MEASURING CLIMATE RESILIENCE IN THE BUILT ENVIRONMENT AROUND THE ATLANTA BELTLINE

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MEASURING CLIMATE RESILIENCE IN THE BUILT ENVIRONMENT AROUND THE ATLANTA BELTLINE

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SUMMARY

There is a need to reorient the discourse around urban sustainability and, increasingly, urban resilience away from a reliance on intuition and appearance toward more rigorous evaluation of performance – particularly at the scale of interacting systems rather than individual sites. Large-scale, “sustainable redevelopment” projects are appropriate testing grounds for this kind of quantitative evaluation. This thesis looks at the Atlanta BeltLine, a 22-mile loop of repurposed rail corridor encircling the urban core of Atlanta, as a case study for measuring progress toward urban climate resilience objectives at the district scale. Specifically, it considers Subarea 5 of the BeltLine Planning Area between 2009 and 2017 in order to compare conditions before and after construction of the project’s first flagship trail and a 17-acre park. Findings suggest that the study area experienced a small net loss of tree canopy coverage (-3.3%) and small net gain in impervious surfaces (+2.4%) despite the addition of BeltLine green infrastructure. At the same time, using a methodology based on the LEED for Neighborhood Development (LEED-ND) certification system, the author estimated that just over a quarter of the study area’s “green growth” land supply – those parcels endowed with locational characteristics conducive to more resource-efficient development patterns – had been redeveloped by 2017. The findings underscore the importance of policies that explicitly seek to protect and enhance tree canopy in neighborhoods where green infrastructure is expected to spur redevelopment. It also raises questions about reconciling potential conflicts between strategies to pursue urban climate resilience through compact “green urbanism” on one hand and “green” land cover on the other.

CHAPTER 1. INTRODUCTION

Intuition and orthodoxy continue to guide decision-making in many planning interventions – whether they be at the scale of urban block, urban district, or beyond. There remains a tendency to lean on unchallenged assumptions of best practice. That tendency is evident in the discourse around urban sustainability and its successor, urban resilience. Planners, policymakers, and developers often appraise the more superficial impacts of “green” practices in isolation without considering their cumulative impact on energy and material flows at broader scales. More must be done to accelerate the adoption of a more quantitatively robust approach to measuring sustainability and resilience in the built environment.

1.1 Research Question

This thesis investigates the question, “Has the Atlanta BeltLine measurably enhanced urban climate resilience in the adjacent built environment?” Its analysis focuses largely on ecological and physical outcomes, but the broader discussion considers implications for planning policy and process: If the BeltLine *has* enhanced resilience, to what extent are these improvements driven by codified design and development requirements, rather than market signals? Are there more stringent requirements or incentives that could enhance this effect? Are there opportunities to migrate away from vague commitments to sustainability toward clearly articulated policy goals around climate resilience? And lastly, how and where may technical capacities be expanded in order to measure and monitor progress toward these goals?

1.2 Additional Considerations

Holistic, large-scale "sustainable redevelopment" projects are appropriate testing grounds for this kind of systems-level appraisal of cumulative ecological impact and preparedness for the uncertainties of climate change. This thesis looks at the Atlanta BeltLine – a 22-mile loop of repurposed rail corridor encircling the urban core of Atlanta – as a case study for measuring progress toward sustainability and resilience objectives at the district scale. This thesis will also address a pressing need for robust data on the sustainability impacts of the Atlanta BeltLine. Apart from Atlanta BeltLine, Inc.'s progress toward acreage targets for parkland and brownfield remediation, there are few data points available regarding sustainability outcomes where trails and other infrastructure have been constructed to date.

The Atlanta BeltLine Zoning Overlay was adopted in 2007 as a regulatory approach that anticipates and actively guides private development within about a half mile of the BeltLine corridor. Atlanta BeltLine, Inc. (ABI) and the City of Atlanta are in the early stages of considering updates to the Overlay, and this thesis will attempt to provide clear analysis that can inform that discussion. Moreover, there are signs ABI is poised to engage a consultant to develop Design Guidelines for the Overlay that more intentionally address issues related to sustainability and resilience, including building massing, materials, green infrastructure, and pedestrian facilities. These guidelines are likely to produce a Sustainable Design Standard, which could serve as a "scorecard" for design review and eventually be codified in the Overlay Regulations. Robust data on the performance of BeltLine-adjacent private development in the past decade should help inform this discussion, as well.

At the broader municipal level, the City of Atlanta is also currently in the process of drafting an updated tree protection ordinance and developing its first-ever Urban Ecological Framework, which is likely to designate “conservation zones” and “growth zones” throughout the Atlanta BeltLine Planning Area (BPA).

This work is primarily targeted to local policymakers at City of Atlanta and Atlanta BeltLine, Inc.. The analysis and recommendations are also pertinent to a number of communities of practice and constituencies, including:

- Local non-government organizations engaged in conservation research and advocacy;
- “Green building” practitioners and the development community;
- Stormwater management practitioners interested in scaling up so-called green infrastructure practices; and,
- Planners and designers interested in repurposing widely adopted certification schemes, like the LEED for Neighborhood Development (LEED-ND) methodology, for use in scenario planning exercises or integration into planning support systems.

CHAPTER 2. LITERATURE REVIEW

2.1 Definitions

This thesis attempts to translate the benefits of sustainable redevelopment projects like the Atlanta BeltLine into terms that are evidence-based, measurable, and directly comparable to alternative design scenarios. This project points to a more elemental challenge: to reorient the discussion around urban sustainability and urban resilience away from intuition and superficial appearance toward more rigorous evaluation of performance – particularly at the scale of systems rather than individual sites.[1] To be sure, this thesis is one of countless incremental efforts over several decades to steer the discourse in that direction by way of research and academic writing, certification schemes, rating standards, building codes, legislation, and municipal initiatives. These efforts have produced a well-trodden literature around many different metrics by which to evaluate sustainability in the built environment.

Still, in order to approach an evaluation of such sweeping scope, we must first settle on precise definitions of "resilience" and "sustainability" – particularly in urban contexts and in the age of climate change. This clarity will help identify the most fundamental objectives we hope to achieve by promoting climate-resilience urban design. Lastly, and

[1] This reorientation is more acutely needed in some disciplines than others: for example, engineers have been grappling with metrics of building energy performance for many years. Planning orthodoxy preaches design principles that tend to produce more sustainable outcomes, descendant from Jane Jacobs' "fine-grained diversity," but has been ill-equipped to more directly measure and optimize for sustainability or, more recently, urban resilience.

perhaps most critically, is the task of choosing the right mix of performance metrics that may be easily compared and conveyed.

2.1.1 Sustainability

Our interpretation of sustainability is influenced by our own individual worldviews, motivations, and relationship to the physical environment we inhabit. For the conservationist, the word may conjure images of preserved old-growth forest unspoiled by human activity. The urbanist could picture a dense fabric of buildings stitched together with infrastructure for walking, biking, and public transit infrastructure. The suburban townhome developer may instead envision bamboo flooring and high-efficiency home appliances. Needless to say, these interpretations can be widely divergent and difficult to reconcile.

Upon drilling down to the literatures most relevant to this thesis, these definitions begin to converge somewhat. The American Society of Civil Engineers (ASCE) in 1998 defined sustainable water systems, specifically, as “designed and managed to fully contribute to the objective of the society, now and in the future, while maintaining their ecological, environmental, and hydrologic integrity.” Another consideration is ensuring that systems with such long lifespans will remain financially tenable for localities.[2]

For our purposes, sustainability implies the consumption of natural resources (from the more tangible – land, fresh water, fisheries – to the more abstract, like our planet’s

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[2] Delleur, Jacques W. 2003. “The Evolution of Urban Hydrology: Past, Present, and Future.” *Journal of Hydraulic Engineering* 129(8). https://doi.org/10.1061/(ASCE)0733-9429(2003)129:8(563). 569-570.

