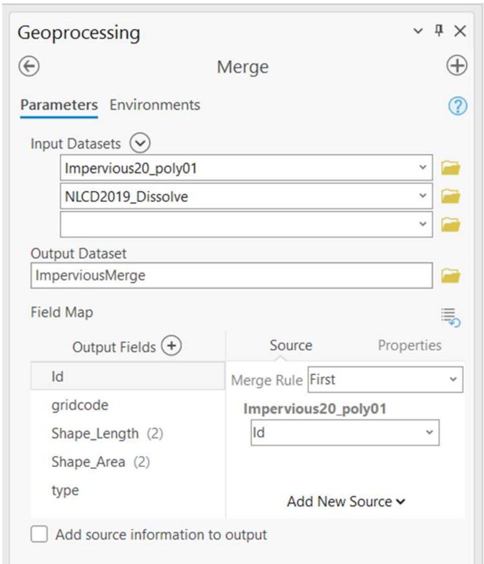




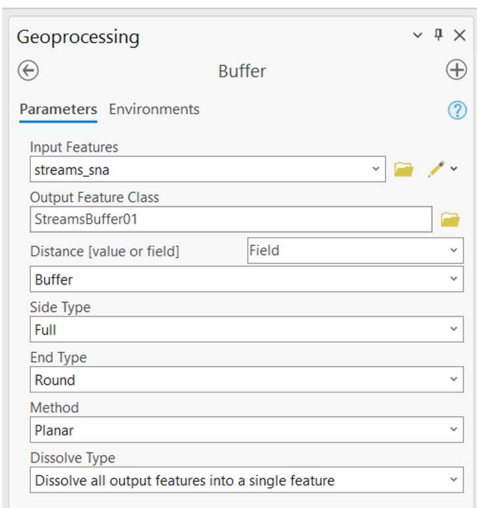
- Convert Impervious layer with **Raster to Polygon** tool.
    - Reclassified Impervious Cover
    - Field: Value



- **Merge** Impervious layer with the Impervious polygon from Land Use dataset.
    - Input Datasets: Dissolved Land Cover (with “impervious” land use type selected), Impervious Cover polygon.



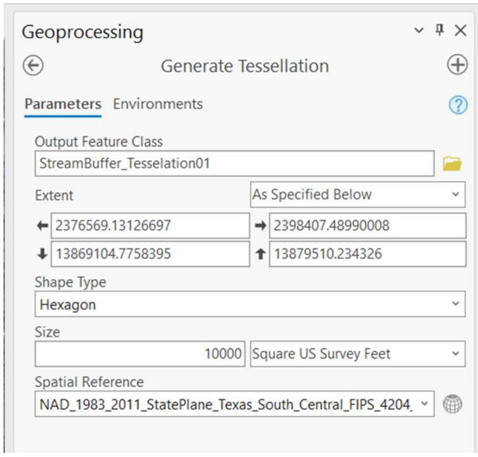
- **Buffer** streams based on drainage area.



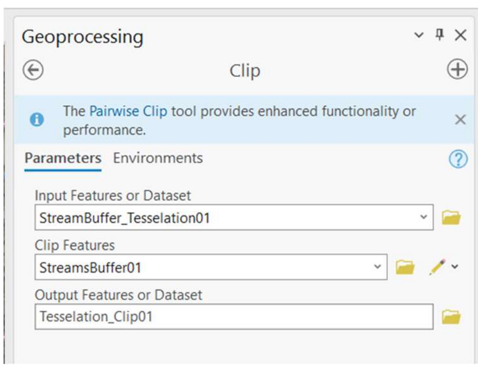
Field: Selection:

	_1 *	Shape *	Reach *	acres	Buffer	Shape_Length	Shape_Area
1		Polygon	TBC09	812.566842	300	34314.754976	35395553.229975
2		Polygon	TBC25	420.145246	200	22876.490906	18301600.10732
3		Polygon	TBC24	308.900779	100	16644.577262	13455771.748009
4		Polygon	TBC08	178.639896	300	13945.027638	7781584.974468
5		Polygon	TBC21	94.211419	100	10535.127258	4103865.832372

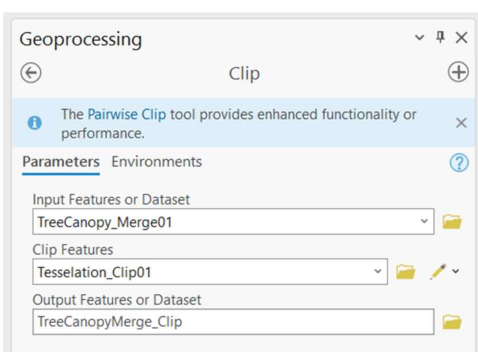
- Create IRI score grid using Generate Tessellation.

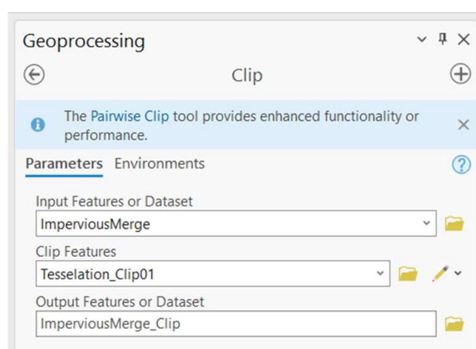


- Select hexagons that intersect with stream buffers, export as new layer.
- Clip hexagonal grid to stream buffers.

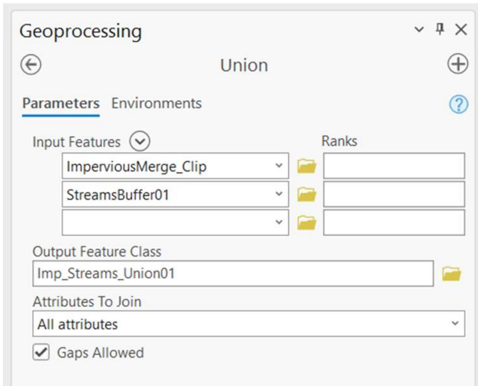


- Repeat this step with impervious and tree canopy layers.

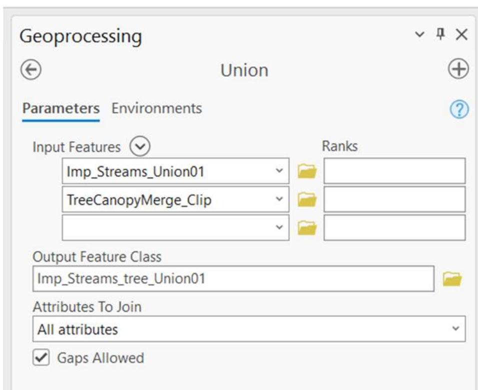




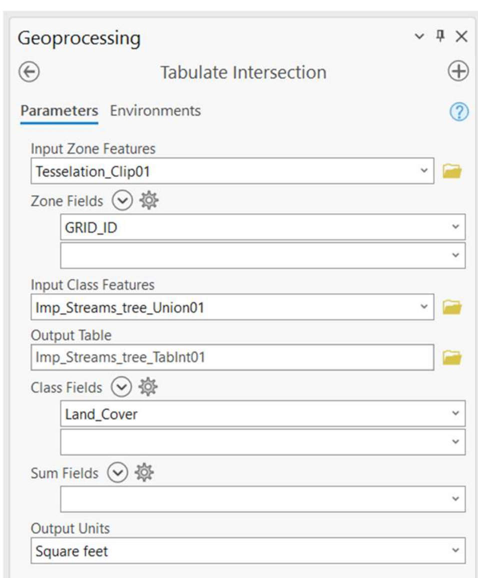
- Perform **Union** with impervious layer and stream buffer.



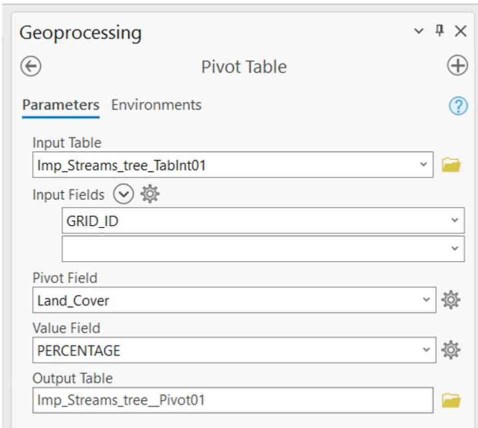
- Perform **Union** with output of first Union and tree canopy layer.

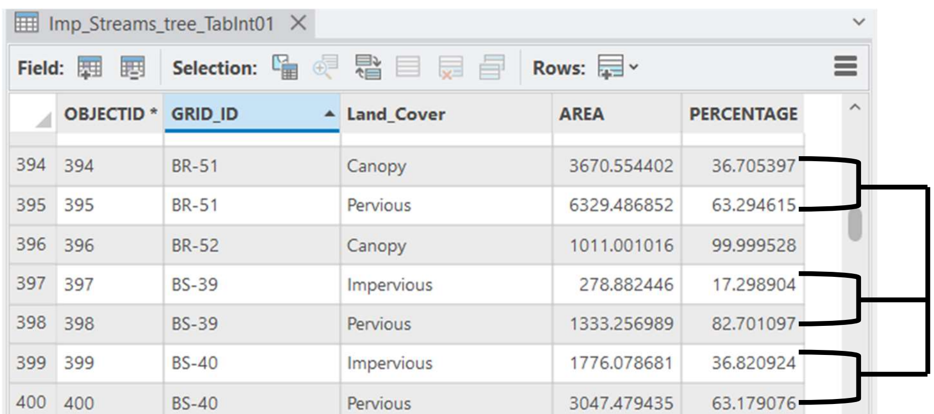


- **Tabulate Intersection** between hexagonal grid and the output of the second **Union**.



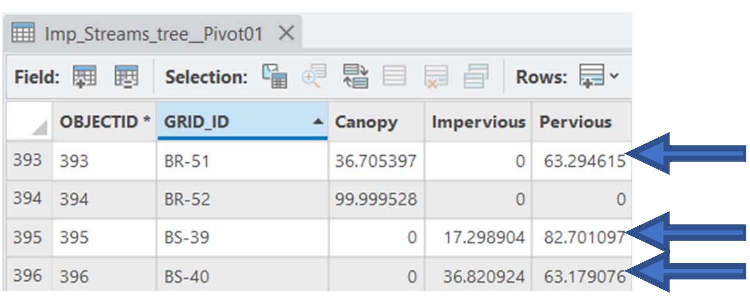
- Run **Pivot Table** on the output from the **Tabulate Intersection**. Creates one to many relationship with land cover and hexagonal grid
  - Input Table: Tabulate Intersection output
  - Input Field: GRID_ID
  - Pivot Field: Land Cover type
  - Value Field: Percentage





	OBJECTID *	GRID_ID	Land_Cover	AREA	PERCENTAGE
394	394	BR-51	Canopy	3670.554402	36.705397
395	395	BR-51	Pervious	6329.486852	63.294615
396	396	BR-52	Canopy	1011.001016	99.999528
397	397	BS-39	Impervious	278.882446	17.298904
398	398	BS-39	Pervious	1333.256989	82.701097
399	399	BS-40	Impervious	1776.078681	36.820924
400	400	BS-40	Pervious	3047.479435	63.179076

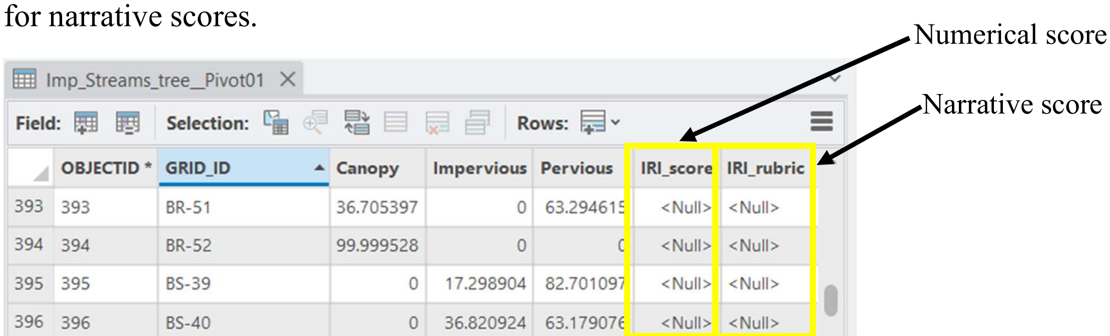
Before: There are multiple entries for each hexagon for each land use category.



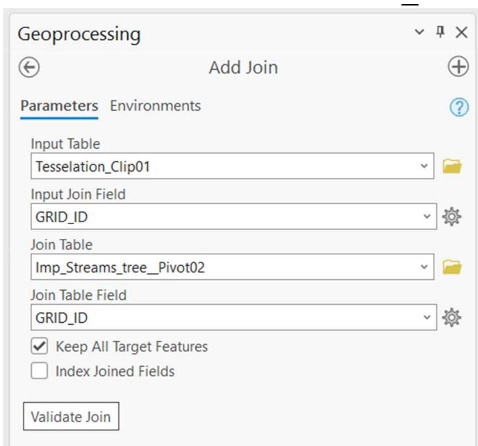
	OBJECTID *	GRID_ID	Canopy	Impervious	Pervious
393	393	BR-51	36.705397	0	63.294615
394	394	BR-52	99.999528	0	0
395	395	BS-39	0	17.298904	82.701097
396	396	BS-40	0	36.820924	63.179076

After: The entries are flattened so that the land use categories are represented as attributes.

- Add a new field to calculate Index of Riparian Integrity numerical score, add new field for narrative scores.

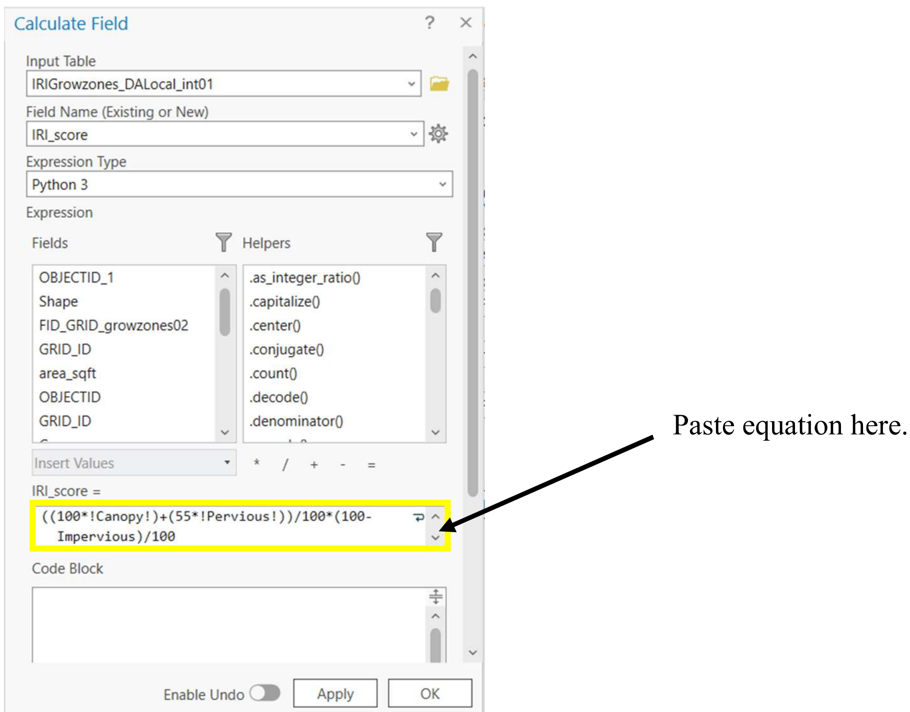


- **Join** the pivoted table to the clipped hexagonal grid & **Export** as new dataset.
  - Input Table: Hexagonal Grid
  - Input Join Field: GRID_ID
  - Join Table: Pivot Table
  - Join Table Field: GRID_ID



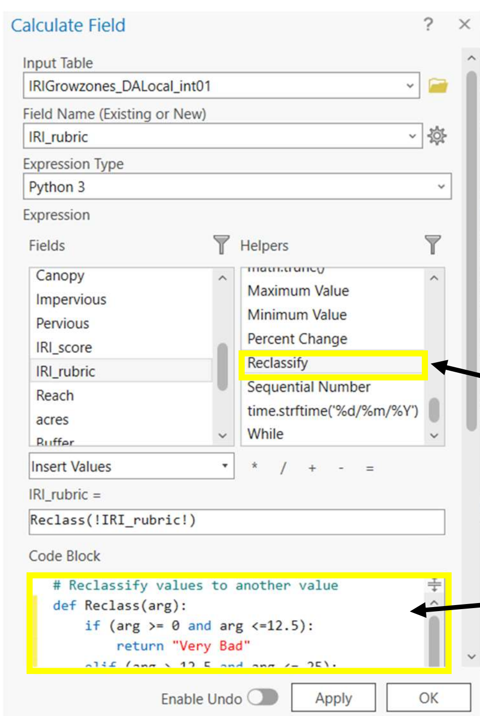
- **Calculate** numerical and narrative scores:
    - For numerical scores, copy and paste this equation (be mindful of whether you used area or percent cover) in the **Calculate Field** dialog box. *Make sure to double check that you change the field names in the equation to match the field names that you used in your analysis. *

*When using area:	((100*(!Canopy!/!SUM_Shape_Area!))+(55*(!Pervious!/!SUM_Shape_Area!)))*((1-!Impervious!/!SUM_Shape_Area!))
When using % Cover:	((100*!Canopy!)+(55*!Pervious!))/100*(100-Impervious)/100



- For narrative scores, copy and paste this equation in the Calculate Field dialog box.:

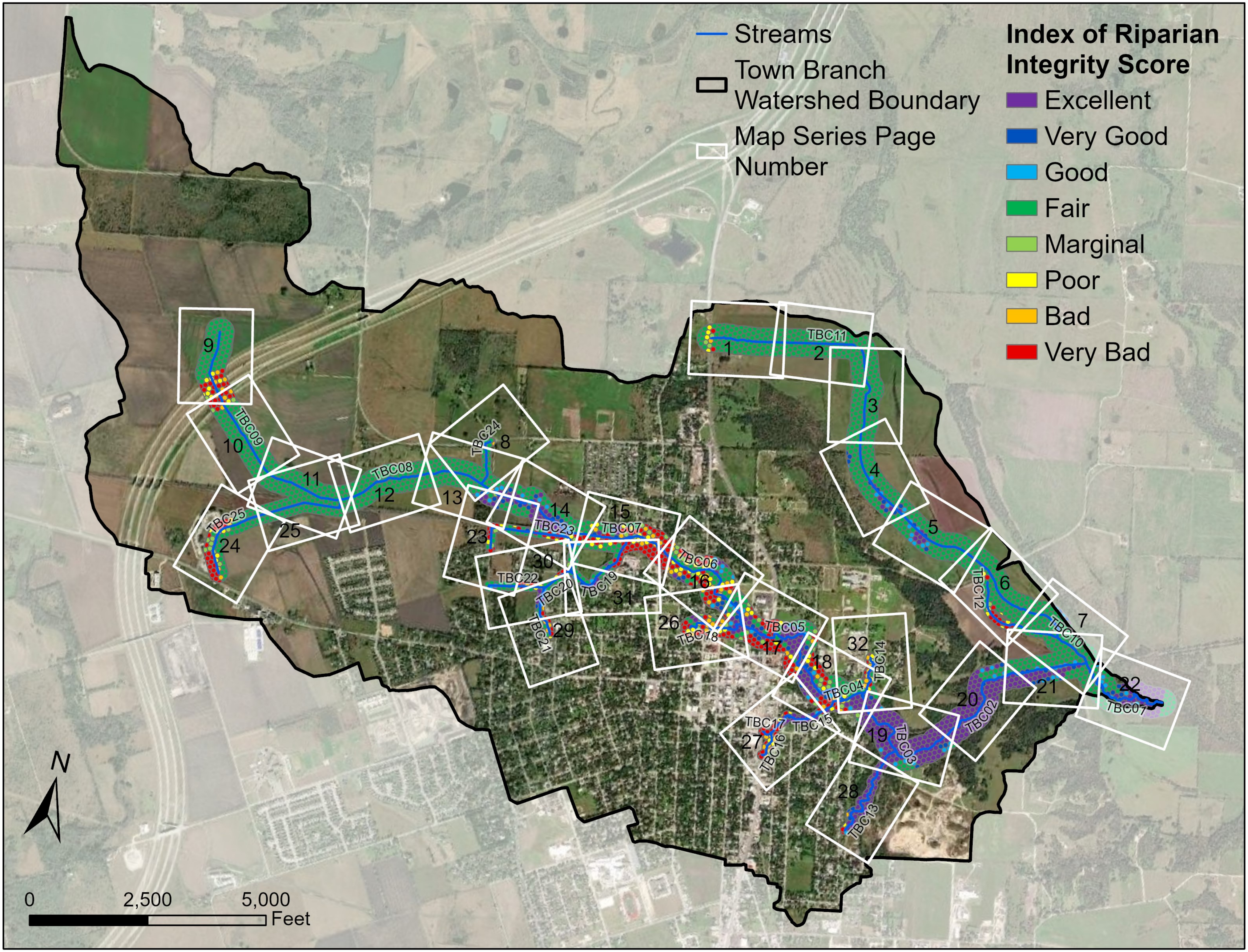
```
# Reclassify values to another value
def Reclass(arg):
    if (arg >= 0 and arg <=12.5):
        return "Very Bad"
    elif (arg > 12.5 and arg <= 25):
        return "Bad"
    elif (arg > 25 and arg <= 37.5):
        return "Poor"
    elif (arg > 37.5 and arg <= 50):
        return "Marginal"
    elif (arg > 50 and arg <= 62.5):
        return "Fair"
    elif (arg > 62.5 and arg <= 75):
        return "Good"
    elif (arg > 75 and arg <= 87.5):
        return "Very Good"
    elif (arg > 87.5 and arg <= 100):
        return "Excellent"
```



1. Find "Reclassify" to the Helpers box, double click so that "Reclass(!Field!)" appears in the dialog box below.
2. Make sure to replace "!Field!" with the narrative score attribute, called IRI_rubric in this example.
3. Paste code into the Code Block box.

APPENDIX B

Index of Riparian Integrity Results: Baseline



Streams
Town Branch Watershed Boundary
Map Series Page Number
Index of Riparian Integrity Score
Excellent
Very Good
Good
Fair
Marginal
Poor
Bad
Very Bad
N
0
2,500
5,000
Feet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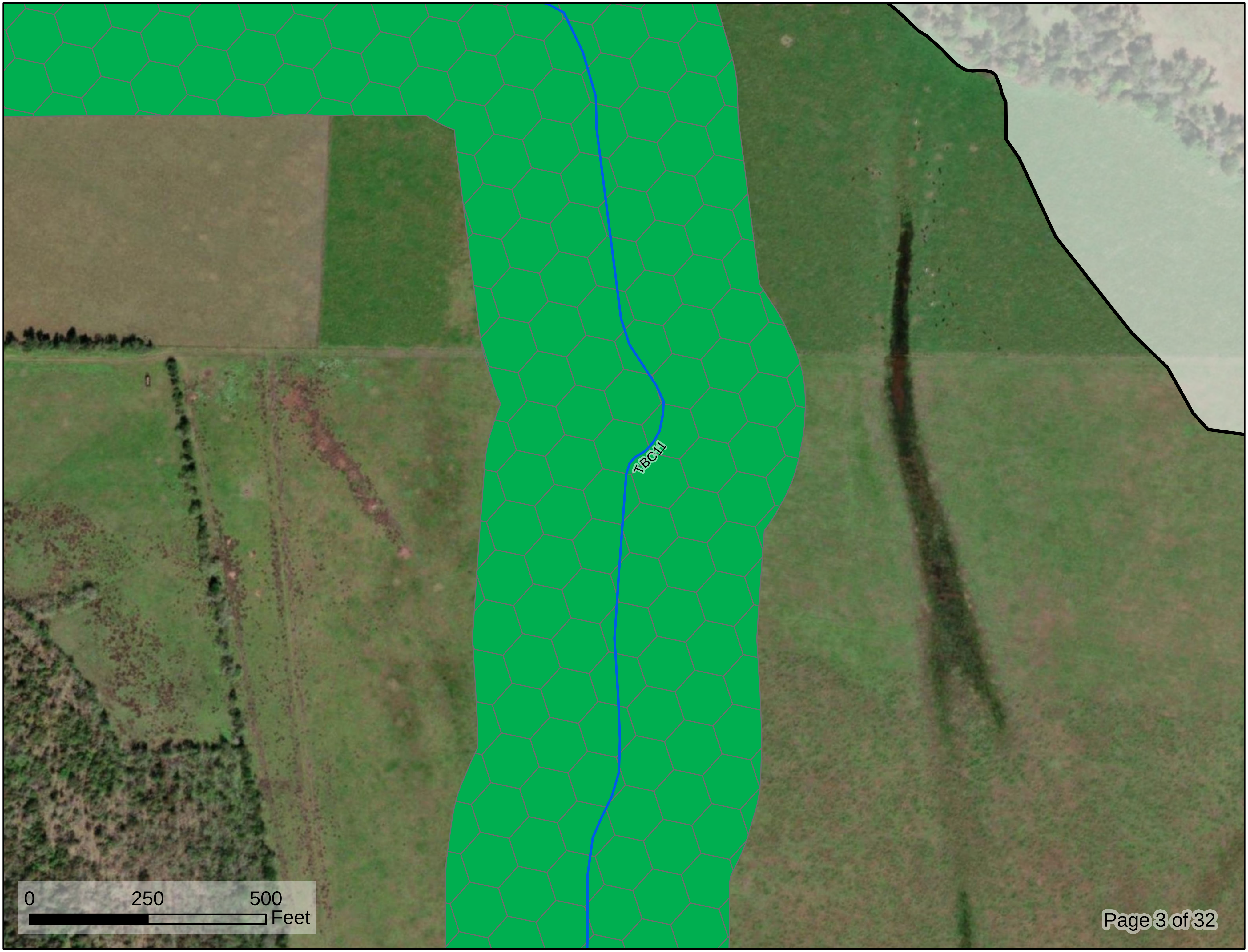
0
250
500
Feet
Page 1 of 32


TBC11
0
250
500
Feet
Page 2 of 32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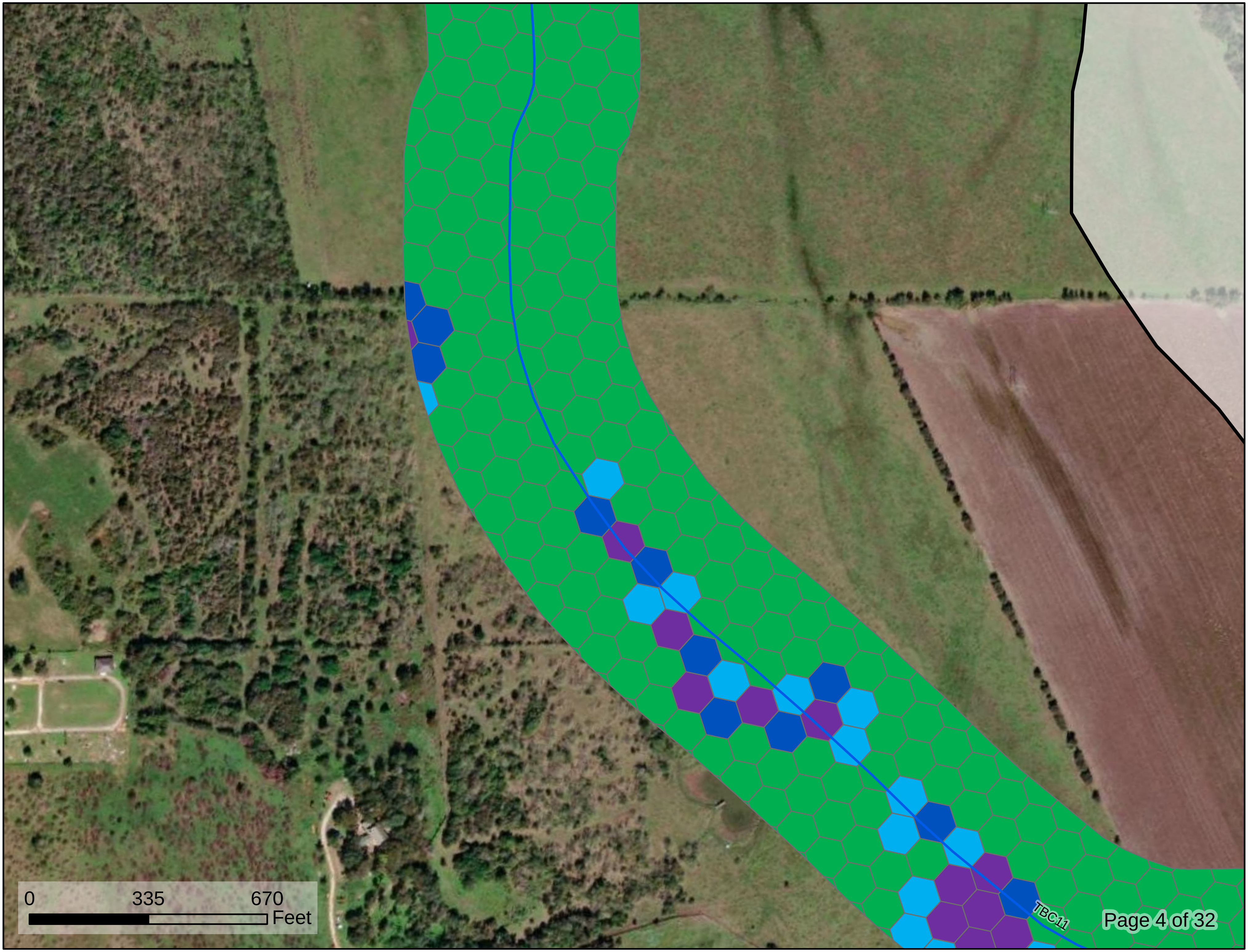
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Page 5 of 32

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TBC10
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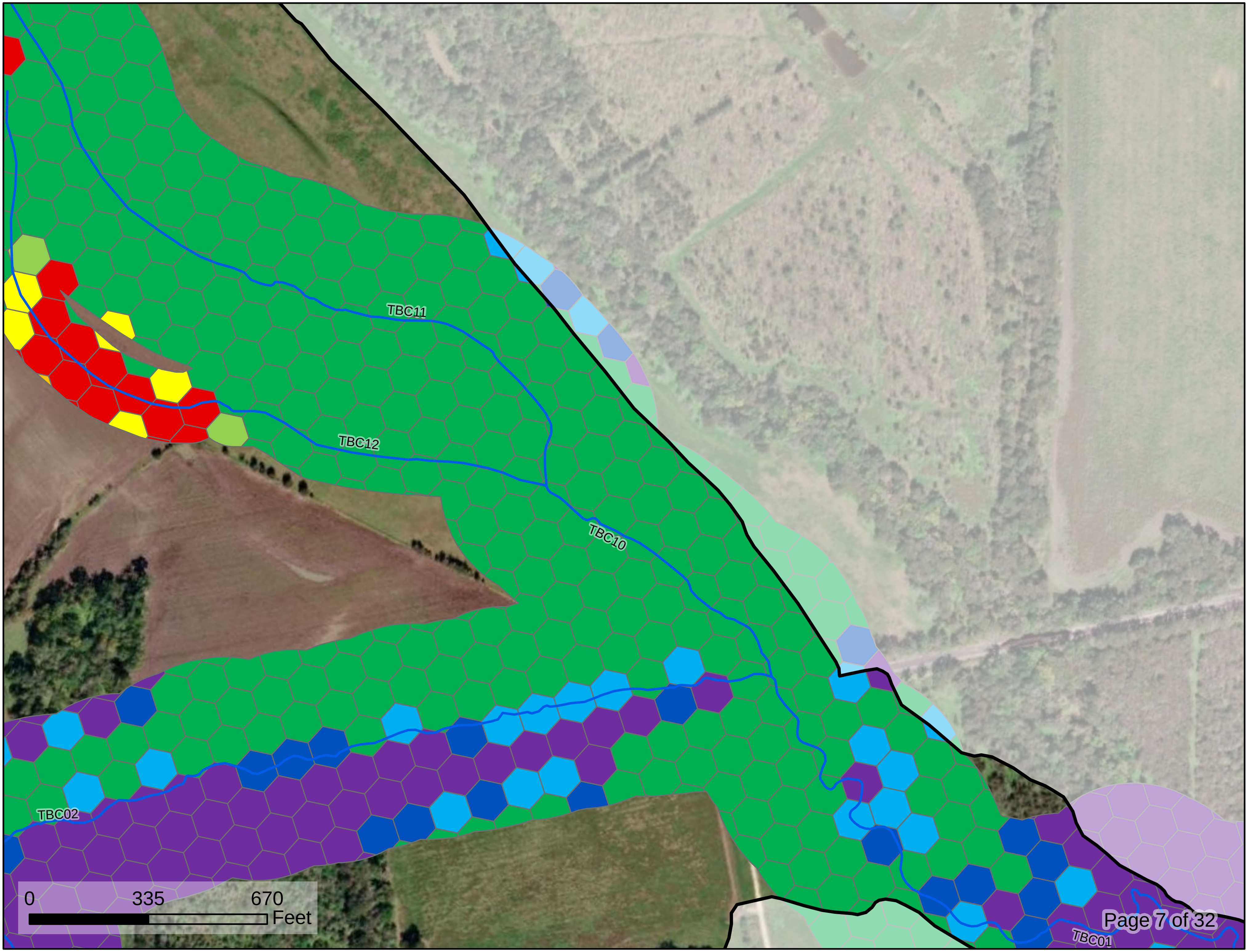
335
670
Feet
Page 6 of 32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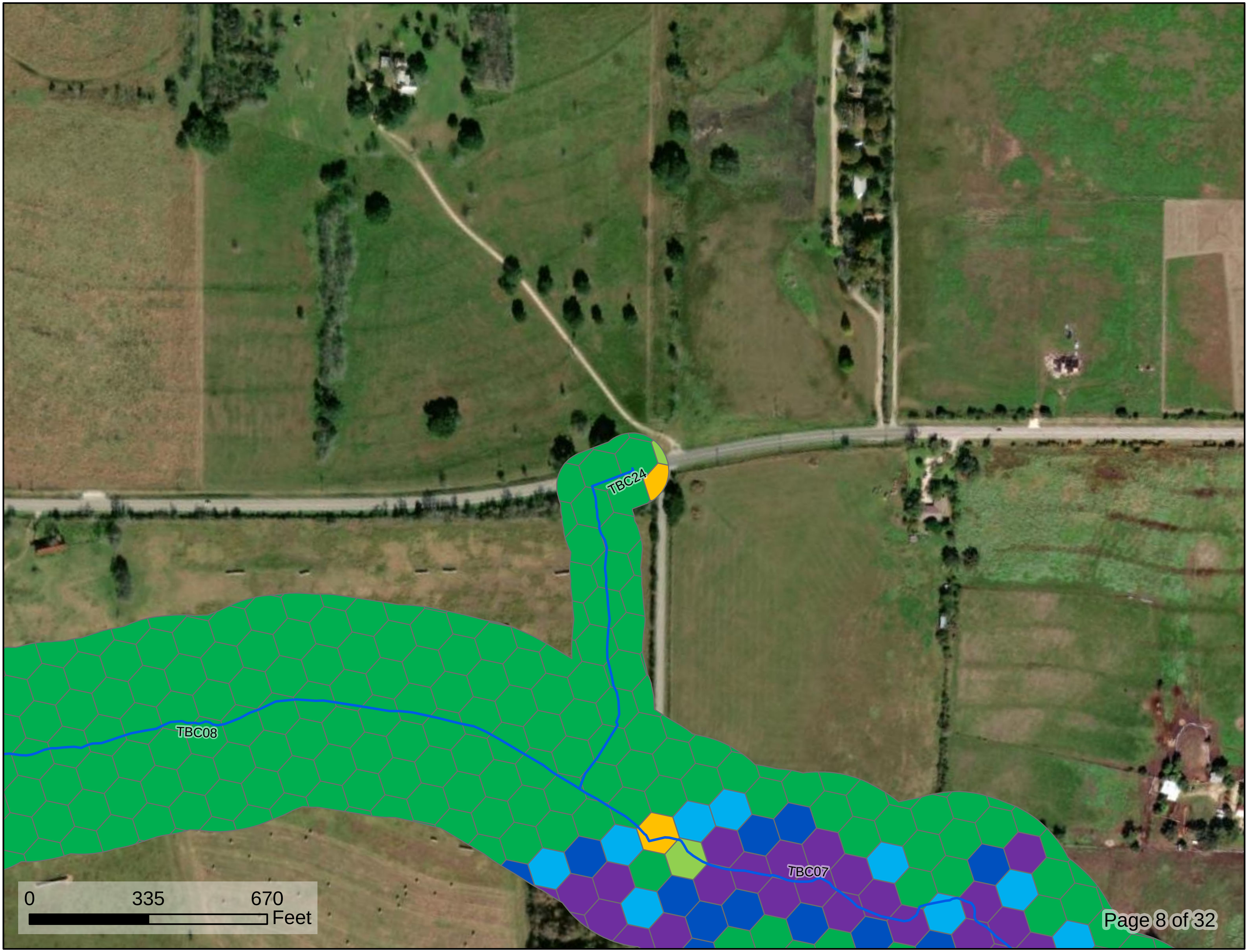
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Feet
Page 9 of 32


TBC09
0
335
670
Feet
Page 10 of 32


TBC09
TBC08
TBC25
0
250
500
Feet
Page 11 of 32


TBC08
TBC09
TBC25
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Feet
Page 12 of 32