"carbon budget") in patterns that do not deprive future human generations of the same quality of life and natural systems. This echoes the UN Brundtland Commission's foundational definition of sustainable development ("…meets the needs of the present without compromising the ability of future generations to meet their own needs"[3]) and takes on distinct meaning when applied to different scales and contexts. In the built environment of the city, for example, land use remains a critically important consideration, but its sustainable management has more to do with strategically densifying and intensifying human activity and less to do with preservation. Stated differently, "urban areas will always be net consumers of resources, and major degraders of the environment, however, it may be possible to move toward a greater degree of sustainability."[4] This interpretation of sustainability, in turn, lends itself to the following fundamental objective: minimize urban settlements' contribution to climate change as well as their broader ecological footprint.

Some academic disciplines and communities of practice that focus on sustainability would dispute this emphasis on ecology. The "three-pillar" model of sustainability – social, economic, and environmental, often depicted in an interwoven Venn diagram – is an iconic fixture in PowerPoint slides everywhere from public policy and community development programs to business schools and international development organizations. While its interdisciplinary origins surely helped bring sustainability into mainstream consciousness, its broad interpretation has likely hampered efforts to articulate and implement tangible goals. "Sustainability discourse [arose] from broadly different schools of thought

[3] U.N. World Commission on Environment and Development 1987.
[4] Lewin 2012.

historically," Purvis et al. contend; it is "context-specific and ontologically open." The absence of a "theoretically solid conception frustrates approaches towards a theoretically rigorous operationalization" of sustainability.[5] In the interest of specifying context, the reader should note that this study applies an "ecology-first" interpretation of sustainability that acknowledges its economic and social co-benefits, as well as its social equity pitfalls.

The arguments in favor of pursuing sustainability in urban contexts are numerous – both in terms of purely ecological benefits as well as economic and social co-benefits – but several are particularly germane to this analysis. Urban trees deliver benefits as diverse as cleaner air, lower heating and cooling loads for buildings, and reduced stormwater runoff.[6] High-performance new building construction and retrofits are more resilient to fluctuations in energy costs and can generate significant operational cost savings over their lifetimes. Sustainable urban form is especially critical: the "passive urbanism" one might find in the pre-World War II streetcar suburbs most major American cities represents the lowest-cost form of climate action because building compact, walkable communities is cheaper than the auto-oriented alternative development patterns that replaced them.[7] Moreover, this conservation-oriented approach to sustainability is far more accessible to working class communities that lack the resources to adopt green technologies in the early phases of market penetration. Simply living in a mid-rise apartment building or an older row house is a much more widely attainable entryway to a sustainable lifestyle than covering the roof of your suburban single-family home with solar panels.

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[5] Purvis, Mao, and Robinson 2019.
[6] Green, Robinson, and Millward 2018, 25.
[7] Calthorpe 2010, 4, 126.

Despite its decades-long influence across numerous disciplines and at the highest levels of intergovernmental policymaking, sustainability is at risk of becoming obsolete. In an era of unprecedented ecological and economic volatility, the theory is often ill-equipped to explain existing circumstances; worse, it is utterly impoverished as a policy framework designed to offer up durable solutions in all but the most stable contexts. The concept of "resilience" has been deployed to address these inadequacies in some governance structures and in the popular urban planning lexicon. However, its advantages over sustainability are too often expressed in superficial terms – or left unexplained altogether – that point to shifting fashions more than substance. For the purposes of this study, it is essential to disentangle the two concepts and avoid conflating them or dismissing their fundamental differences.

2.1.2 Resilience

Although resilience has only entered the city planning lexicon in the past 20 years (and risen to prominence in the past decade),[8,9] the term has a "long and diverse history" in social and physical sciences dating to the 17th century. Figure 1 plots these disciplinary linkages over time; Alexander (2013) argues that what binds their eclectic definitions is that, "one way or another, they all express dynamism." [10,11] In the context of disaster risk reduction, urban sustainability, and climate change adaptation, "resilience" traces its

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[8] Earlier insinuations notwithstanding: Davoudi (2012, p301) notes that CIAM's 1933 "Charter of Athens" portrayed a good city as resting in "a state of equilibrium among all its respective functions."
[9] See Figure 1 in Meerow and Newell 2016, a bar chart that illustrates the rapid rise in references to urban resilience in literature between 1999 and 2014.
[10] Figure source: Alexander 2013, 2714
[11] Alexander 2013, 2714

heritage to the field of ecology in the 1960s and 1970s.[12] In his landmark 1973 paper, "Resilience and Stability of Ecological Systems," Canadian ecologist C.S. Holling defined resilience as a measure of an ecosystem's "persistence…and their ability to absorb change and disturbance and still maintain" basic functions.[13] In later writing, he began to explore the distinction between *engineering* and *ecological* resilience.[14] Engineering resilience, according to Holling, represents a system's ability to bounce back from a disturbance and return to equilibrium.[15] This interpretation of resilience tends to undergird the language and logic of many contemporary examples of applied "resilience planning." Resilience is understood as "a buffer capacity for *preserving* what we have and *recovering* to what we

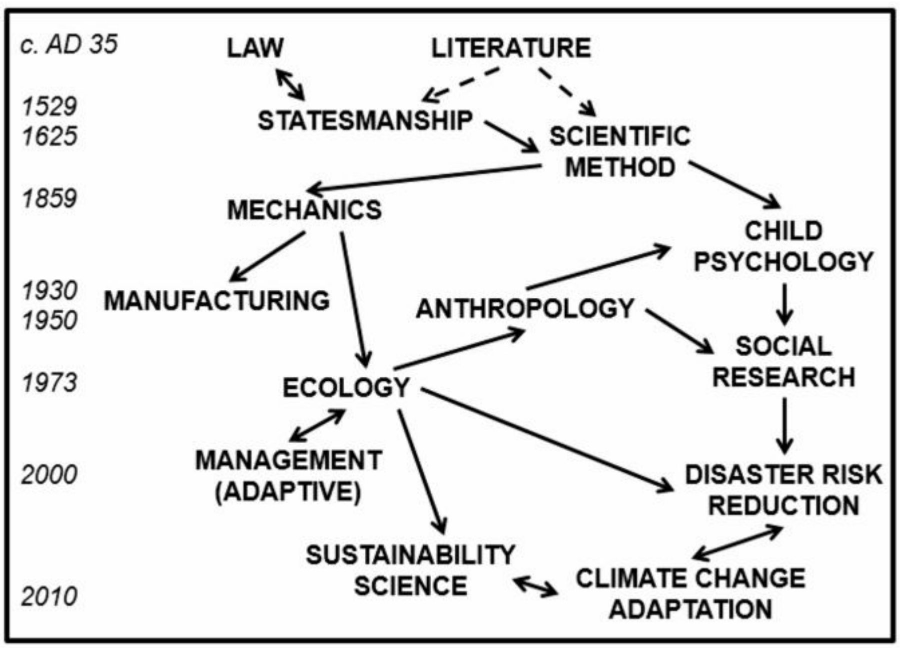

Figure 1: Disciplinary Etymology of "Resilience"

[12] Alexander 2013, 2711
[13] Holling 1973, 14-15
[14] Meerow and Newell 2016, 3
[15] Kim and Lim 2016, 3

were;" troublingly, "the emphasis is on the return to 'normal' without questioning what normality entails."[16]

According to Holling, ecological resilience focused instead on the "magnitude of the disturbance that can be absorbed before the system changes its structure."[17] Critically, the ecological interpretation eschewed the notion of a single equilibrium in favor of multiple equilibria and the possibility that a system might "transform and reach an alternative equilibrium."[18] What distinguished the latter from the former was an emphasis on "bouncing forth" rather than simply "bouncing back."[19] A third interpretation – less embraced in mainstream planning practice than in theory – is *evolutionary* resilience, which rejects equilibrium altogether and instead treats resilience as "the ability of complex socio-ecological systems to change, adapt, and, crucially, transform in response to stresses and strains."[20] This model is often represented visually by the "panarchy" model, a cycle of four phases (growth, conservation, creative destruction, and reorganization) culminating in a "transition into a regime with a greater amount of resilience."[21]

In 2012, the journal *Planning Theory & Practice* devoted a feature to the question of whether resilience represented a "bridging concept" or "dead end" for planners. Contributors observed that resilience was "replacing sustainability in everyday discourses in much the same way as the environment has been subsumed in the hegemonic imperatives

[16] Davoudi et al. 2012, 301-302, paraphrasing Folke et al. 2010 and Pendall et al. 2010
[17] Davoudi et al. 2012, 300
[18] Kim and Lim 2016, 3
[19] Davoudi et al. 2012, 301
[20] Ibid, 302
[21] Kim and Lim 2016, 4

of climate change."[22] Resilience thinking was quickly penetrating the city planning lexicon – but as an elastic concept, unmoored from its philosophical roots and lacking consensus around agreed-upon definitions, objectives, or measures. They cautioned that without critical scrutiny, the term could meet the same fate as sustainability: "a hollow concept for planning…an empty signifier which could be filled to justify almost any means."[23] At the same time, its editors expressed optimism that the concept could reinvigorate planning practice by "break[ing] open sterile analyses and rigidly conservative interventions" and "break[ing] planning out of its obsession with order, certainty, and stasis."[24] This was thought to be particularly true of the "evolutionary" model of resilience, which had yet to influence climate adaptation strategies to the same degree as its accompanying "engineering" and "ecological" paradigms. That the concept embraced transformation and emphasized "bouncing forward" rather than "bouncing back" to an idealized status quo made it better equipped than sustainability to address questions of equity and justice.[25]

Indeed, where urban resilience and sustainability seems most incompatible is in the question of stationarity and equilibrium. The "traditional view of a system for which a linear progression and singular equilibrium are assumed" has given way in recent resilience discourse to one of a dynamic, evolving "network based on a nonlinear progression and multiple equilibria" (or none at all).[26] The "equilibrium perspective" that informed city planning theory and orthodoxy has been rendered obsolete but the reality of nonlinear,

[22] Davoudi et al. 2012, 299
[23] Ibid, 329
[24] Ibid., 330
[25] Ibid, 330
[26] Kim and Lim, 1

dynamic observed systems, Kim and Lim (2016) insist. In its place, an urban resilience perspective "must focus on the potential for improvement and capacity-building, rather than on recovering a pre-existing equilibrium."[27]

Others have traced the conceptual relationship between urban sustainability and resilience to the notion of disaster risk reduction. Kim and Lim (2016) credited the 2002 United Nations Summit on Sustainable Development with establishing that "cities need to be resilience in the face of natural disasters if they are to be sustainable" and thus, implicitly, resilience came to be seen as a characteristic – or precondition – of urban sustainability.[28]

Researchers often describe the objectives of sustainability and resilience as mutually supportive but often distinguish their features or situate the concepts as pieces of a more nuanced synthesis, such as "urban climate resilience." Childers et al. (2015) describe a design-ecology "nexus" that, by joining design, infrastructure, and urban development, can "achieve urban climate resilience and enhance sustainability."[29] The authors describe socio-ecological resilience as a "mechanism" of sustainability, which for too long has neglected "an explicit consideration of design" in favor of "the more comfortable realm of policy and management," particularly around natural resources. Many locally adopted sustainability plans, they maintain, "are not adequate to prepare cities for the crises and tipping points" they face, due in part to a "narrow focus on existing 'hard' infrastructure…and on 'low hanging fruit' green infrastructure" such as parks and

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[27] Ibid, 5-6
[28] Ibid, 6
[29] Childers et al., 7

public trees. Moreover, these plans are seldom integrated in tangible ways into neighborhood-scale urban design practice. Only by integrating urban design can cities achieve "urban systems resilience" in the face of heat, drought, and flooding, the authors assert.[30]

The evolutionary model sheds assumptions of equilibrium and stationarity; resilience is no longer preoccupied with returning to "normal" but rather with "the ability of complex socio-ecological systems to change, adapt, and, crucially, transform in response to stresses and strains."[31] This model may be best positioned to explain the dynamic conditions at the intersection of late capitalism and accelerating climate crisis, however it is also the most challenging for planners to operationalize, for two reasons. First, it renders obsolete much of the theoretical orthodoxy inherited from rational planning models and, perhaps more fundamentally, "challenges the adequacy of planners' conventional 'toolkits' such as extrapolation of past trends in forecasting and for reducing uncertainties."[32] Second, the concept's "limitations in terms of specifying and measuring capacity" post a second obstacle to operationalizing resilience in planning practice.[33] The evolutionary interpretation vastly complicates the already-enormous task of articulating outcomes for urban climate resilience and devising indicators with which to measure achievement of those outcomes.

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[30] Ibid, 7
[31] Davoudi 2012, 302
[32] Ibid, 302-303
[33] Kim and Lim 2016, 7-9

Davoudi (2012) observed that references to resilience in government communications and everyday parlance are typically rooted, implicitly or explicitly, in the engineering paradigm and its emphasis on “bouncing back” from shocks and stresses.[34] Some scholars have lamented that the engineering paradigm continues to dominate in mainstream applications of resilience planning, notably in municipal climate adaptation plans. Obvious examples include strategies to combat sea level rise and coastal erosion using sea walls and beach nourishment. Even where resilience and adaptation plans do embrace a more expansive, socio-ecological interpretation that acknowledges the bounded nature of social and ecological vulnerabilities and tipping points, Fünfgeld and McEvoy (2012) contend that an overarching focus on risk management undermines ambition and imagination. In these instances, “conserving the status quo” eclipses other objectives; “most decision-makers at the helm of organisations would consider profound transformation as a system failure rather than part of a healthy process of maintaining resilience.”[35]

While planning theorists continue to litigate these distinctions and debate how best to move practitioners toward an of interpretation that is less averse to upheaval and transformation, putting urban climate resilience poses additional challenges. Within the various communities of practice that are invested in pursuing urban climate resilience, there continues to be vigorous debate over how best to operationalize even a basic engineering or socio-ecological interpretation of the concept. Here, the concept’s plasticity and versatility – the very properties that make it a potent “boundary object” and “bridging

[34] Davoudi 2012, 300-302
[35] Fünfgeld and McEvoy 2012,

concept" to unite stakeholders across a diverse set of disciplines – also pose significant barriers to reaching clarity and consensus.[36,37] For example, planners continue to agonize over whether to design indicators that are "outcomes-based" or "process-based"; and whether to prioritize universal or context-specificity.[38]

Ultimately, urban climate resilience was selected as the most appropriate framework through which to evaluate the BeltLine's performance. Some scholars have expressed alarm about the speed with which resilience entered the planning lexicon in the past decade. They have also cautioned that without common definitions (that remain faithful to its philosophical underpinnings of "evolutionary," transformational change) or tangible parameters and indicators, the concept could quickly become a depoliticized, meaningless buzzword. Still, unlike urban sustainability, resilience has not yet been exhausted of its intellectual vigor and versatility. More importantly, its accommodation of dynamic, nonstationary systems makes it far more relevant to the current socio-ecological and political moment, which cannot be adequately explained by a framework that insists upon stasis and equilibrium.

2.2 Indicators of Urban Climate Resilience

Urbanization has important implications for climate change impacts across several dimensions, which can be mediated by the specific character of urban form at multiple scales. For example, climate change is anticipated to increase building energy demands for

[36] Davoudi et al. 2012, 325-327
[37] Leichenko 2011, 166
[38] Feldmeyer et al. 2019, 2-4

cooling across U.S. regions. Chicago has been projected to see a 30- to 60-day increase in Cooling Degree Days by 2070, while annual electricity demand in California could rise 20% by the end of the century.[39] Urban form has also been shown to influence urban heat island effect from the parcel to regional scale. Somewhat counterintuitively, both low- and high-density development patterns can exacerbate urban heat for different reasons. Compact development may generate "urban canyons" that trap daytime heat and inhibit nighttime cooling. Similarly, the extensive impervious surface cover and loss of vegetation that tends to accompany low-density sprawl intensifies urban heat.[40] This contradiction disappears at the regional level: examining annual trends from 1956 to 2006, Stone et al. (2010) found that the number of extreme heat events each year grew in sprawling metropolitan areas at over double the rate observed in the most compact metros.[41] Compact development has also been found to outperform sprawl in terms of managing stormwater runoff and flooding.[42] These conclusions have been presented in support of compact development broadly and, more specifically, policies that aim to expand green space, substitute mass transit and active transportation for automobile travel, enhance urban tree canopies, and promote high-albedo surface materials.[43]

The remainder of this section reviews recent writing on the design of appropriate performance indicators from several perspectives within the urban climate resilience discourse. These perspectives include a local city government; an international standard-

[39] Larsen et al. 2011, 26
[40] Ibid, 27
[41] Stone et al. 2010, 1426
[42] Larsen et al. 2011, 28
[43] Stone et al. 2010, 1427

setting body; academics operating in highly developed, urbanized countries; and an international development bank.