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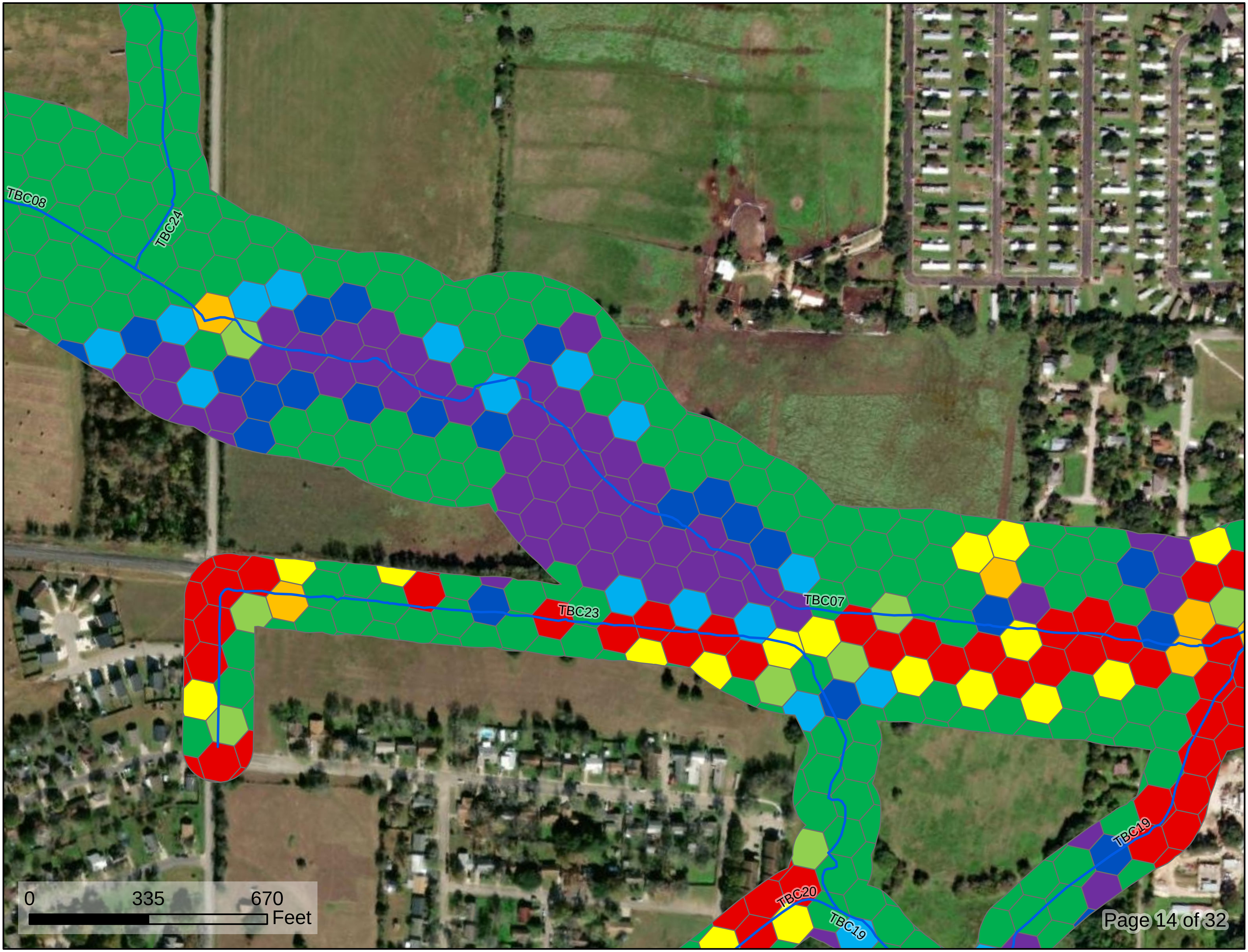
TBC08
TBC07
TBC23
0
250
500
Feet
Page 13 of 32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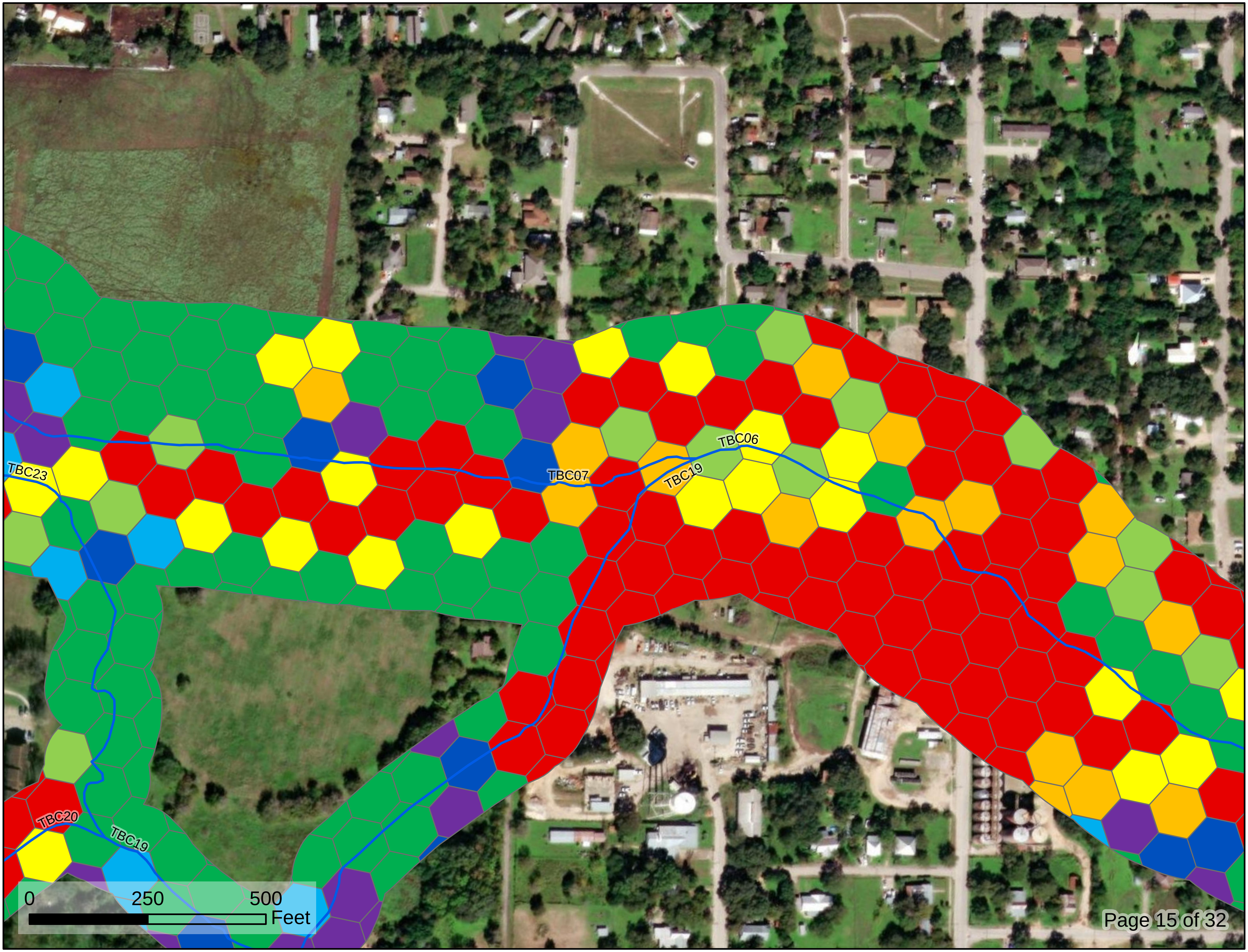
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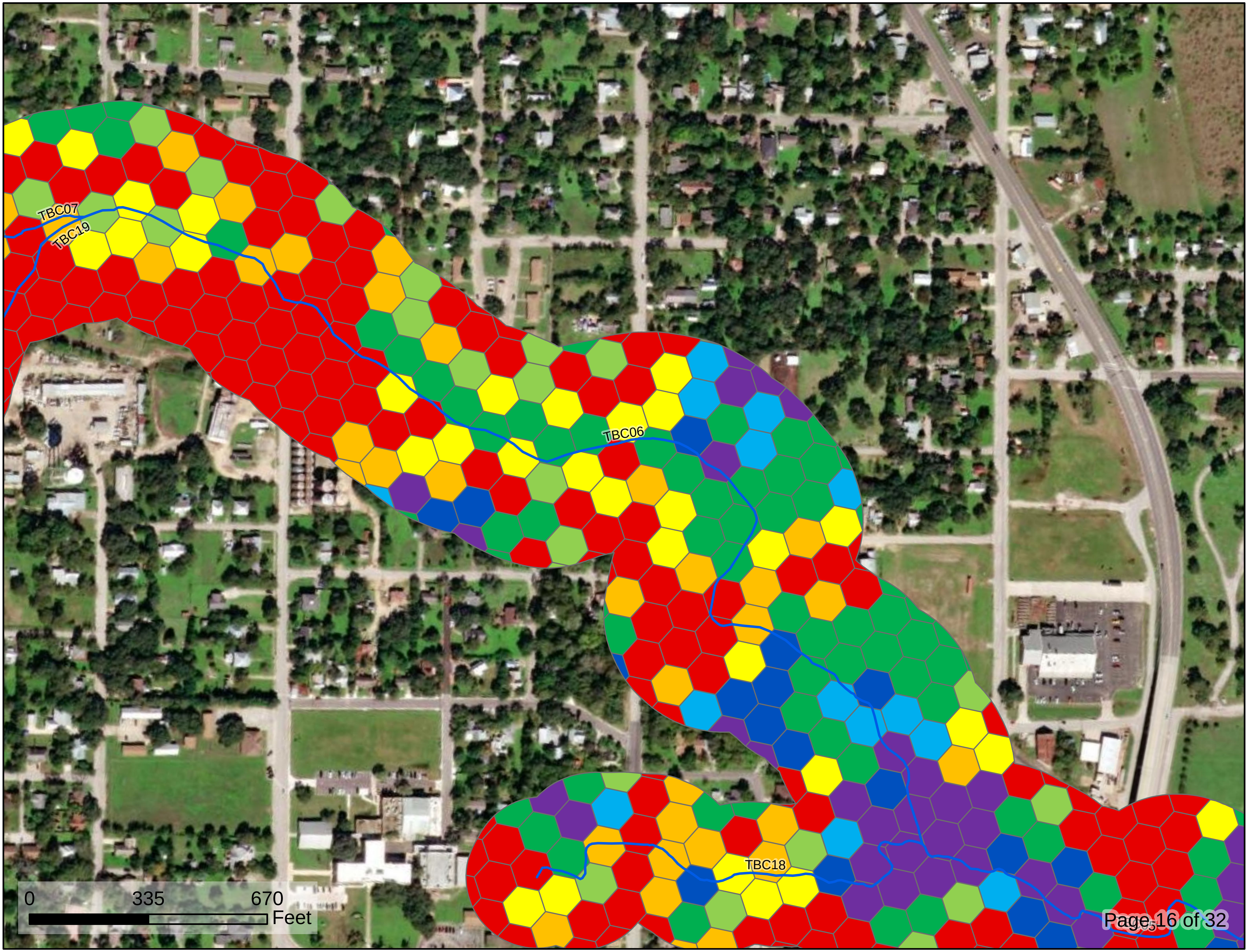
Page 15 of 32