In 2016, the Urban Sustainability Directors Network (USDN) and a working group of U.S. cities led by Washington, D.C. published a literature review of climate adaptation indicators. Authors reviewed seven adaptation frameworks from an initial pool of 28 documents. Selected frameworks included C40's Climate Risk Assessment Framework and Taxonomy (CRAFT); a draft Climate Change Adaptation Framework for Boston; the Obama White House's US Climate Resilience Toolkit; and the City Resilience Framework developed to assist members of Rockefeller Foundation's (now defunct) 100 Resilient Cities network. Metrics ranged from abstract or process-oriented to painstakingly precise. Boston's plan emphasized many "soft" objectives, like community engagement around relevant topics or consideration of climate change in city plans.[44] Conversely, Rockefeller Foundation developed 12 broad "indicators" which they planned to populate with up to 54 sub-indicators, themselves made up of as many as 150 tangible and intangible "variables" of resilience.[45] In its "Indicators for Sustainable Development and Resilience in Cities," the International Organization for Standardization (ISO) had prepared a framework more akin to a LEED rating system. It served as both a set of indicators and a certification, addressing 14 themes including "Resilient Infrastructure," "Walkability and accessibility," "Transit and mobility," and "Green buildings."[46]

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[44] Urban Sustainability Directors Network et al. 2016, 3-4.
[45] Ibid, 13.
[46] Ibid, 14.

ISO would further iterate on this standard two years later in ISO 37123:2019, devoted to "Indicators for resilient cities," specifically. Its indicators are broadly interdisciplinary and mostly address the engineering and socio-ecological paradigms of urban resilience.[47] The thematic area devoted to "Environment and climate change" provide the indicators most relevant to this thesis, namely:

- Magnitude of urban heat island effects
- Annual frequency of extreme rainfall events
- Annual frequency of extreme heat events
- Annual frequency of flood events
- Percentage of city land area covered by tree canopy
- Percentage of city surface area covered with high-albedo materials contributing to the mitigation of urban heat islands.[48]

Notably, the "Urban planning" section also contains the indicator, "Pervious land areas and public space and pavement built with porous, draining materials as a percentage of city land area."[49]

In examining efforts underway in German cities using the socio-ecological interpretation of resilience, Feldmeyer et al. (2019) used a mixed-method approach to develop a set of 24 indicators to "measure and monitor urban climate resilience for municipalities."[50] (They reasoned that a set of around 20 indicators was far more

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[47] International Organization for Standardization (ISO) 2019.
[48] Ibid.
[49] Ibid.
[50] Feldmeyer et al. 2019, 14.

manageable to implement than, say, the 52 proposed by Rockefeller's City Resilience Index). These indicators serve important political purposes by "[building] and evidence base and [making] resilience more tangible for decision and policy makers as well as society at large" and by helping "to structure the new field of urban climate resilience."[51] They noted that the multi-scalar natural of resilience – applicable at the level of region, city, district, and household – complicated efforts to pin down unifying indicators and performance measures. Survey responses and interviews with both academic researchers and practitioners revealed strong consensus around environment- and infrastructure-related indicators. These included "degree of unsealed ground" (e.g., pervious surface area), "state of water bodies," and "nature conservation and protection areas" within the environmental dimension; and "building density" and "per capita energy consumption" among infrastructure indicators. Respondents ranked two indicators from the Governance dimension among the top five overall: "strategies against heavy rain and heat in plans" and "inter-offices working group regarding risk, climate change, and resilience."[52] Conversely, opinions diverged around the relevance of economy-based indicators.

Interviews with sector practitioners revealed that lack of data availability for indicators on a municipal level posed significant barriers, particularly for Infrastructure and Society-related indicators.[53] Because large portions of local energy, transport, and communications infrastructure are managed by private or non-local entities, it was difficult to obtain data "with a sufficient resolution on a municipal level."[54] In addition to data

[51] Feldmeyer et al., 2.
[52] Ibid, 8.
[53] Ibid, 13.
[54] Ibid, 13.

availability, data *transparency* emerged as a critical component – particularly for identifying and resolving conflicts between indicators when contradictions arise. (For example, whereas impervious surfaces are undesirable in the contexts of stormwater management, air quality, and urban heat islands, "they are necessary for a redundant infrastructure and other urban functions."[55]) In this regard, "the Rockefeller approach seems like a black box because it is difficult to deduce what adaptation measures are used as a data basis, and indicator calculations are unclear."[56]

The Inter-American Development Bank cautions that adaptation and climate resilience are not necessarily interchangeable but defines the latter term as a synthesis of its broader concepts – wherein systems are strengthened "to withstand climate-related shocks or stressors where adaptation and resilience intersect."[57] IADB's framework prescribes that climate resilience metrics "facilitate evaluation of the technical performance of the project, contributing to the sustainability and resilience of communities and businesses."[58] Although this particular framework is more relevant to international climate finance, it includes several observations that may be salient in an assessment of the BeltLine's impact. One of the unifying principles it proposes for climate resilience metrics is that they must be equipped to cope with ambiguity around project boundaries. Project impacts "may often lie outside the physical boundaries of the project" and can act on "downstream communities."[59]

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[55] Ibid, 13.
[56] Ibid, 13.
[57] Inter-American Development Bank (IDB) 2019, 9.
[58] Ibid, 16.
[59] Ibid, 15.

2.3 Theoretical Intersections and Evolution

In "The End of Sustainability," Benson and Craig argue that sustainability has been subsumed under the more practicable or tangible vehicle of sustainable *development* – "a broader goal about how development should proceed – namely, with sufficient consideration of the environment to ensure the continued availability of natural capital."[60] In part because the concept of sustainable development germinated and took root in the age of climate change consciousness, it has tended to dominate policy frameworks around climate action, despite a decades-long record of "fail[ing] to meaningfully change human behavior."[61] To remain relevant as a concept that adequately explains observed reality, sustainability relies on the assumptions that: we know what can be sustained; and we remain able to maintain "stationarity." Resilience, by contrast, "acknowledges disequilibrium and nonlinear, continual change," and provides a framework for identifying "critical ecological thresholds" that will likely demarcate tipping points between present and future resting-state conditions.[62] In their view, resilience provides a lens and a metric that is intrinsically better equipped to "formulate ecological governance goals" in the post-stationary era and "reorient current research and policy efforts toward *coping* with change."[63] Moreover, they see resilience as better positioned to explain conditions within the complex dynamics of globalization and through the lens of social justice, which sustainability has tended to approach and appraise within the blinkered parameters of a neoliberal balance sheet.

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[60] Benson and Craig 2014, 1.
[61] Ibid, 2-3.
[62] Ibid, 3-4.
[63] Ibid, 3-4.