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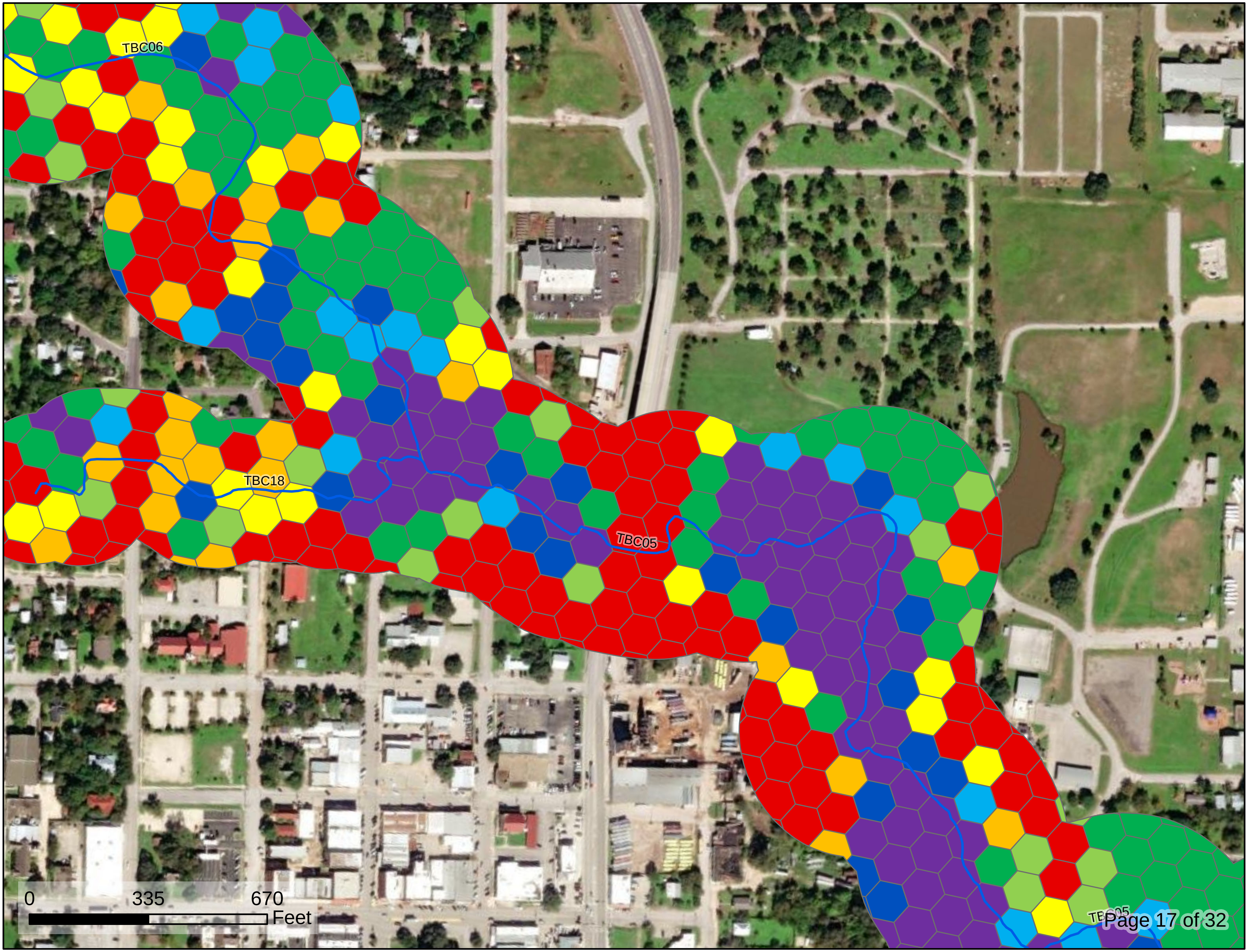
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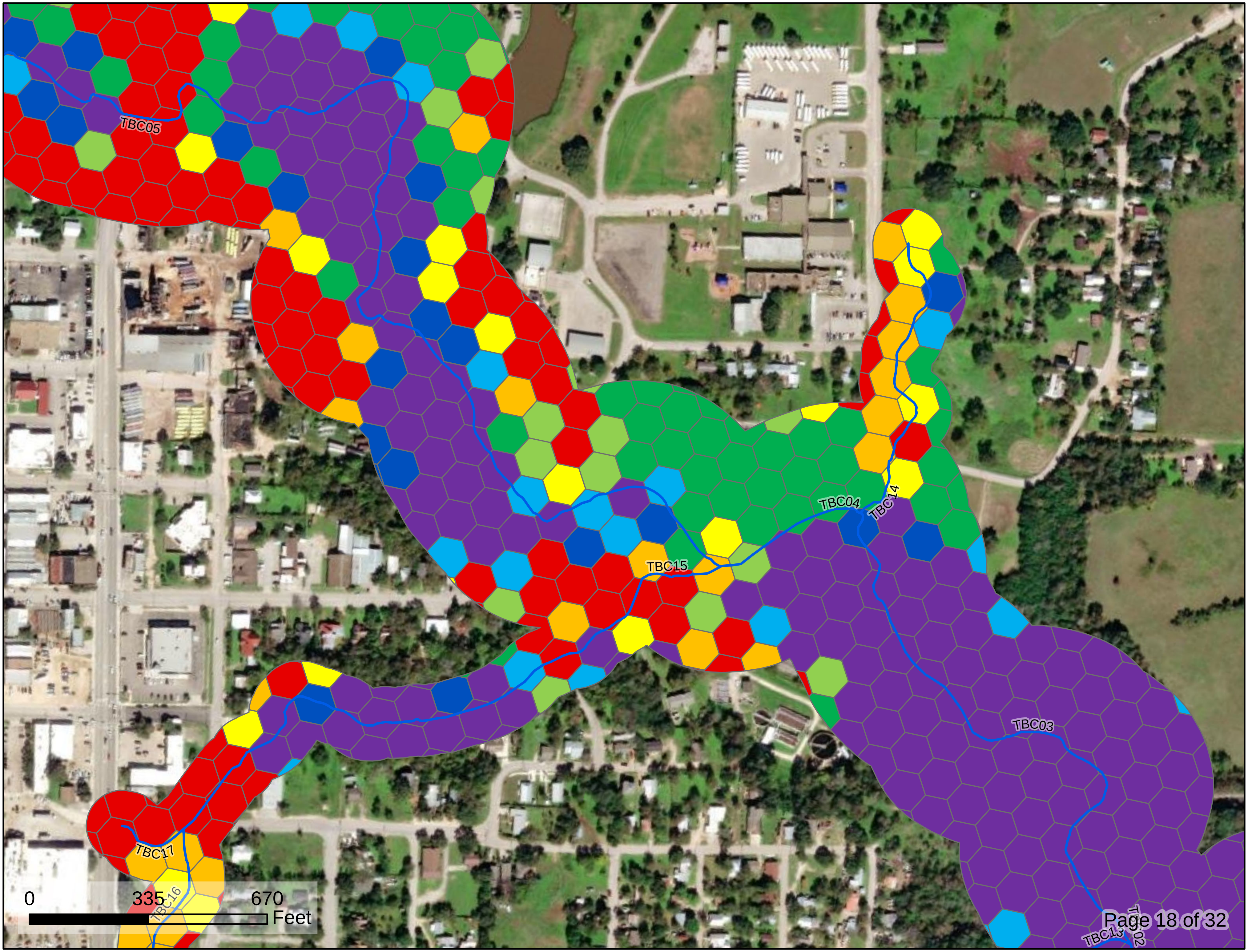
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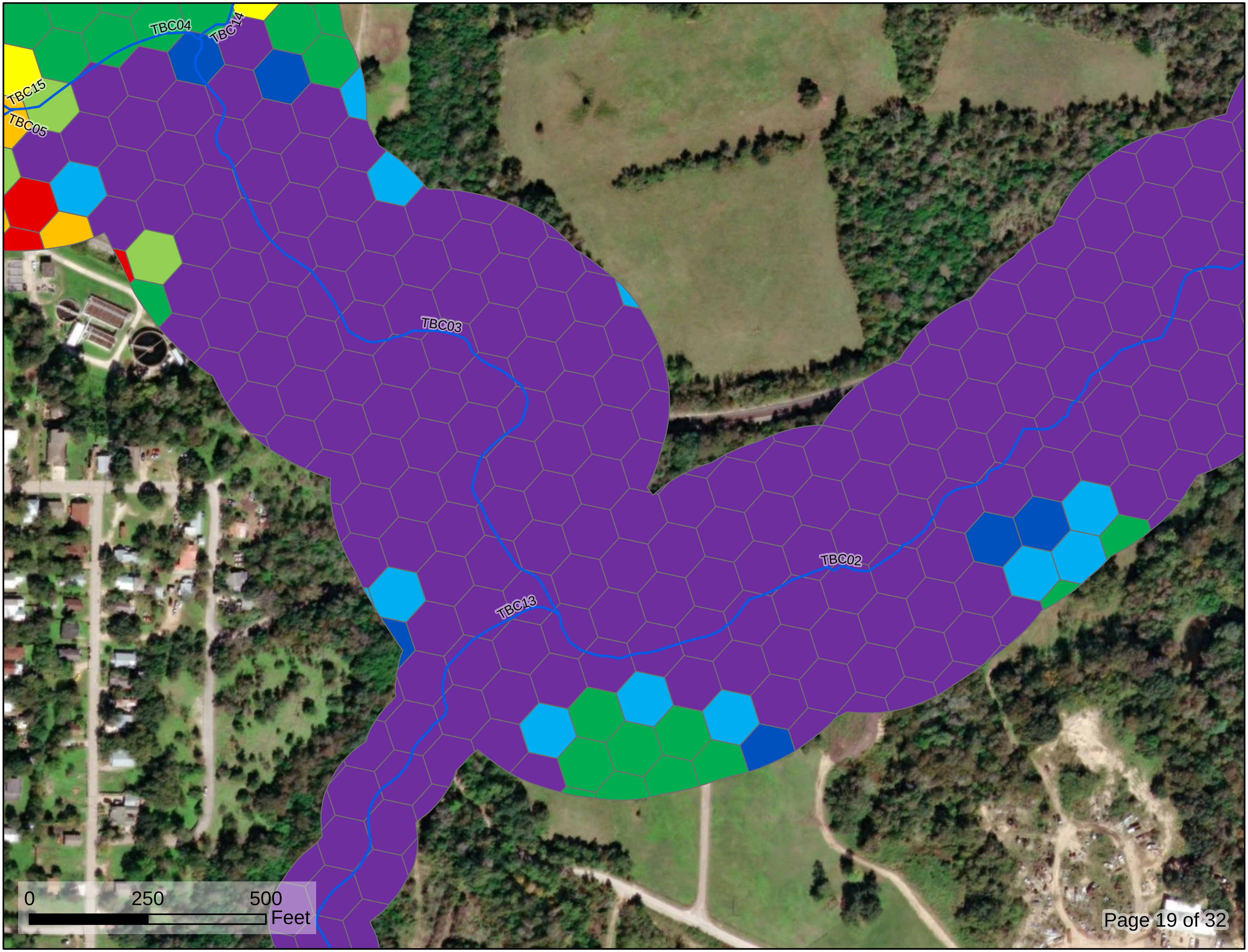
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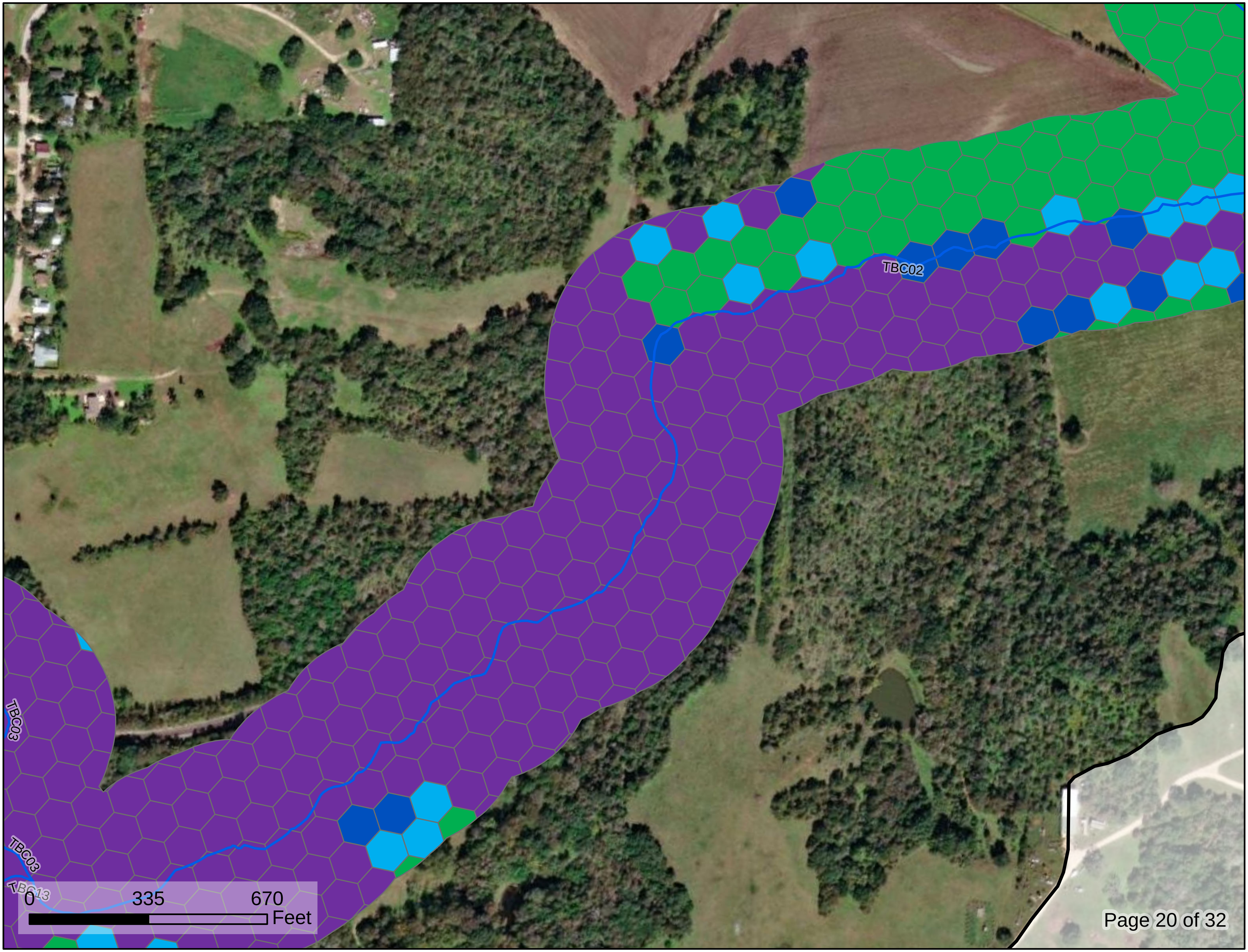
Page 19 of 32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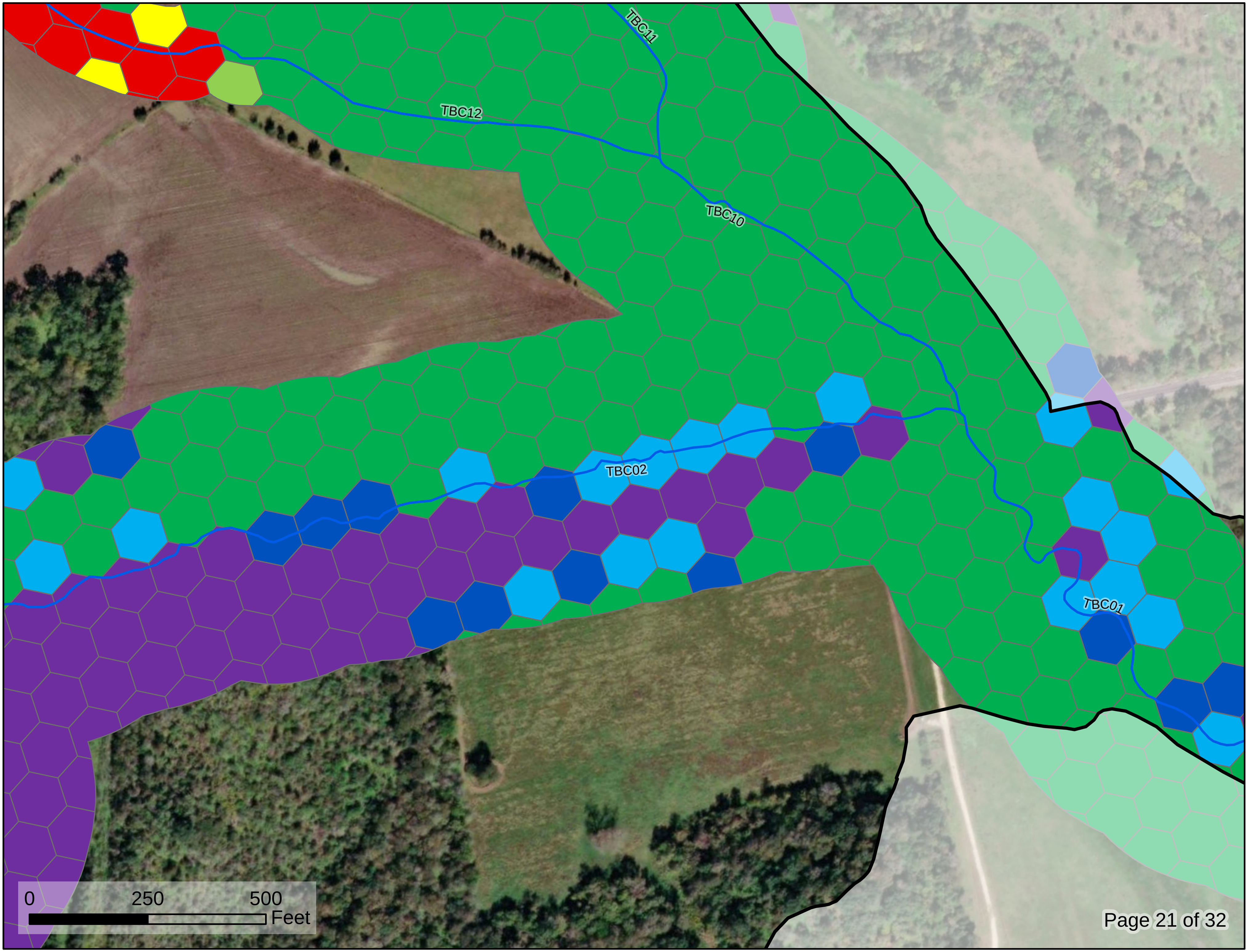
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TBC02
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250
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Feet
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TBC08
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TBC19
TBC20
TBC22
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Page 23 of 32


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Feet
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500
Feet
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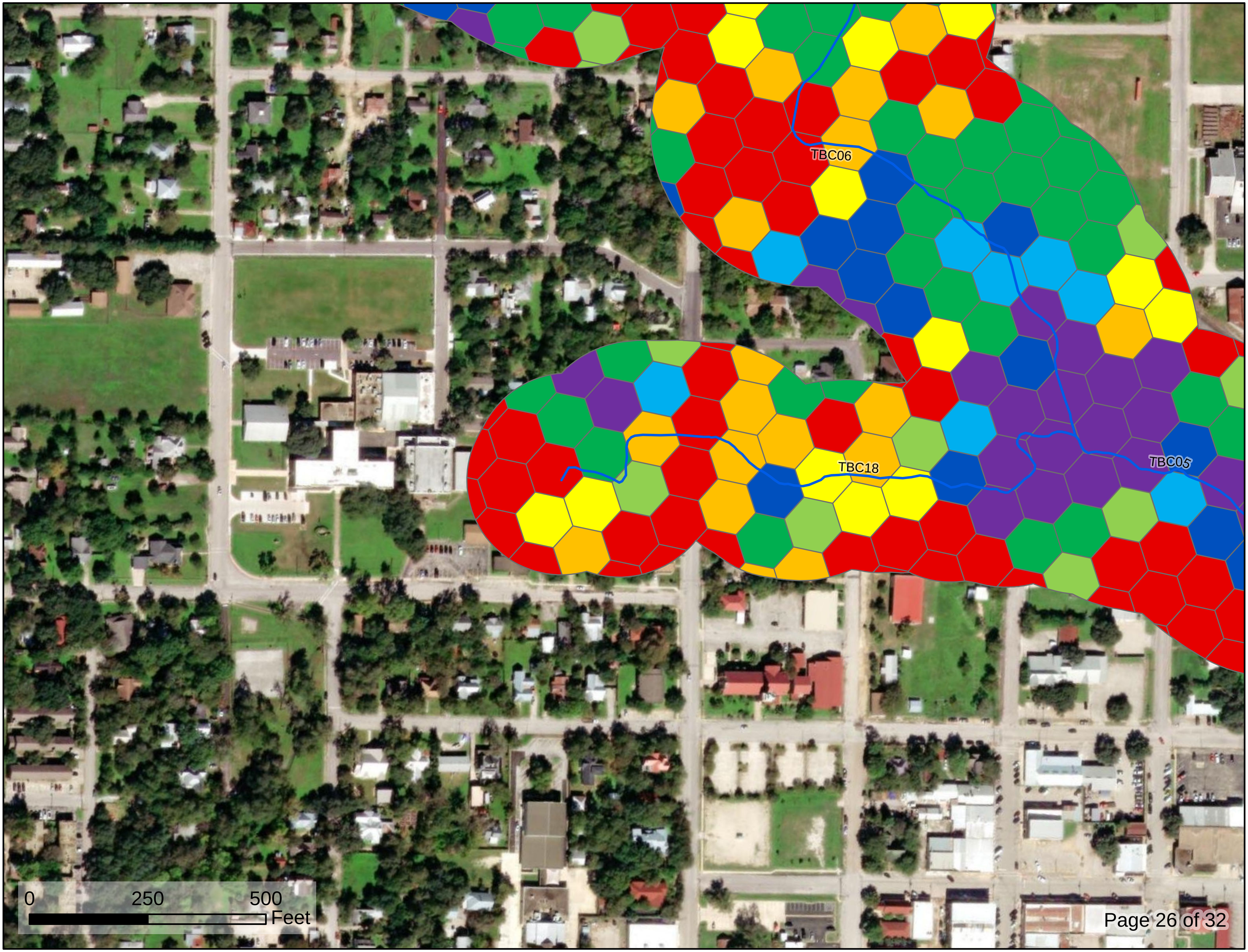
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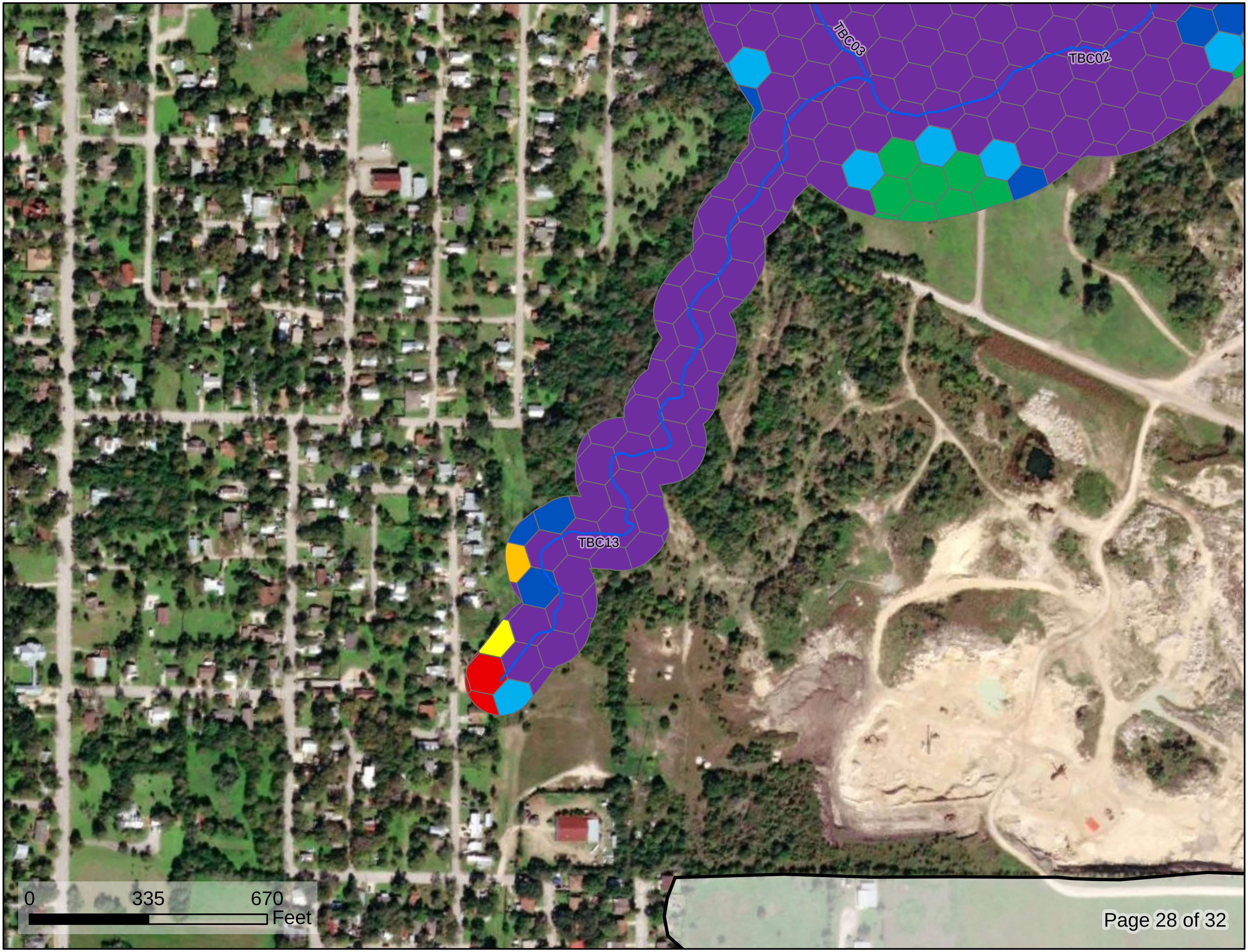
670
Feet
Page 27 of 32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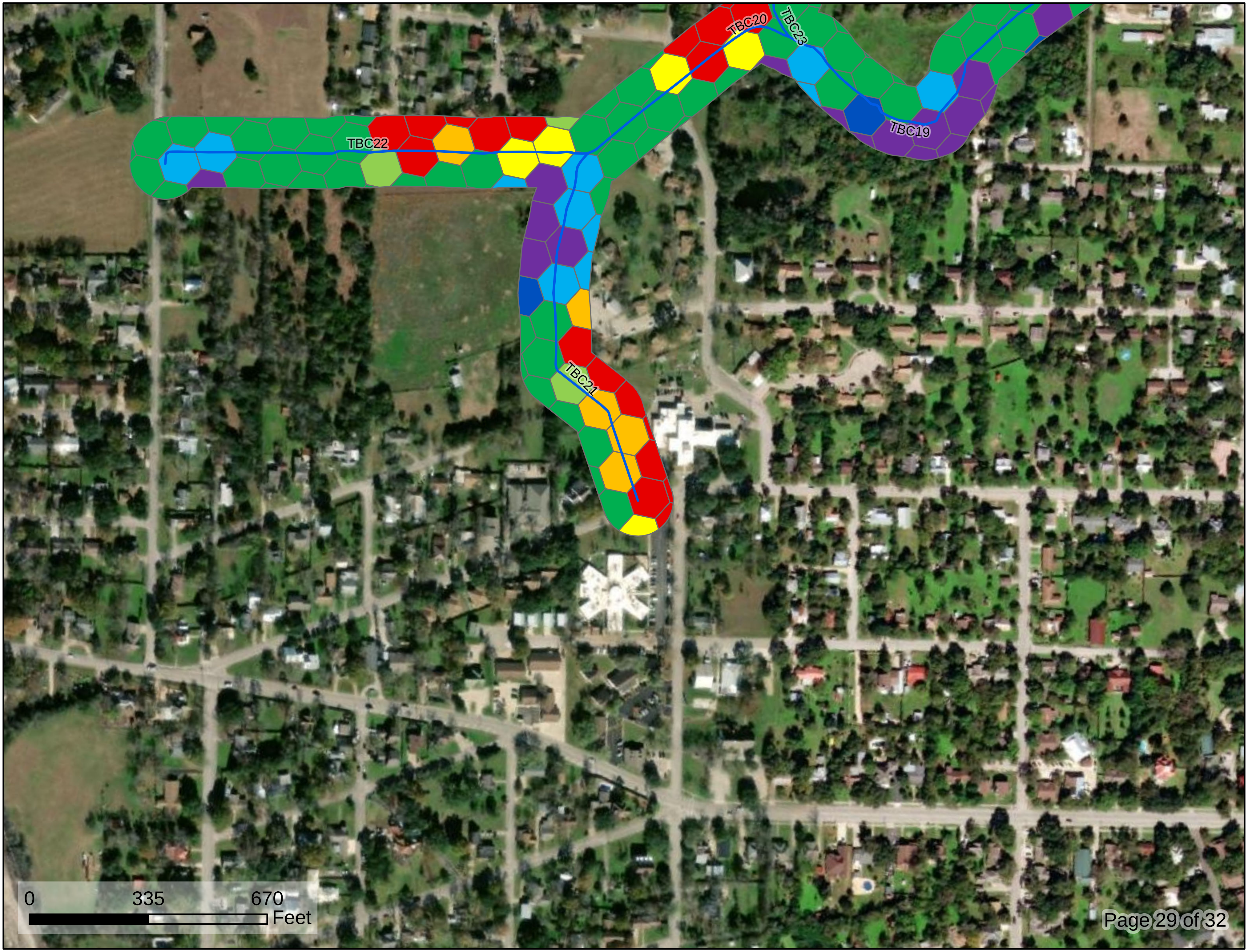
Feet
Page 28 of 32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TBC21
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TBC22
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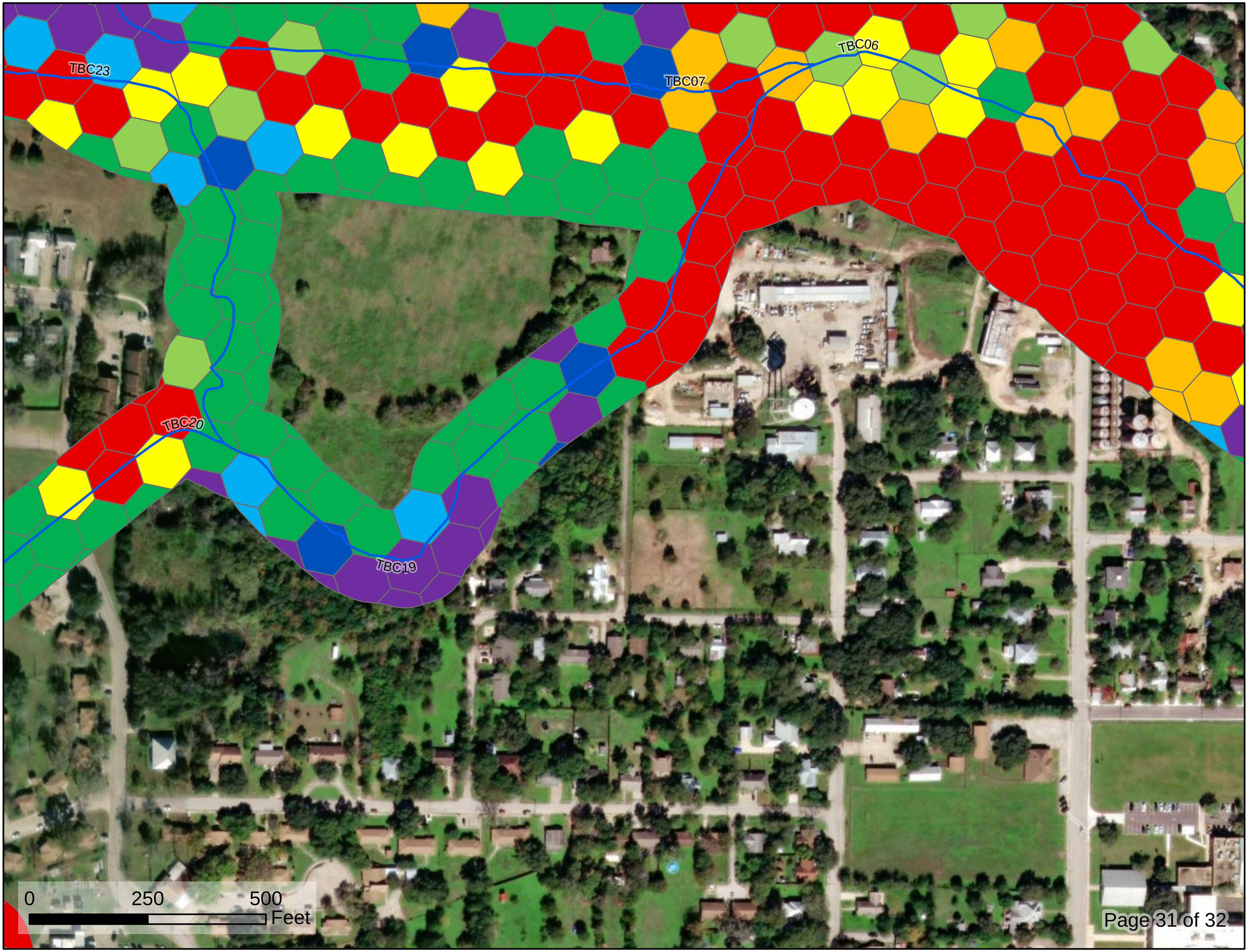
Feet
Page 30 of 32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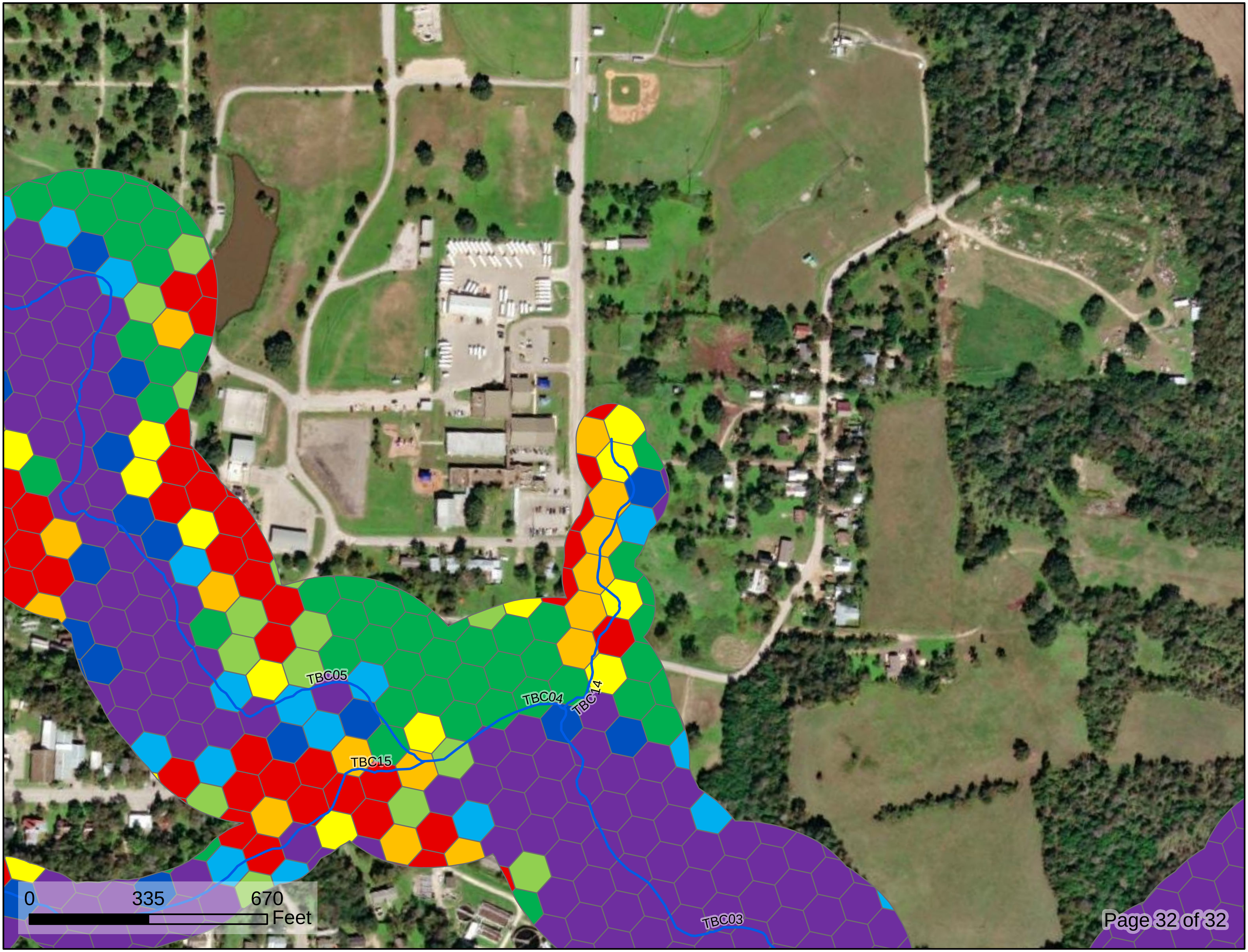
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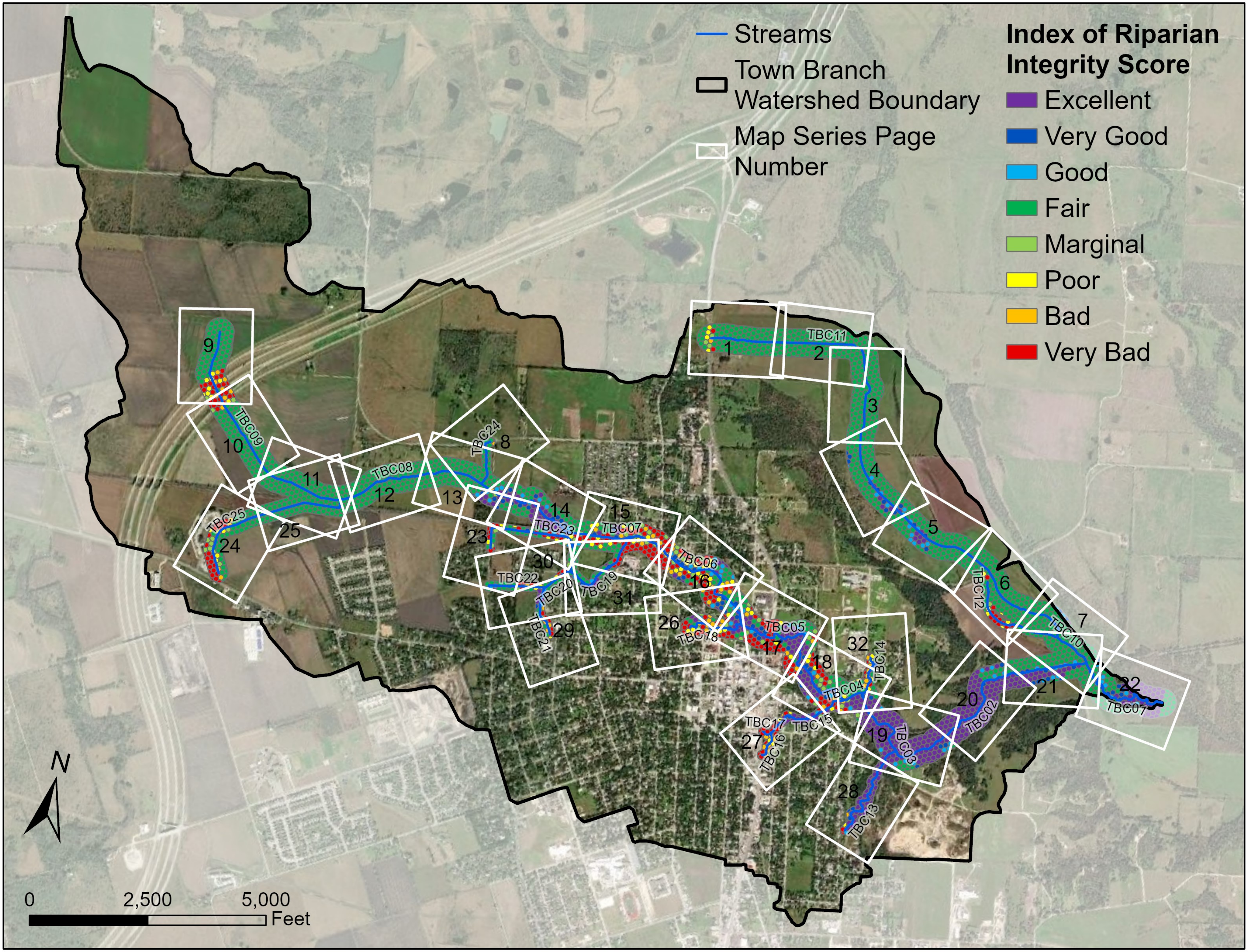
Feet
Page 32 of 32

APPENDIX C

Index of Riparian Integrity Results: Grow Zones


Streams
Town Branch Watershed Boundary
Map Series Page Number
Index of Riparian Integrity Score
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Very Good
Good
Fair
Marginal
Poor
Bad
Very Bad
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0
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5,000
Feet


TBC11
0
250
500
Feet
Page 1 of 32


TBC11
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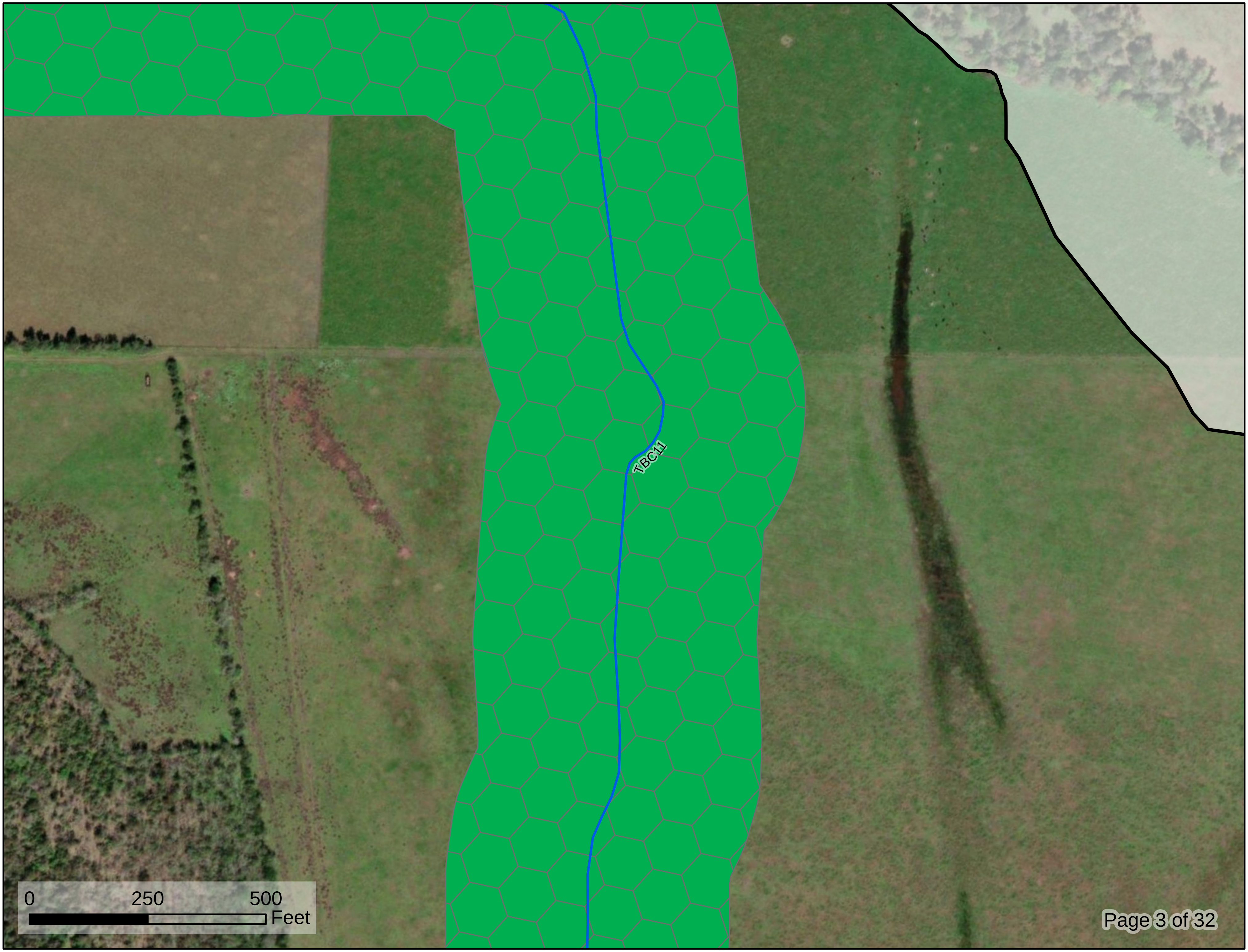
250
500
Feet
Page 2 of 32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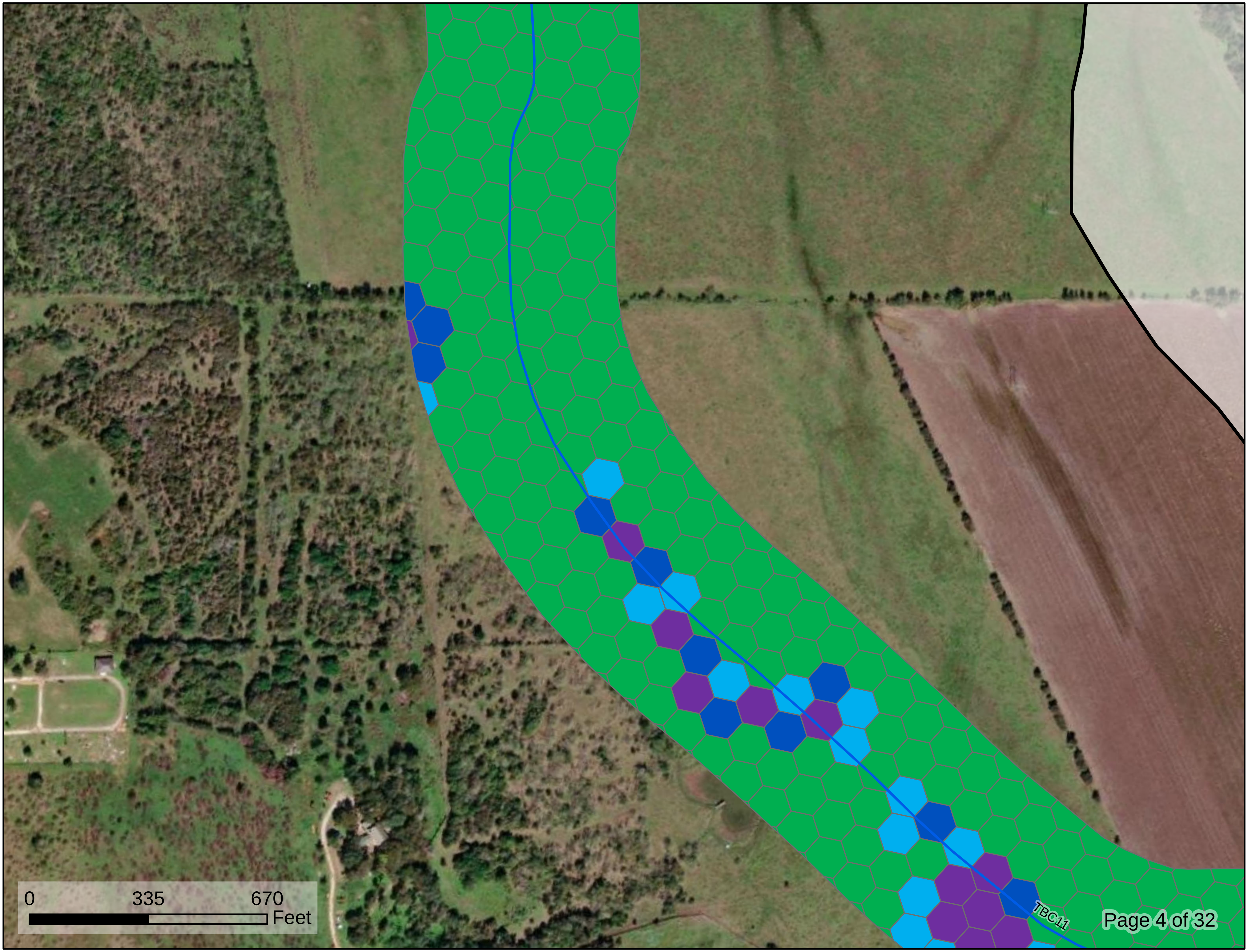
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670
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Page 4 of 32