While reorienting policy discourse from sustainability to resilience could offer new opportunities to center justice and social equity as non-negotiable priorities, the shift is also accompanied by new risks of policy capture and semantic sleight of hand. "Addressing the increasingly evident threats of climate change in the neoliberal, post-financial-crisis city raises several questions about its equitable implementation," Long and Rice cautioned in 2018; "transition from policy rhetoric to climate action presents a potentially problematic landscape of inequality and injustice."[64]

As organizing principles for thought and action, both sustainability and resilience are critical to the project of preparing for – and, where possible, avoiding or minimizing – the impacts of climate change on human settlements and the systems that support them. Shifting policy priorities entirely to resilience at the expense of sustainability, however, could signal the abandonment of ambitious action to mitigate climate change and a tacit admission that adaptation poses the new best-case scenario. In a 2010 essay entitled, "Who Will Build the Ark?", Mike Davis lays out two alternative visions for how the emerging Anthropocene might play out. Part one, "Pessimism of the intellect," presumes that climate change mitigation is a doomed endeavor, as CO2 emissions already baked into the global economy appear likely to push the atmosphere beyond even the most generous carbon budget estimates. The prospects are just as dim for an equitable adaptation response that protects vulnerable populations, as it would require political buy-in from the Global North for a redistributive revolution "of almost mythic magnitude."[65] In this nightmare vision of

[64] Long and Rice 2018, 1.
[65] Davis 2010, 38.

zero-sum climate crisis, a more likely outcome is an exclusionary and ever-diminishing number of climate-adapted enclaves:

> *"Instead of galvanizing historic innovation and international cooperation, growing environmental and socio-economic turbulence may simply drive elite publics into more frenzied attempts to wall themselves off from the rest of humanity. Global mitigation, in this unexplored by not improbable scenario, would be tacitly abandoned – as, to some extent, it already has been – in favor of accelerated investment in selective adaptation for Earth's first-class passengers. The goal would be the creation of green and gated oases of permanent affluence on an otherwise stricken planet."*[66]

Davis presents a rosier outlook in his alternate ending, "Optimism of the imagination," which casts the city as "its own solution." Although he believes the carbon-intensive Northern Hemisphere city of the 21st century is "rapidly destroying the ecological niche – Holocene climate stability – which made its evolution into complexity possible," he is encouraged by the "consistent affinity between social and environmental justice, between the communal ethos and a greener urbanism."[67] Examples of diverse co-benefits point to a unifying principle: "that the cornerstone of the low-carbon city, far more than any particular green design or technology, is the *priority given to public affluence over private wealth*."[68]

Viewed from the high-level perspective of this "consistent affinity" and Davis' unifying axiom of public enrichment, the distinctions between urban sustainability and

[66] Ibid, 38.
[67] Ibid, 42.
[68] Ibid, 41-43.

resilience may feel inconsequential. However, there are numerous instances where achieving ecological sustainability (or, more often simply gesturing toward it) is not sufficient to ensure resilience. In her book *Neighborhood*, Emily Talen demonstrates how an organic "everyday neighborhood" achieves lower carbon emissions through walkable access (e.g., fewer vehicle miles travelled) to a mix of uses (e.g., efficiencies in land and energy intensity) while also fostering social diversity. However, violating the "mutually reinforcing relationship" between diversity and mix of services by producing enclaves that are socially homogenous, Talen asserts, results in "'lifestyle centers' and other inauthentic brands of neighborhood that are increasingly difficult to push on a skeptical public."[69] In this example, although both districts may achieve the same level of performance on a sustainability assessment scorecard, the "everyday neighborhood" is likely more resilient to economic downturns, demographic shifts and neighborhood succession, or disruptions to transportation infrastructure following extreme weather events.

More immediately, in terms of the health impacts of climate change – already an urgent reality in many frontline communities; and expected to quickly escalate in reach and severity – it is worthwhile for policymakers and communicators to carefully distinguish between sustainability and resilience. Bringing limited resources to bear in pursuit of one principle, rather than the other, will likely produce different outcomes in a public health context. Perhaps for this reason, sustainability is conspicuously absent from the U.S. Global Change Research Program's 2016 *Climate and Health Assessment*, which instead acknowledges "climate mitigation, adaptation, and resilience strategies."[70] The report

[69] Talen 2019, 252.
[70] USGCRP 2016, "About this Report."

approaches resilience in the context of health *vulnerability*, which it defines as an interaction between three determinants: exposure, sensitivity, and adaptive capacity. With regard to adaptive capacity, the report acknowledges “a related term, resilience, is the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events.”[71] While the two may seem interchangeable, it is important to note that interventions designed to reduce exposure or alleviate sensitivity also make communities more resilient.

While they aren’t entirely analogous, for the purposes of this analysis climate mitigation and adaptation are considered proxies for sustainability and resilience, respectively. Despite the synergies evident in interventions that advance both mitigation and adaptation, like enhancing urban tree canopies, more often than not each objective entails very different design prescriptions. These prescriptions apply to both urban morphology (scale and configuration of street grids) and typology (scale and configuration of buildings). Peter Calthorpe’s vision for “green urbanism,” which focuses on making cities less carbon-intensive by cutting *demand*, involves retrofitting and replicating the pedestrian-scale streetcar suburbs of the early 20th century with modern transit and energy-efficient building technologies.[72] At major nodes and town centers, this model necessitates relatively high density and an overhaul of housing stock composition to limit the proportion of detached single-family homes. Although this green urbanism can achieve much higher performance in terms of greenhouse gas emissions, water consumption, and land use – important metrics of sustainability – fellow New Urbanism theorist Andres Duany has

[71] Ibid, 25-42.
[72] Calthorpe 2010.

pointed out that these settlements are ill-equipped to handle shocks to energy and transportation infrastructure.[73] The tightly packed, transit-serviced urbanism of Manhattan, he argues, might be an excellent model for reducing per-capita carbon emissions, but it is acutely vulnerable to extreme heat events like the 2003 European heat wave that resulted in over 70,000 deaths.[74] These episodes increased in frequency, intensity, and duration over the past half-century, a trend that is likely to continue. Given that such events are likely to exacerbate many urban centers' precarious access to electricity, fresh food, and sanitary drinking water – the 21st century may demand a new urban design paradigm that prioritizes adaptive capacity and resilience over traditional notions of sustainability.

Benson and Craig reach this same conclusion in "The End of Sustainability." Here, they define sustainability as "the long-term ability to continue to engage in a particular activity, process, or use of natural resources;" and describe sustainable development more concretely as grounded in the aim to "assure the continuing availability of natural capital and other ecological amenities."[75] They argue that Anthropocene circumstances – namely "extreme complexity, radical uncertainty, and lack of stationarity" – demand a new orientation to "formulate ecological governance goals by some metric other than sustainability."[76] To date, sustainability has continued to frame policy discussions despite its growing irrelevance, after decades of failed intergovernmental efforts to effectively mitigate climate change by pursuing "sustainable development" goals. "It's not that sustainability is a *bad* idea…[but rather] whether the concept of sustainability is still *useful*

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[73] Duany, Andres, 2019, "Principles of New Urbanism," presentation at CNU 27, June 12.
[74] Habeeb, Vargo, and Stone 2015, 1652.
[75] Benson and Craig 2014, 2.
[76] Ibid, 3.

as an environmental governance goal."[77] Resilience thinking, in contract, acknowledges disequilibrium and nonlinear change; emphasizes adaptive capacity over stationarity; and identifies critical thresholds for avoiding irreversible disruption.

It is against the backdrop of this complexity and uncertainty – and in the light of accelerating climate change impacts that render historical observations increasingly obsolete – that jurisdictions must plan both for growth and for resilient infrastructure to accommodate and organize it. In the process, they will be forced to look beyond design orthodoxy geared toward traditional notions of sustainability and climate mitigation, even evidence-based models advanced by New Urbanists like Calthorpe and (historically) Duany, toward new prescriptions. These prescriptions must be flexible enough to address acute crises and long-term challenges such as ever-growing economic inequality and its spatial outcomes; increasing disruptions to food and transportation systems; and erratic, intra-regional climate migration. The remainder of this thesis will attempt to issue its interpretations and policy recommendations through this lens; however, they represent only incremental steps toward the vast and urgent project of reorienting planning practice to respond to these rapidly emerging crises.

Sections 2.1 and 2.2 sought to demonstrate the advantages of applying resilience – rather than sustainability – as a theoretical framework for investigating the Atlanta BeltLine. The Results chapter will present findings on several indicators of urban *climate* resilience, specifically, that are relevant to the BeltLine's intended outcomes of *diminished urban heat island* and *resource-efficient, compact development.* The Discussion and

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[77] Ibid, 3.

Conclusion chapters will devote further attention to the policy implications of these findings. First, the remainder of this chapter will consider two large bodies of literature. One is concerned with technical research methods and performance indicators that were considered in designing this analysis; the other consists of a range of local policies and plans that both guide the build-out of Atlanta's physical structure and dictate its plasticity and adaptability. Both contexts will be discussed over the remainder of this chapter.

2.4 Methodologies

In the past two decades (but particularly in the wake of the 2015 Paris Climate Agreement) scholars and practitioners have developed numerous frameworks for measuring urban resilience and urban *climate* resilience. Due to the eclectic conceptual heritage that undergirds resilience theory and the diversity of stakeholders invested in its applications – from city planning and public health to international development and finance – some frameworks are far more relevant to Atlanta, with its highly developed infrastructure and formalized policy environments. The research question this thesis investigates is concerned with measuring climate resilience impacts resulting from key early phases of the Atlanta BeltLine infrastructure project. As such, an important first step in developing a method of inquiry was to review established frameworks and their accompanying performance indicators.[78] Drawing from the literature presented in Section

[78] For the purposes of this thesis, the term "indicator" is understood as a shorthand to encompass measures of performance that are qualitative and quantitative, direct or indirect – e.g., proxies. There are substantive nuances in terminology around "metrics" and "indicators," summarized on page 13 of Inter-American Development Bank's 2019 *Framework and Principles for Climate Resilience Metrics in Financing Operations*.

2.2, the author considered a handful of appropriate indicators for which reliable, high-resolution data might be obtained and analysis conducted with sufficient rigor.

Toward that end, the remainder of this chapter explores four dimensions of urban climate resilience: building energy performance, tree canopy coverage, stormwater runoff, and urban morphology. Key performance indicators and established methodologies for measuring and evaluating each of them are presented in the following sections.

2.4.1 Building Energy Performance

Residential and commercial buildings accounted for nearly 40% of U.S. energy consumption in 2017.[79] Updating this building stock with high-performance new construction and retrofitting existing buildings to enhance efficiency are two relatively straightforward strategies to promote both sustainability and resilience. This metric is particularly relevant to the study area in question, as an unprecedented number of new mixed-use and multifamily residential developments have gone up alongside the Atlanta BeltLine Eastside Trail in the past decade. Moreover, the larger portion of the BeltLine Overlay that encompasses this trail segment has seen considerable new construction on single-family lots (although, because many of these homes are substantially larger and more luxurious than the modest structures they replaced, it remains to be seen whether they will outperform their predecessors).

[79] "How much energy is consumed in U.S. residential and commercial buildings?", 2018, U.S. Energy Information Administration: https://www.eia.gov/tools/faqs/faq.php?id=86&t=1.

Unfortunately, it's difficult to quantify with any degree of certainty a building's estimated energy use intensity (EUI, measured here in kWh/m^2 conditioned floor area); even the most sophisticated existing building energy models struggle to accurately predict observed energy consumption. For the purposes of evaluating progress toward more sustainable development patterns within a limited study area, these models are more than adequate to compare design alternatives on a site-by-site basis and determine which is most likely to perform better. However, this approach is too time-intensive and computationally taxing to be readily applied at a district scale.

Li et al. (2018) found that "numerous attempts have been made for simulating building energy consumption at a neighborhood or city scale."[80] These models are classified as "top-down" (in which buildings are treated as a single energy body, conditioned by long-term economic data) or "bottom-up" (wherein individual buildings are modeled and then scaled up in proportion with the neighborhood composition). These attempts have reportedly had limited success due to low-resolution data bottlenecks such as oversimplified TMY weather data or building parameters provided by the Energy Information Administration (EIA) that must be used to plug data gaps.[81]

Early in scoping this thesis, the author had hoped to employ a kind of "bottom-up," coarse-grained analysis using the Energy Performance Calculator (EPC), an Excel-based energy modeling software that focuses on the building envelop (roof, walls, and windows) rather than granular details about internal behavior and equipment. Jige Quan et al. (2015)

[80] Li et al 2018, 107-8.
[81] Ibid, 108.

successfully integrated the EPC with GIS data, filling in missing model inputs with data from reference building models provided by the Department of Energy. These models "contain three categories of building vintage (based on the construction year), each of which includes 16 building types representing most of the commercial buildings across 16 US climate zones."[82]

However, the scoping phase uncovered several challenges that would render such an approach unfeasible and confound any attempt to attribute any district-wide changes in energy performance to the BeltLine itself. The most obvious obstacle was the task of identifying an analog district elsewhere in the City of Atlanta that could serve as a natural control or counterfactual example.[83] The most ideal example would be a redevelopment cluster or corridor with similar urban design and market characteristics as the study area; one that experienced similar development trends from 2009 to 2017, but without the BeltLine. While there is no shortage of districts around the city's urban core with similar morphology and building stock mix, the Subarea 5 study area was uniquely poised for growth due to the relative affluence of surrounding residential neighborhoods. In this sense, similar conditions could be found in areas northwest of Midtown, which experienced a flurry of development over the same time frame despite having the most distant (and uncertain) time horizon for BeltLine trail and transit construction. Ultimately, though, assembling and analyzing a separate sample of buildings in this second study area was deemed too great a departure from the focus and scope of this exercise.

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[82] Jige Quan et al. 2015, 452.
[83] Email correspondence with Dr. Jason Brown, Assistant Professor, School of Architecture. February 7-14, 2019.

More daunting still was the prospect of isolating the influence of the BeltLine from the universe of factors that could affect energy performance in an evolving local building stock.[84] Zoning regulations for the BeltLine Overlay, the primary instrument for dictating design practices near the corridor, did not explicitly address energy consumption or efficiency in new developments. Moreover, the building codes that *do* set the standards for energy performance in new construction underwent major changes during the study period. Most notably, substantial updates to the Georgia State Minimum Energy Code took effect in January 2011 that codified the 2009 International Energy Conservation Code (IECC) and ASHRAE Standard 90.1-2007 in all new residential and commercial construction in Atlanta.[85] The state had adopted the 2004 IECC and ASHRAE standards in January 2008, shortly prior to the study period in question, meaning that the early years of the BeltLine coincided with two rounds of unprecedented enhancements to the building codes that drive energy performance in Atlanta's new buildings. These developments posed a major challenge in estimating with any confidence the impact of the BeltLine in this area, and so this dimension was removed from the analysis.

2.4.2 Stormwater management

For decades, researchers and practitioners have been aware of the impact that urbanization has on local hydrology, both in terms of increase storm runoff and degraded water quality. Delleur (2003) cites a memorable Wisconsin case study wherein what had

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[84] Ibid
[85] Georgia Department of Community Affairs 2010, 1

been a 100-year flood for one watershed in 1960 became, after 50 years of urbanization, the new 3- to 4-year high flow.[86]

As traditional stormwater infrastructure, such as large detention ponds and open channels, becomes more difficult to site (and more inadequate) in urban environments where land use is intensifying, management practices that retain and treat stormwater where it falls are becoming more popular.[87] While these “green infrastructure” practices appear effective at the site level, there is a need for more research to measure their cumulative impact at the watershed level. Versini et al. (2016) attempted such an analysis in two French neighborhoods and concluded that installing green roofs on half of the eligible sites (as identified through GIS land cover classification) would reduce peak discharge in the watershed by 15%.[88]

There are a number of widely used modeling software that can simulate the volume and rate of stormwater discharge within geographical scales ranging from small catchments and sub-watersheds to entire basins. Each of these physical models is best suited to a particular purpose, spatial scale, and land cover conditions, and they tend to model both total runoff volume and peak rate of discharge based on a site’s topography, land cover, soil composition, and other factors. The first of these tools, introduced in 1971, was SWMM (stormwater management model), which has spawned other specialized variants.[89] Other commonly used models include the Rational Method, which is built on a simple

[86] Delleur 2003, 567.
[87] Versini et al. 2016, 372.
[88] Ibid, 378.
[89] Delleur 2003, 567.

equation to solve for peak discharge and is "best used only for simple approximations of peak flow from small watersheds,"[90] and the USDA's Natural Resources Conservation Service (NRCS) methodology. The latter is reportedly best-suited for "comparing pre- and post-development peak rates," and thus was initially targeted for use in this analysis.[91]

Unfortunately, the limited availability of digital records on stormwater modeling for approved development projects in Atlanta, along with uncertainties about practices not visible to the naked eye – like stormwater detention vaults – that could only be addressed with access to site plans or models, also rendered this portion of the analysis unfeasible.