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335
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Feet
Page 5 of 32


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TBC10
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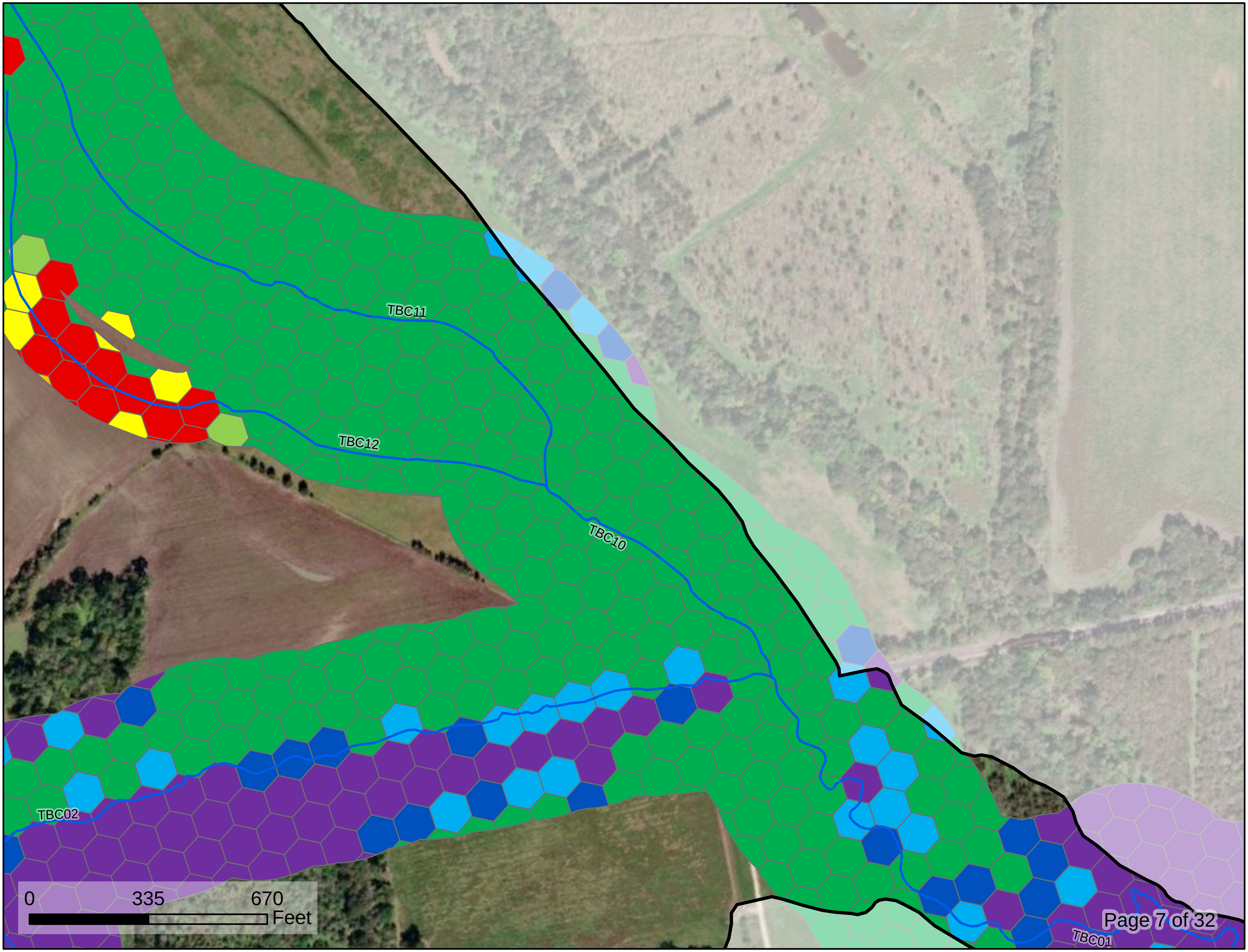
670
Feet
Page 6 of 32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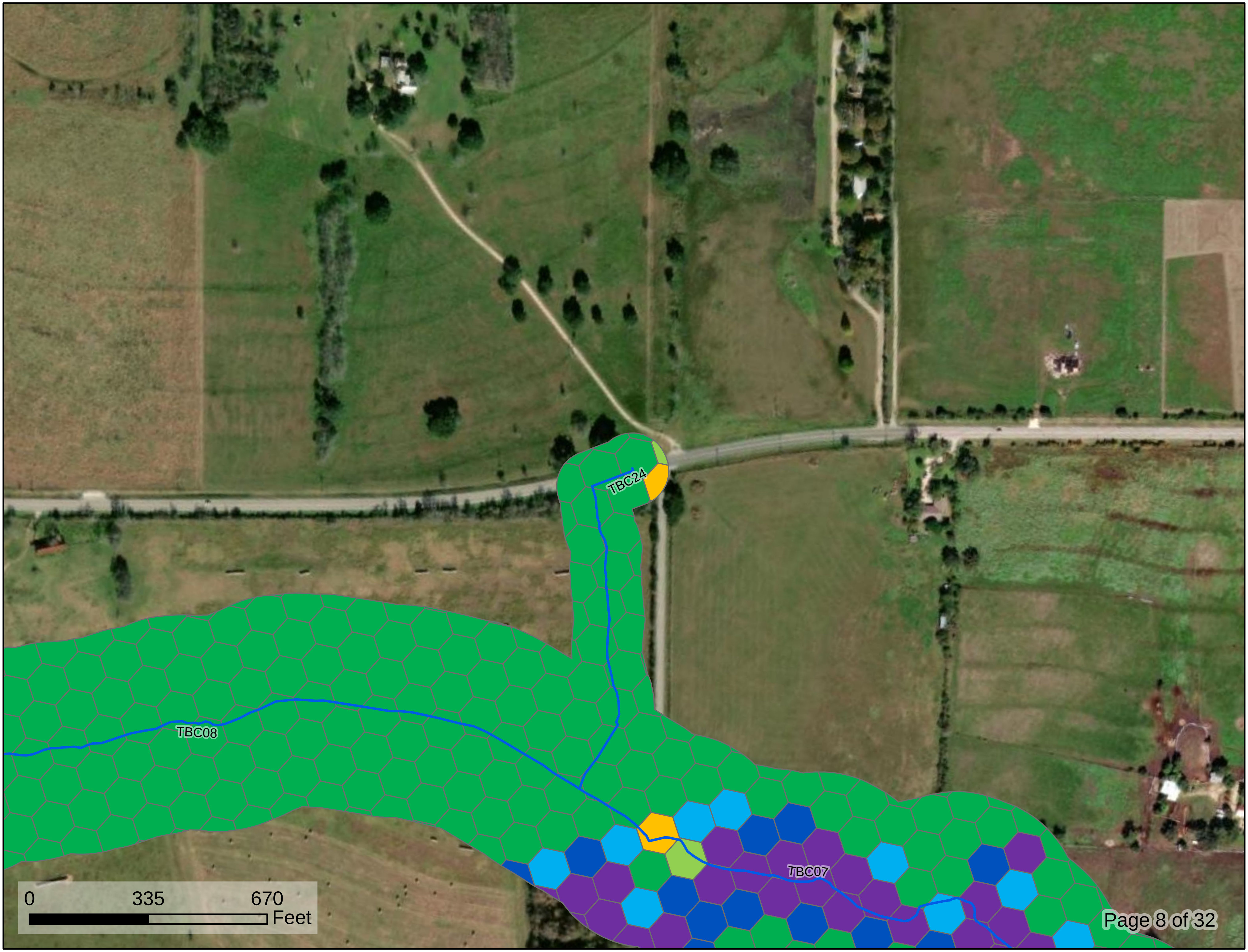

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Page 8 of 32

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Feet
Page 9 of 32


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500
Feet
Page 11 of 32


TBC08
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670
Feet


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Feet
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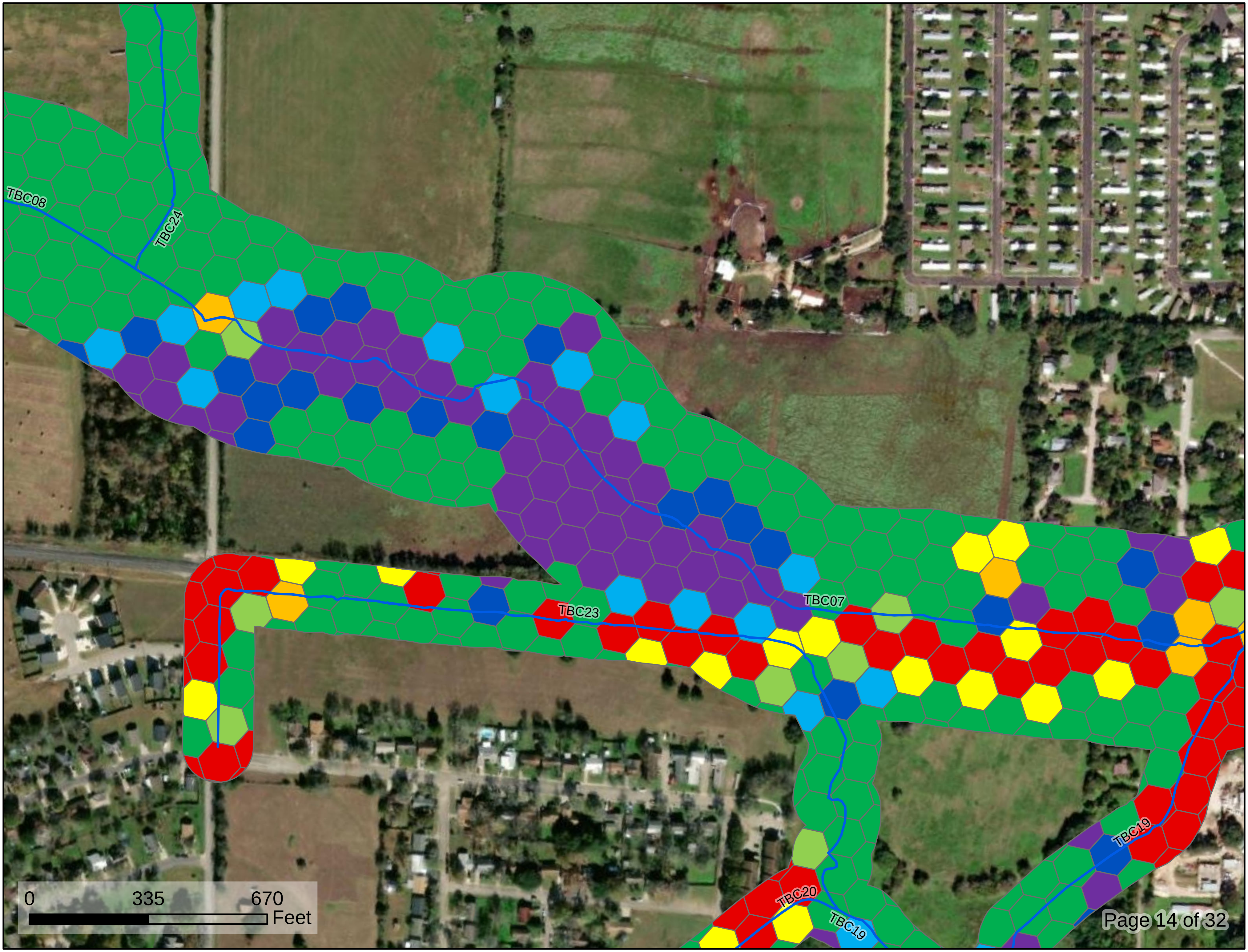
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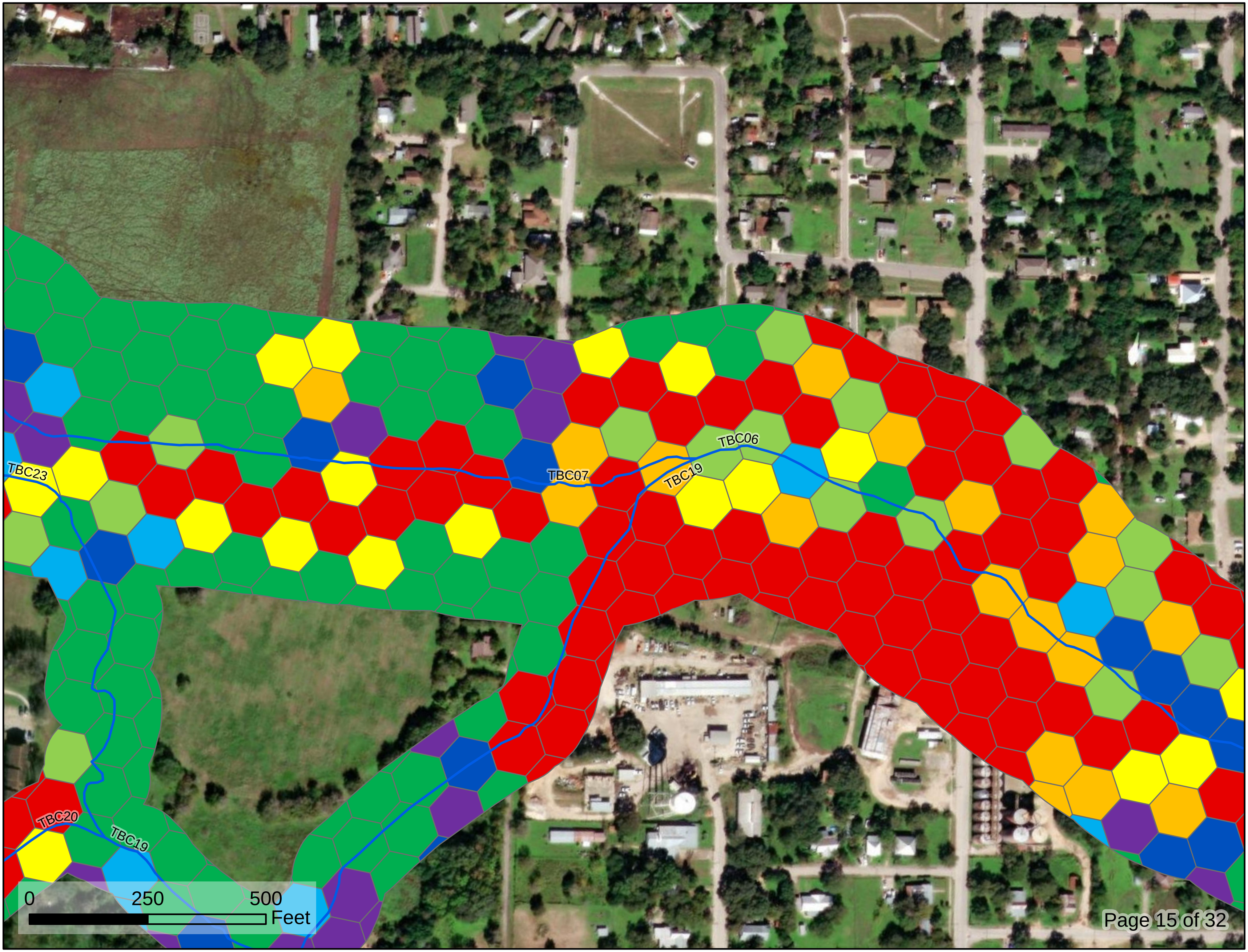

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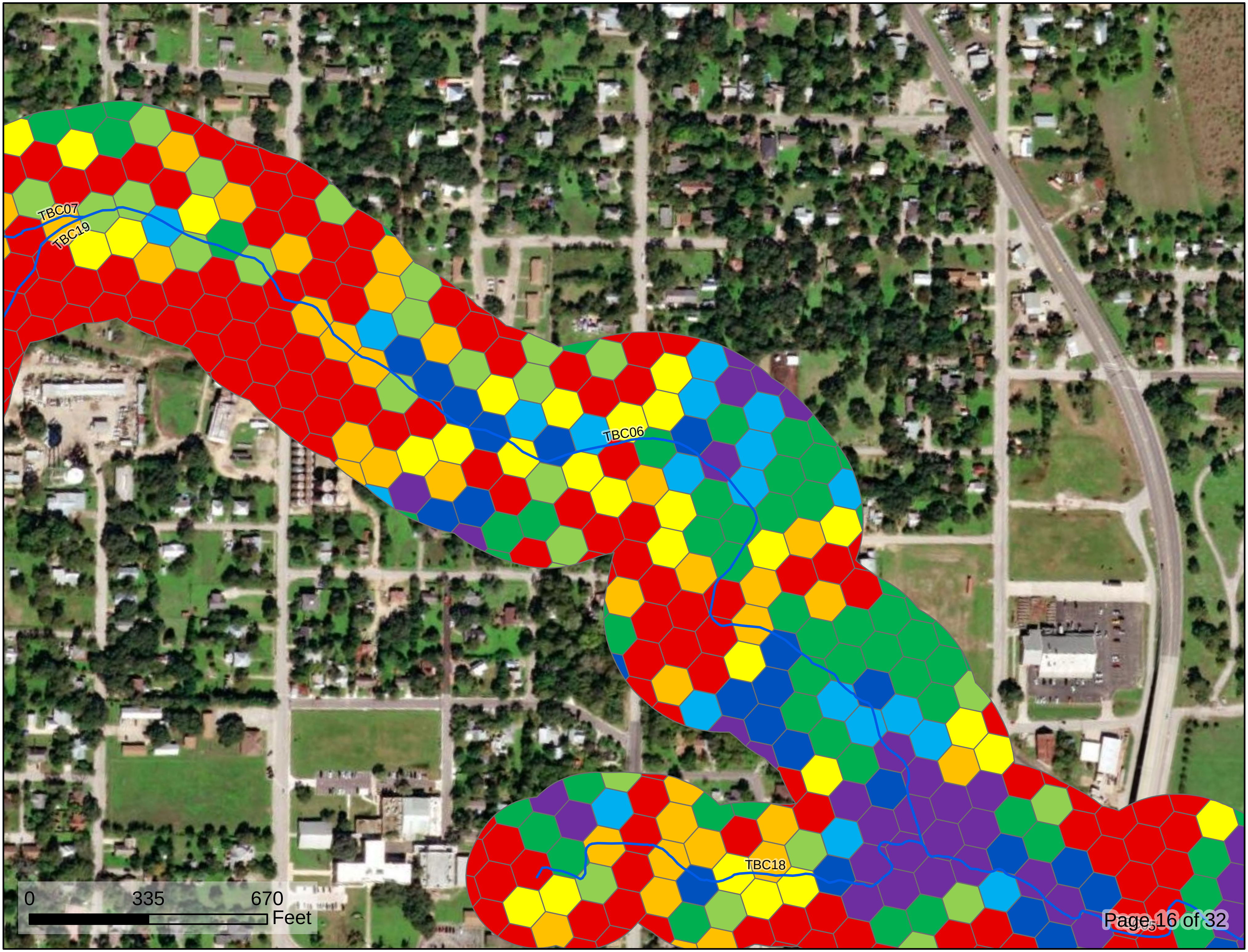
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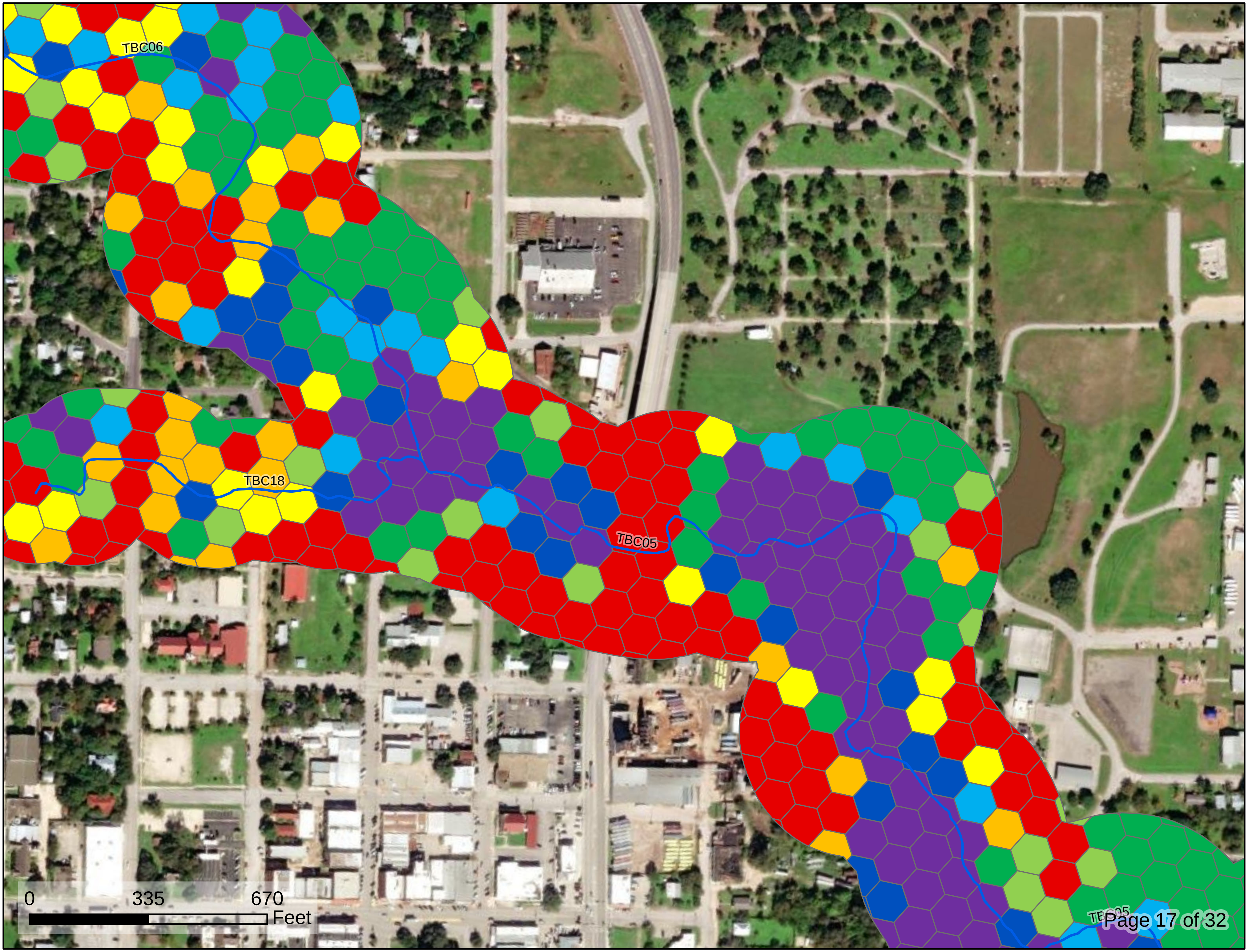
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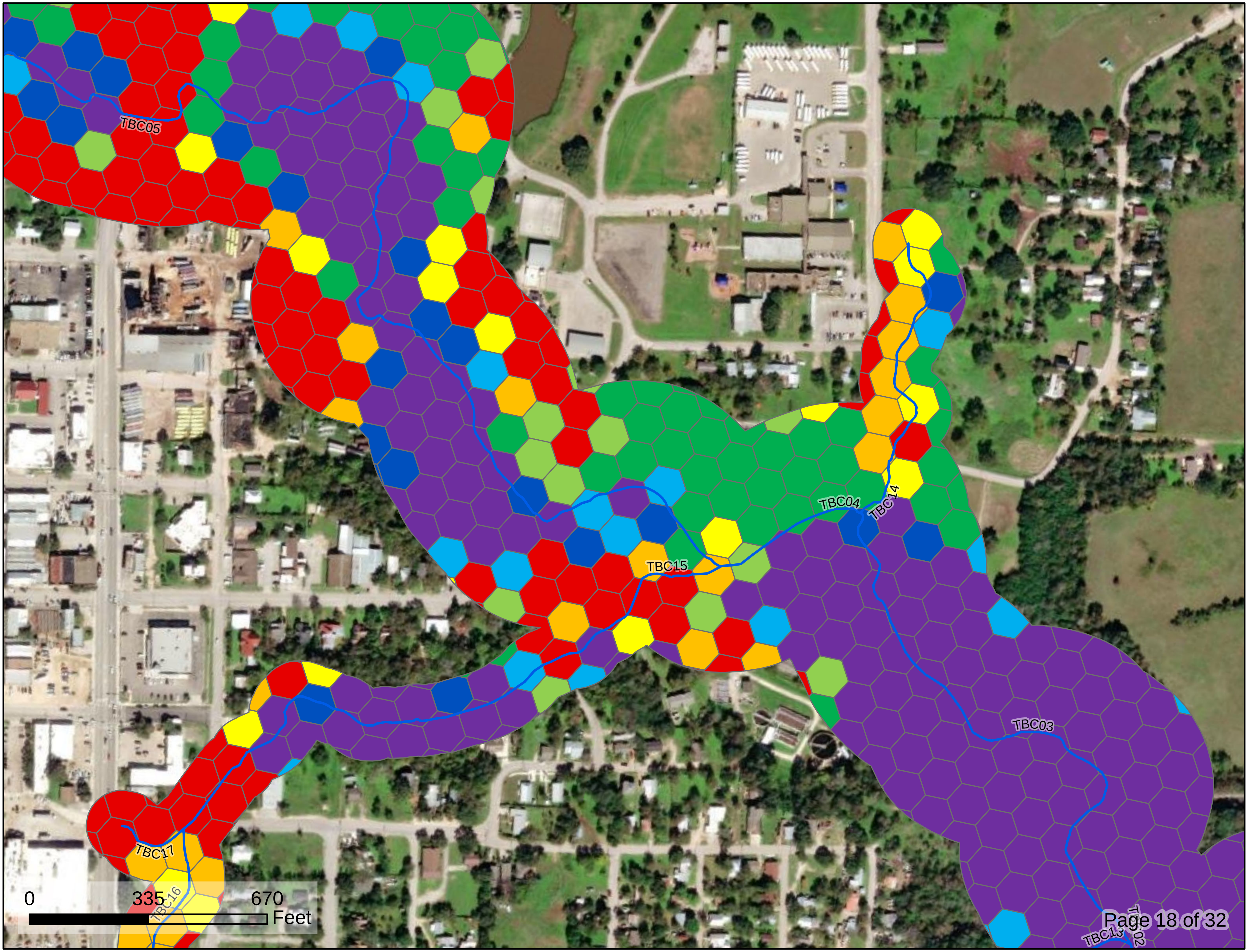
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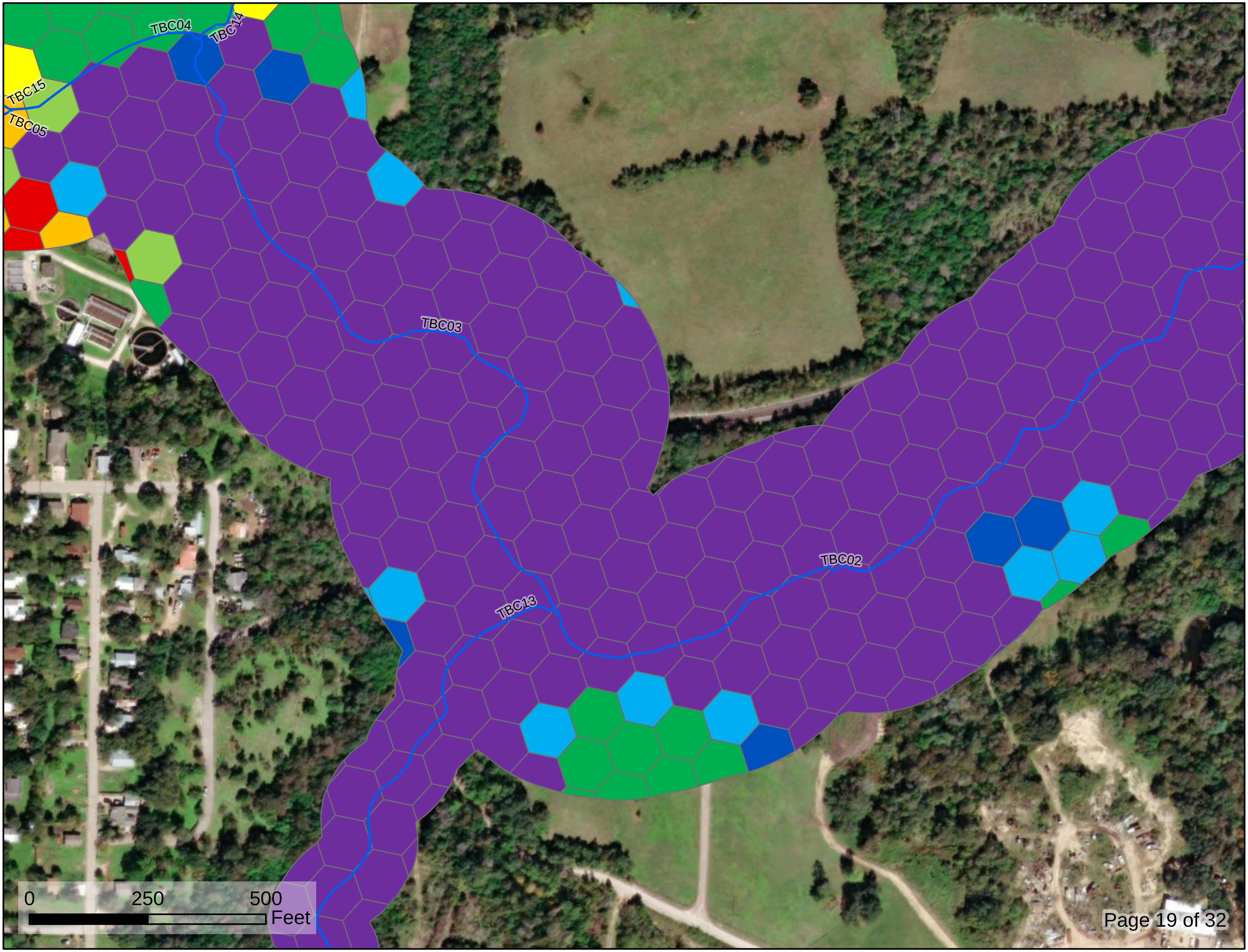
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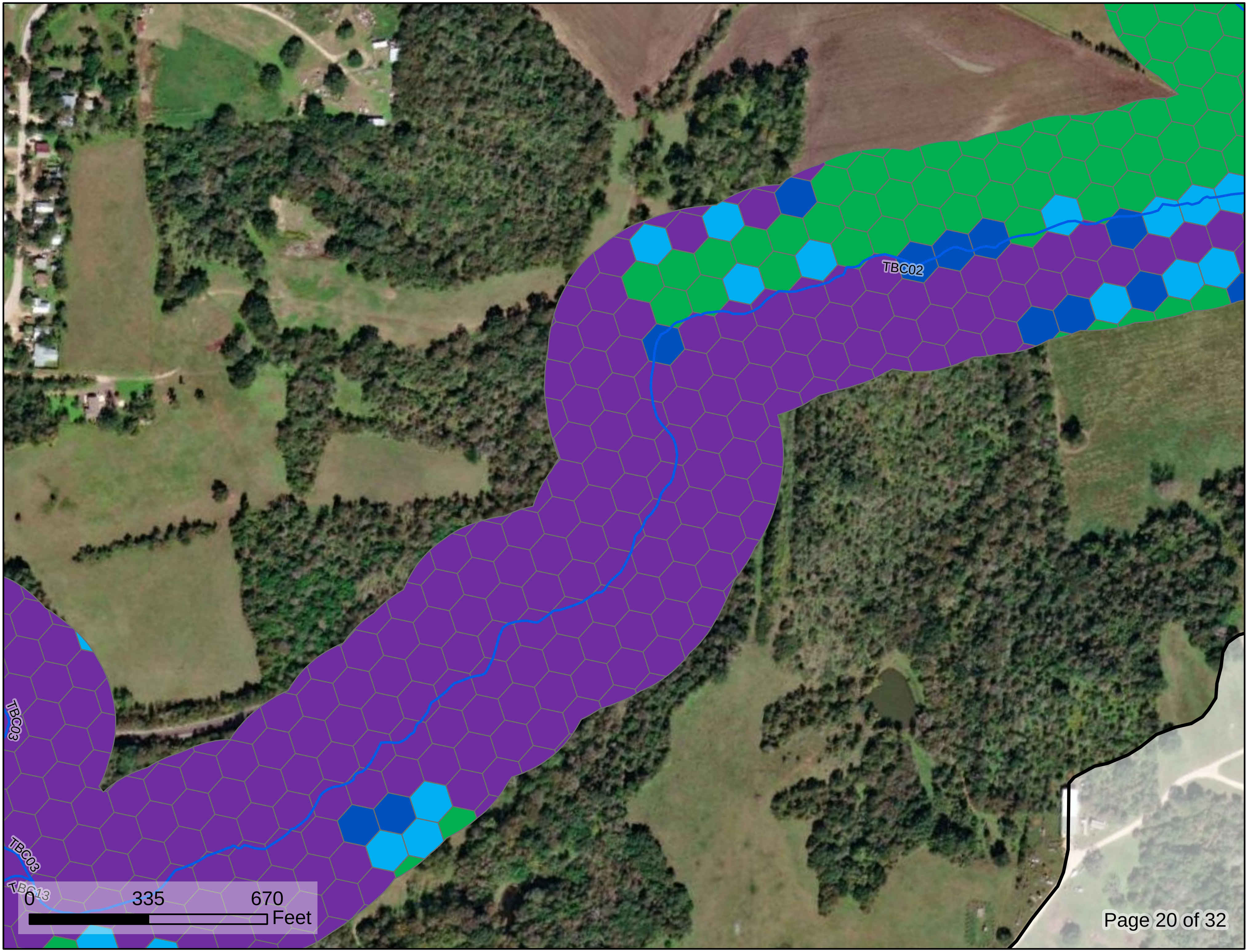
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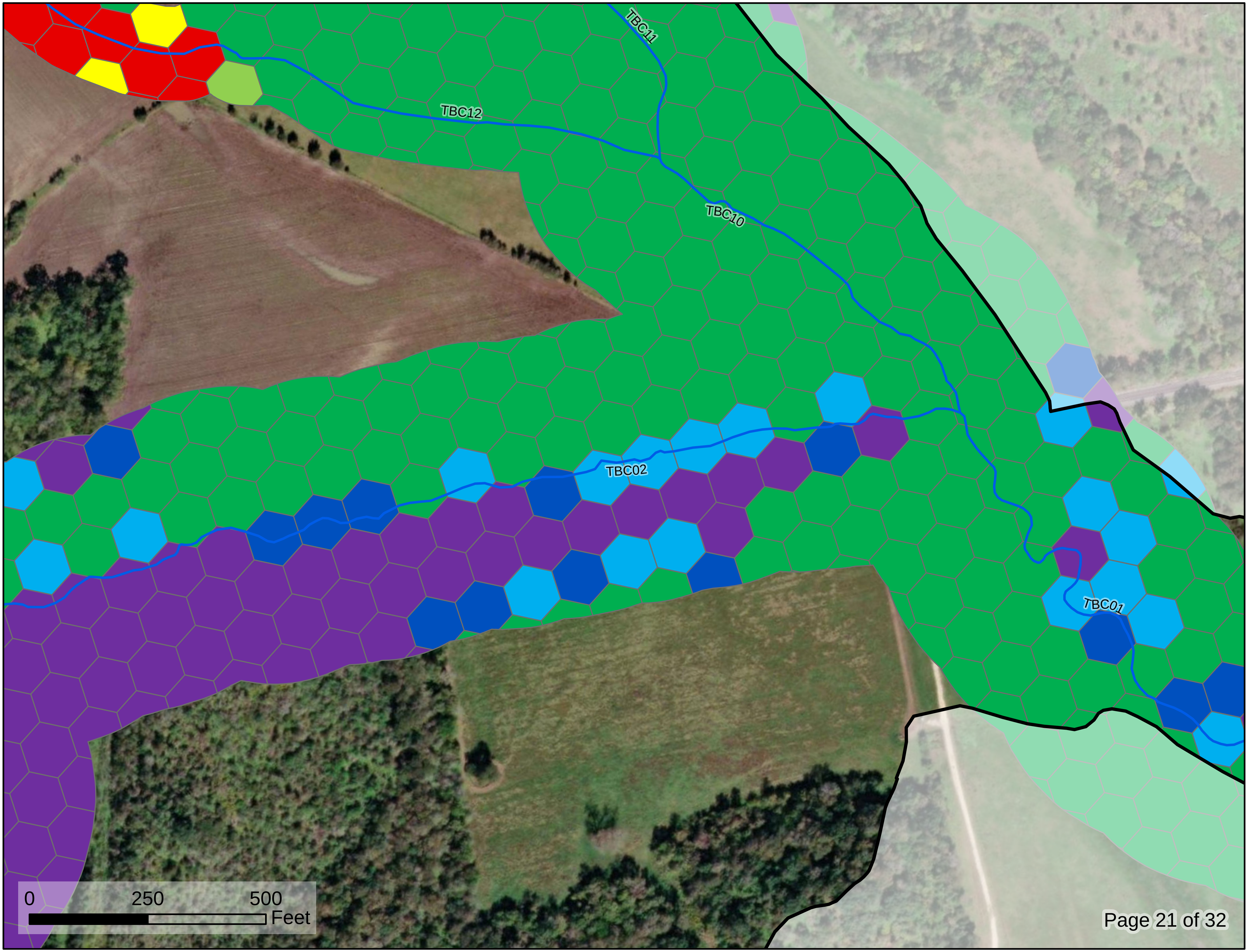
Page 20 of 32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TBC02
TBC01
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250
500
Feet
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Page 23 of 32