2.4.3 Land Cover and Urban Tree Canopy

Canopy cover is typically expressed as a percentage of land area within a jurisdiction of interest that is obscured by tree leaves when viewed from directly above (e.g., planimetric view). This metric is especially useful for communicating sustainability principles to the public because it is a visually intuitive measure than can be clearly mapped.[92] It is also especially pertinent to Atlanta, which lives up to its reputation as the "City in the Forest" with an estimated canopy cover of 48% as of 2008 – the most of any U.S. city examined by Giarrusso and Smith (2014).[93] Koo (2017) and Nowak and Greenfield (2012) reported even higher tree cover figures of 51.6% based on data as recent as 2013, although this generous tree cover is unevenly distributed across the City of Atlanta in an asymmetrical pattern that leaves many neighborhoods with severe canopy

[90] Minnesota Stormwater Manual, n.d.
[91] New Jersey Department of Environmental Protection 2014, 4.
[92] Walton, Nowak, and Greenfield 2008.
[93] Giarrusso and Smith 2014, 50.

deficits.[94,95] To the author's knowledge, no high-resolution analysis focused specifically on the Atlanta BeltLine Zoning Overlay has been published to date.

Methods for measuring tree canopy and vegetative cover in urban environments may include field observation, high-resolution aerial photography, and multispectral satellite imagery and remote sensing. Analysis often involves conducting matrix algebra with the Spatial Analyst extension of ArcGIS to automatically classify land cover into as many as 100 types of similar cells, at which point the analyst identifies each and reclassifies them manually into a handful of classes (e.g., tree, grass, bare dirt, impervious, shadow).[96] This process will be explained in greater detail in the Methods chapter.

Tree canopy analyses conducted at the regional scale or beyond, where there is little need to distinguish between individual small parcels, can (and for the sake of processing time and file size, should) make use of lower-resolution imagery of 30 or more meters. At the city scale, canopy assessment typically demands higher-resolution imagery such as the 0.7-meter multispectral imagery from the Quickbird-2 satellite or freely available 1 meter-resolution satellite imagery frequently collected as part of U.S. Department of Agriculture's National Agriculture Imagery Program (NAIP).[97] Use of multispectral Light Detection and Ranging (LiDAR) data in canopy mapping is also gaining popularity; these datasets are not only extremely precise in the two overhead dimensions, but also contains z- coordinates from which object height may be derived.[98] Walton et al. (2008) tested

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[94] Koo 2017, 29.
[95] Nowak and Greenfield 2012, 24.
[96] Behee 2012.
[97] "NAIP Imagery". n.d. USDA Farm Service Agency: https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/.
[98] Morsy, Shaker, and El-Rabbany 2017.

image classification methods using 30-meter Landsat and 2-foot Emerge imagery against several other methods and concluded that all produced estimates that were likely within a few percent of actual tree canopy cover, but that the high-resolution imagery was more appropriate for the citywide scale and Landsat was better-suited to "city to regional analyses."[99]

2.4.4 Greenhouse Gas (GHG) Emissions Related to Urban Form

More than any other factor, urban morphology often dictates a neighborhood's performance in terms of sustainability and resilience. Spencer Lewin (2012) enumerated the metrics relevant to sustainable urban form in the following order: "decreased energy use; reduced waste and pollution; reduced automobile use; preservation of open space and ecosystems; and a livable and community-oriented environment."[100] Peter Calthorpe (2010) modeled four development scenarios – Trend Sprawl (e.g., business as usual), Green Sprawl (e.g., sprawl with green technology), Simple Urbanism (e.g., passive urbanism) and Green Urbanism (dense urban form wedded with new energy policies and technologies). He estimated that a shift to Simple Urbanism would result in a national urban footprint one-fourth the size of the Trend Sprawl scenario's, along with a 43% reduction in vehicle miles traveled (VMT) and 27% reduction in the annual GHG emissions without any conservation standards or alternative energy investments.[101]

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[99] Walton, Nowak, and Greenfield 2008, 337-8.
[100] Lewin 2012, 45.
[101] Calthorpe 2010, 114.

Growing recognition that "green building" practices at the individual site scale are necessary but not sufficient to achieve sustainable urban form has given rise to "sustainable community assessment" systems.[102] LEED-ND (Leadership in Energy and Environmental Design for Neighborhood Development) is the most well-known of these frameworks, which attempt to establish a holistic composite score of multiple sustainability metrics at the neighborhood or district scale. The U.S. Green Building Council (USGBC) launched the scheme in May 2009 after four years of development and pilot testing in consultation with the Natural Resources Defense Council (NRDC) and the Congress for the New Urbanism (CNU). The creators of LEED-ND had reasoned that "since the bulk of urban growth is forecast to occur in communities of 100,000 to 250,000 people, neighborhoods will be the fundamental units of urban change and innovation," and thus that the neighborhood was the appropriate scale for planning assessment and intervention.[103]

The current LEED-ND structure is built upon five overarching credit "categories": Smart Location and Linkage (SLL), Neighborhood Pattern and Design (NPD), Green Infrastructure and Buildings (GIB), Innovation (IN), and Regional Priority (RP). Each category is composed of a number of more granular prerequisites and credits. For example, the NPD category includes a "Walkable Streets" Prerequisite tied to certain performance indicators, such as sidewalks on 90% of block lengths; it also includes a "Walkable Streets" Credit that awards points based on achievement of up to 16 criteria such as short set-backs and street-level transparent fenestration.[104] Each of these credits, in turn, accrue points that

[102] Wu et al. 2018, 12.
[103] U.S. Green Building Council 2014, 4-5.
[104] "Filter Credits: LEED ND, v4". n.d. U.S. Green Building Council. https://www.usgbc.org/credits/neighborhood-development/v4.

dictate a project's level of achievement along a non-linear scale from Certified (40-49 points) to Silver (50-59) to Gold (60-79) to Platinum (80+). Ultimately, the system is designed to promote more efficient land and resource use patterns, primarily through reductions in energy consumption and greenhouse gas emissions, land consumption, water use, and stormwater runoff. "The cumulative effect of these LEED-ND resource efficiencies, when leveraged across a jurisdiction, is notable fiscal savings from avoided investment in new infrastructure capacity."[105]

As with other LEED iterations, however, LEED-ND carries the inherent limitations of scorecard model whose encoded values disproportionately inflate the real-world impact of certain interventions over others and, in turn, fail to predict outcomes in a linear fashion. "A criticism of LEED rating systems is that all points are weighted equally, even though some have far greater environmental benefits than others," Spencer Lewin acknowledges.[106] For example, how point totals are apportioned in discreet integer values between credits like "Bicycle Network," (1 point), "Housing and Jobs Proximity," (3 points), and "Walkable Streets" (12 points) often seems arbitrary. "LEED criteria in this respect is specialized to fit a certain interpretation of sustainability, which makes it important to be sure that that is indeed the correct interpretation."[107]

Wu et al. (2018) echoed this assessment, finding that the system "may have unbalanced allocation of scores to the three aspects of sustainability[:] economic, social,

[105] Talen et al. 2013, 21.
[106] Lewin 2012, 57.
[107] Ibid, 57.

and environmental."[108] After examining all 55 projects certified under LEED 2009 for which detailed scorecards were available in late 2017, the authors expressed alarm at the "extremely low" percentage of achievement (PoA) in the Green Infrastructure and Buildings (GIB) category. Certified projects scored a mean of 10.80 out of 29 possible points (37.24%) in this category, compared with 17.44 out of 27 in Smart Location and Linkage (SLL; 64.58%) and 24.91 out of 44 in Neighborhood Pattern and Design (NPD; 56.61).[109] Ultimately, the physically oriented NPD category was the "single most important factor" in predicting certification level, and the authors warned that a possible imbalance could "induce stakeholders to believe that sustainability can be achieved by working at the margins instead of integrating its different pillars."[110] (An updated standard released in 2014 as part of "LEED v4" brought incremental revisions to credit criteria and scoring but did not address these fundamental critiques.[111])

Indeed, the ease with which developers can optimize their scorecard for least-cost compliance – in effect "hacking" the system – is what limits the certification scheme's ability to ensure meaningful sustainability outcomes.[112] In particular, critics have questioned whether the system places disproportionate weight on locational criteria, leading to a physical determinism that allows "projects in especially efficient locations [to] be LEED-ND certified without also possessing significant levels of green building construction or technology."[113] Other critiques of LEED-ND focus more on its inability to