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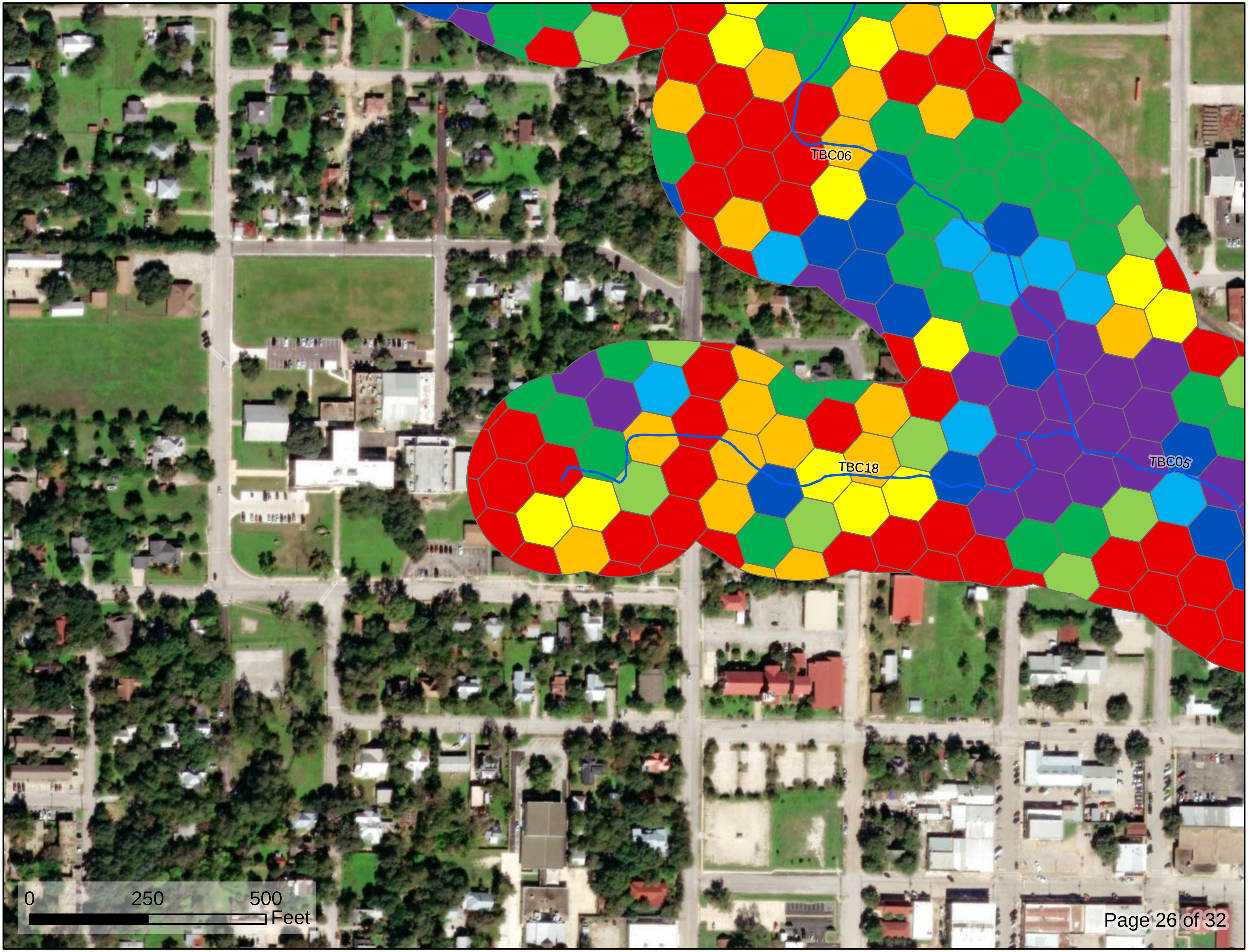
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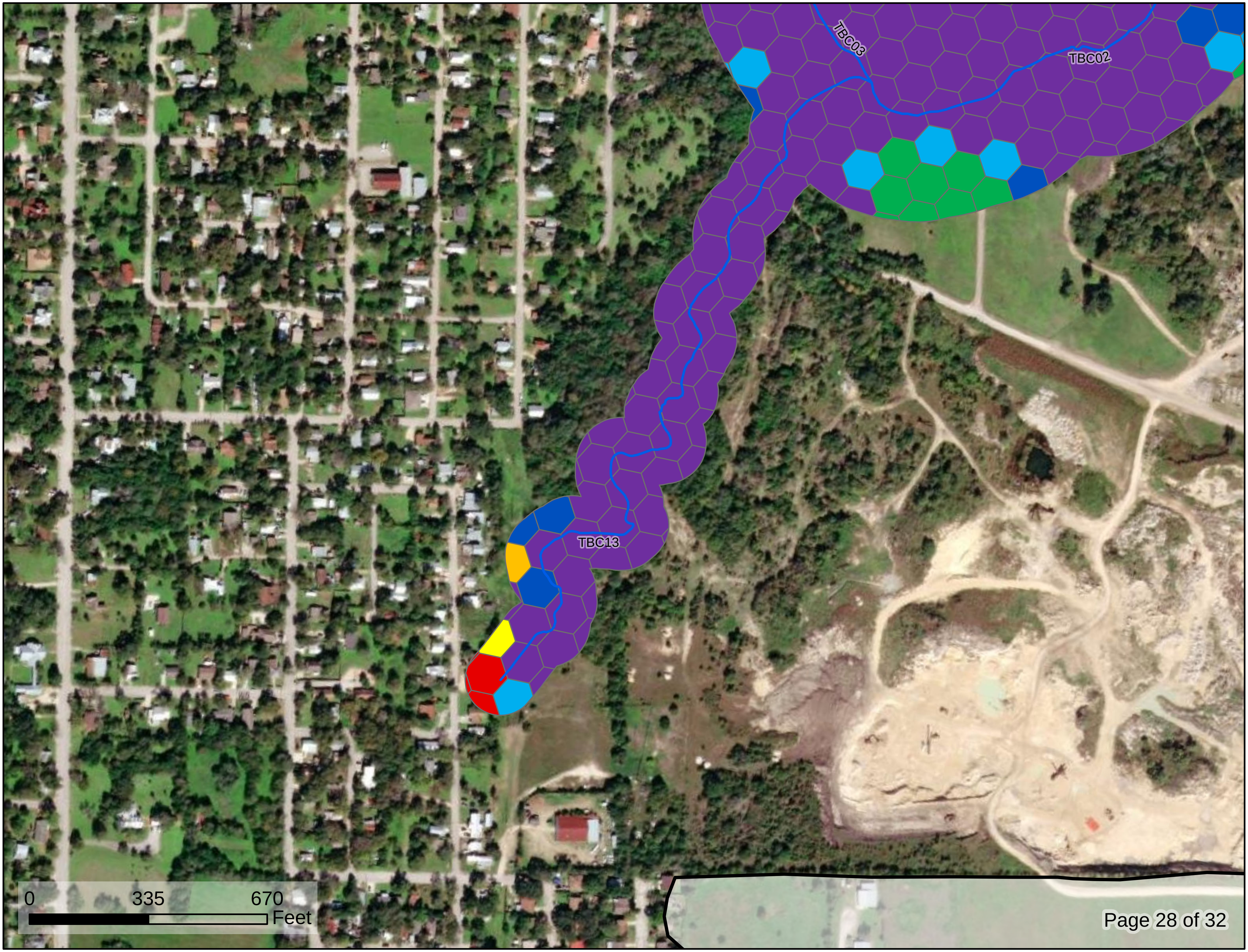
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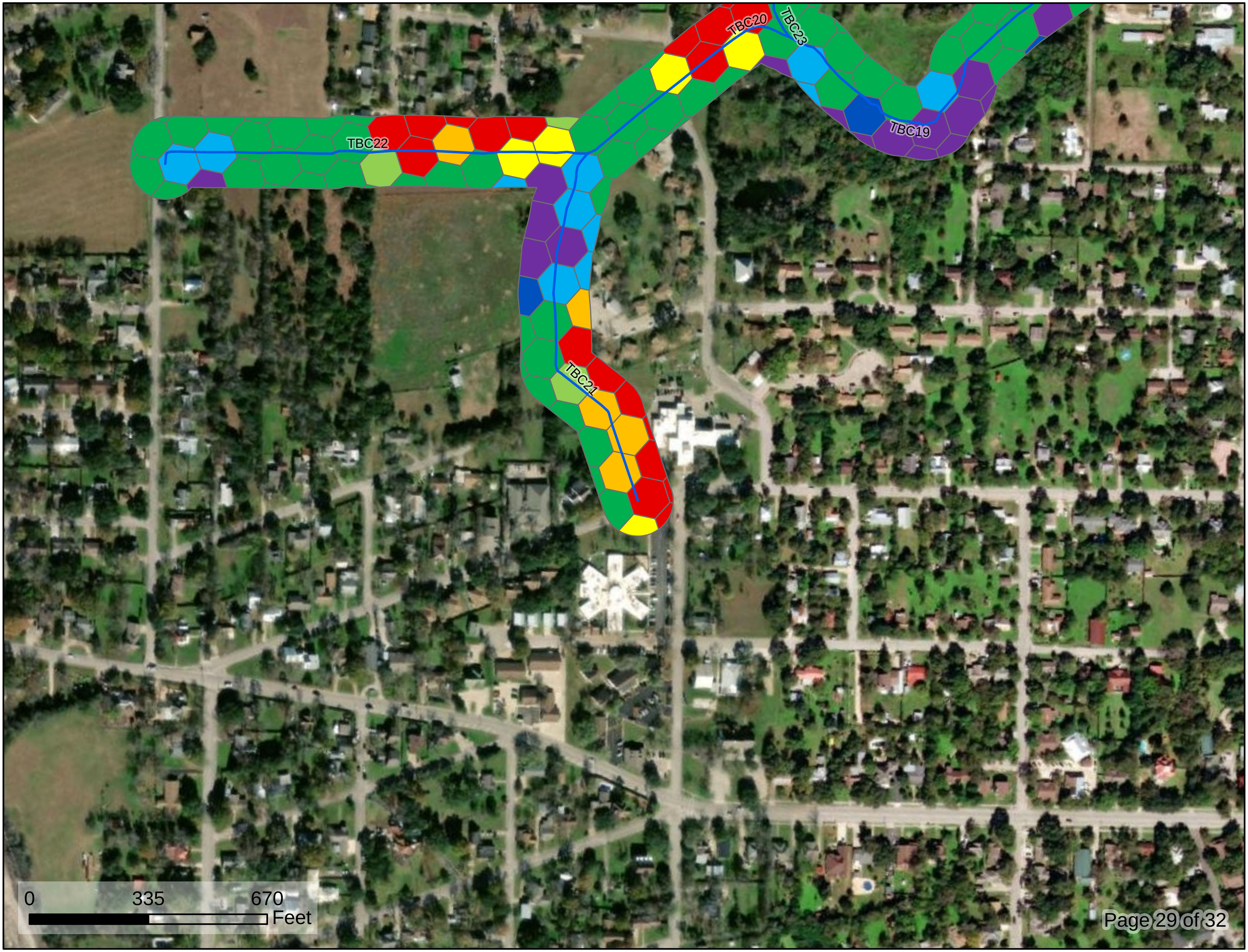
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0
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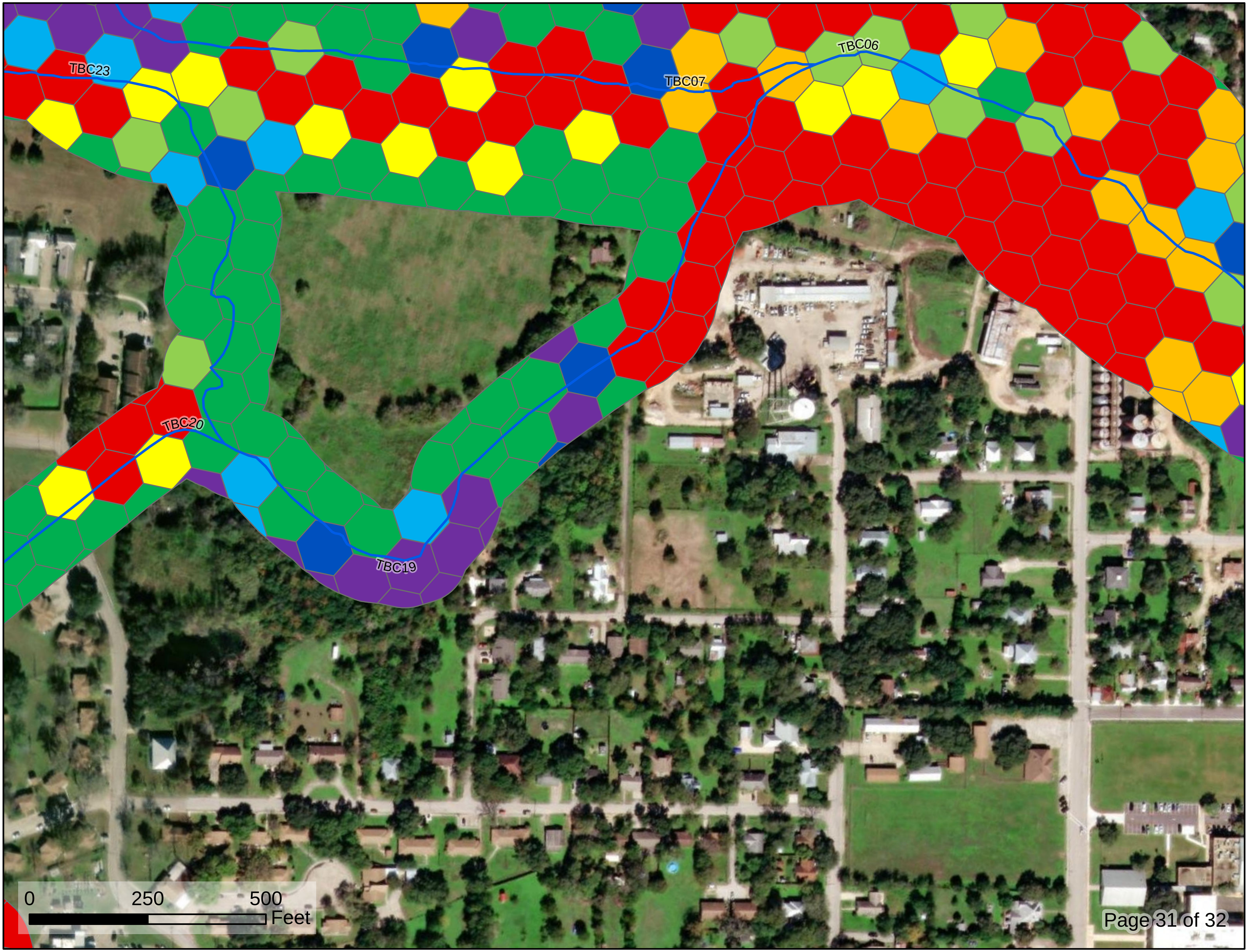
500
Feet
Page 30 of 32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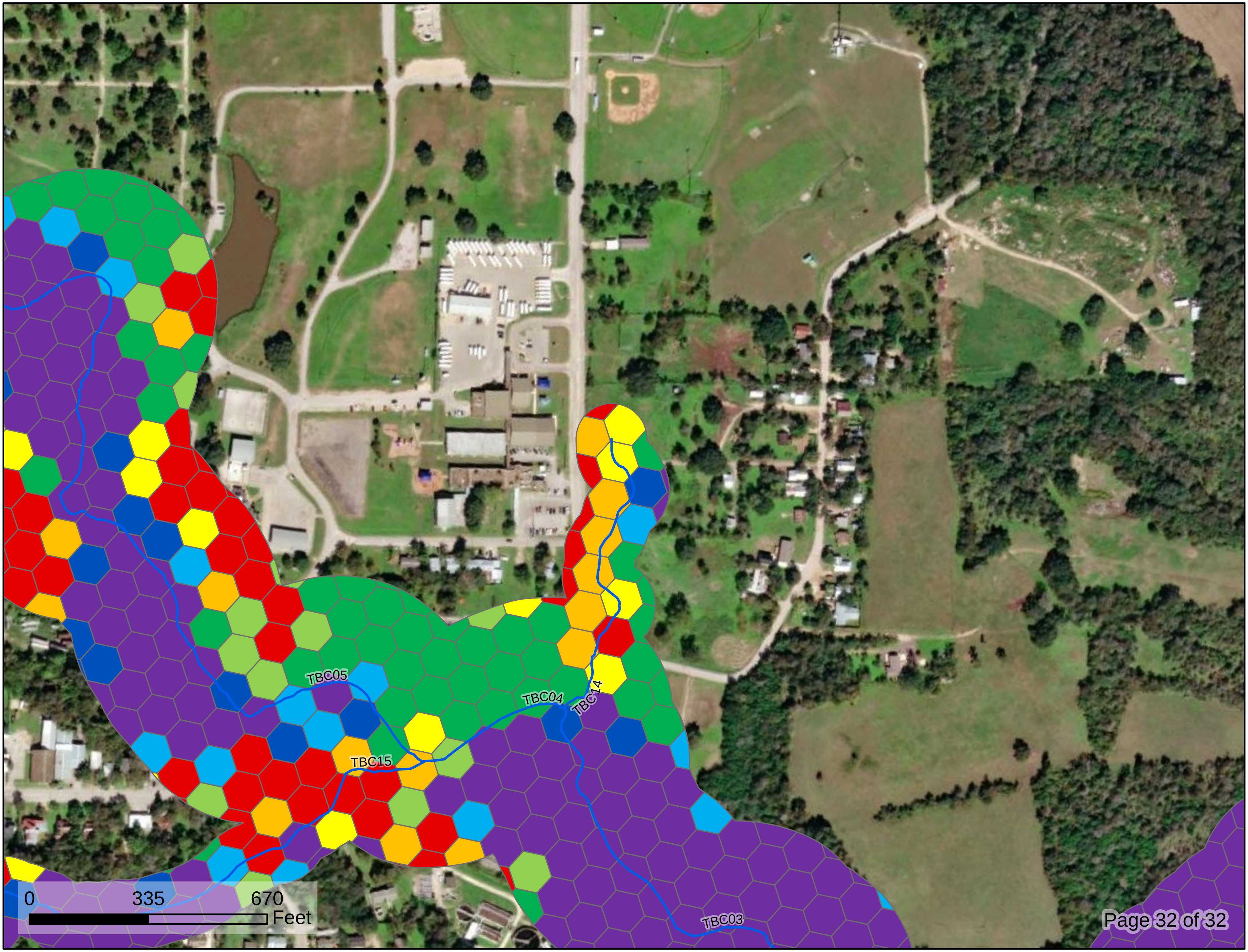
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Page 32 of 32

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