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108 Wu et al. 2018, 10-11.
109 Ibid, 7.
110 Ibid, 9-11.
111 U.S. Green Building Council 2014b, "LEED v4 for Neighborhood Development: Summary of changes from LEED 2009".
112 Talen 2019, 117.
113 Talen et al. 2013, 23.

account for local circumstances and the more qualitative or intangible dimensions of everyday neighborhood life. In an article entitled, “LEED for Neighborhood Development: Does It Capture Livability?”, Aranoff et al. (2013) looked at one San Francisco neighborhood in particular and found wide discrepancies between resident-reported experience and quantitative assessment of the area according to LEED-ND criteria. “Cities must carefully consider the value they place on LEED-ND’s prescriptive standards,” the authors concluded, as they could “impose an inflexible template on the urban form” and reach conclusions contrary to lived experience.[114] This rigidity, along with the economic and technical burdens of achieving certification, has contributed to the sense that LEED-ND is “reserved for large developments that might use certification as a marketing tool or as a way to dampen community opposition.”[115]

Despite these limitations, LEED-ND and other “sustainable community assessment” systems have drawn interest in recent years from researchers hoping to repurpose the certification scheme as a kind of planning support tool – one capable of steering public investment toward more sustainable urban development patterns. A number of studies have attempted to incorporate LEED-ND criteria into geospatial tools to proactively identify suitable parcels for walkable, less carbon-intensive communities. Talen et al. (2013) developed a GIS-based methodology to identify every parcel in Phoenix that satisfied a critical LEED-ND criterion, the Smart Location and Linkage category’s Smart Location prerequisite (coded SLLp1), which they deemed the “most critical

[114] Aranoff et al. 2013, 164.
[115] Talen et al. 2013, 2; Lewin 2012.

determinant of location eligibility."[116] They were surprised to discover that over half of "candidate" parcels and a quarter of "candidate" acreage – e.g., all that remained after LEED-ND-mandated exclusions for use, existing development, etc. – met the location standards.[117] In doing so, they established an "inventory of 'green growth' sites whose development could, if strategically leveraged, profoundly improve a community's long-term sustainability" through reductions in land consumption, vehicle miles travelled, energy and water use, stormwater runoff, and greenhouse gas emissions.[118] Moreover, the inventory provided a launching point for deeper strategic planning: measuring how much forecasted growth these less resource-intensive locations can absorb entails important implications for Phoenix's long-term carrying capacity. The authors proposed incentives such as zoning "density bonuses," tax abatements, and fee waivers to redirect land development activity toward these parcels.

2.4.5 Policies and Local Context

This thesis also incorporates a number of local policies, ordinances, and plans (Table 1) that frame the policy context around urban climate resilience at the site and neighborhood scale. Some aid in this process by putting in place the enabling conditions that may hasten a more resilient built environment; others impose potentially counterproductive constraints. Both elements will be discussed further in subsequent chapters.

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[116] Talen et al. 2013, 21.
[117] Ibid, 33.
[118] Ibid, 33.

Table 1: Formally Adopted Plans Relevant to Study Area

Name	Year
The BeltLine Emerald Necklace	2004
Atlanta BeltLine Redevelopment Plan	2005
Ponce de Leon/Moreland Avenue Corridors Study	2005
Atlanta BeltLine Zoning Overlay	2007
Old Fourth Ward Master Plan	2008
Connect Atlanta Plan	2008
Poncey-Highland Neighborhood Master Plan	2010
Atlanta BeltLine Master Plans for Subarea 5	2009
City of Atlanta Comprehensive Development Plan (CDP)	2011; 2016
Atlanta BeltLine 2030 Strategic Implementation Plan	2013
City of Atlanta Post-Development Stormwater Ordinance	2013
Krog / Lake / Elizabeth / North Highland Plan	2013
City of Atlanta Tree Ordinance Update	In Progress
Urban Ecology Framework	In Progress
Atlanta BeltLine Master Plans for Subarea 5 (Update)	In Progress

The overarching Redevelopment Plan and accompanying Subarea plans offer aspirational visions for how growth around the BeltLine should unfold. In particular, they identify the most promising opportunities for “catalytic” redevelopment – the proverbial low-hanging fruit capable of generating tax revenue at a scale that can in turn subsidize more challenging redevelopment. At a more granular level, the small-area plans also pinpoint the intersections, blocks, and corridors where remedies to historical disinvestment are most urgently needed in BeltLine neighborhoods. But in terms of implementation, the BeltLine Zoning Overlay is the vehicle designed to express these aspirations on Atlanta’s physical form. Nested in Chapter 36 of the city’s zoning code, the BeltLine Overlay District

Regulations applies to a donut-shaped geography roughly coterminous with the "half-mile buffer" BeltLine Planning Area, with two key exceptions. Single-family residential zoning classifications (R-1 through R-5) and "Special Public Interest Districts" – themselves designed to promote denser, less auto-dependent urban form around neighborhood centers – are exempt from the Overlay's provisions, except in the case of lots "immediately adjacent" to the BeltLine corridor.[119]

While lacking the stirring language and visuals of other foundational documents associated with the project, the BeltLine Zoning Overlay demands special attention here, as it poses the most tangible mechanism through which to influence the design of the built environment. Its stated purpose is to "institute a regulatory approach that anticipates, manages, and encourages quality BeltLine development opportunities and impacts."[120] The policy lays out 15 overarching objectives, including "encourage a grid of smaller blocks and connected streets;" create pedestrian-oriented new mixed-use and commercial nodes at future BeltLine transit stops; preserve options for connections with the city's larger trail network; encouraging adaptive re-use of existing buildings, and "maximize air and water quality" through tree planting, greenspace, watershed protection, and bicycle parking.[121]

Despite this ambitious and wide-ranging preamble, the substance of the text consists of a relatively modest set of design prescriptions pertaining mostly to streetscapes,

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[119] "Scope of regulations," Atlanta, Georgia Code of Ordinances. Sec. 16-36-001, 2007, https://library.municode.com/ga/atlanta/codes/code_of_ordinances?nodeId=PTIIICOORANDECO_PT16ZO_CH36BEOVDIRE_S16-36.001SCRE.
[120] "Findings, purpose, and intent," Atlanta Code Sec. 16-36-002, https://library.municode.com/ga/atlanta/codes/code_of_ordinances?nodeId=PTIIICOORANDECO_PT16ZO_CH36BEOVDIRE_S16-36.002FIPUIN.
[121] Ibid.

facades, and vehicular circulation. Its zoning requirements focus on the design of property edges – where building facades, plazas, parking lots, or open space interfaces with the public realm – without explicitly touching on the sustainability performance of the building and site. For example, the Overlay does not address building energy performance, "green infrastructure" for stormwater management (apart from street trees), or sustainable building practices such as high-albedo "cool" roofs, on-site renewable energy production, or construction waste diversion.

In matters related to cars and parking, the policy takes a sort of "harm reduction" approach by, for example, requiring public-facing building facades to incorporate active ground-floor uses; forbidding surface parking from fronting streets and trails; and incentivizing shared parking and public on-street parking. Section 19 of the policy layers more stringent requirements upon the City's existing standards for landscaping of parking lots, with the caveat that existing parking lots "shall not be required to reduce the number of parking spaces by more than three percent as a result."[122] The policy takes pains to conceal off-street parking from public view more than it restricts the provision of parking itself: new multifamily and mixed-use developments, even those directly adjacent to the BeltLine, are bound to parking minimums set forth in their underlying zoning district and still receive relatively generous maximum allowances.[123, 124]

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[122] "Minimum landscaping requirements for surface parking lots," Atlanta Code Sec. 16-36-019, https://library.municode.com/ga/atlanta/codes/code_of_ordinances?nodeId=PTIIICOORANDECO_PT16ZO_CH36BEOVDIRE_S16-36.019MILARESUPALO.

[123] New residential builds, unless within a half-mile of a MARTA station, are entitled to one space per one-bedroom unit and two spaces per larger unit.

[124] Proposed residential and mixed-use residential developments reviewed by the BeltLine Design Review Committee between January and September 2019 called for 5,453 parking spots to accommodate housing 3,288 units and 1.4 million square feet of non-residential uses.

These omissions speak to the constraints and limitations of dictating sustainable design practices through zoning ordinance – especially through an overlay district. Many of these topics are explicitly addressed elsewhere in City code, for example, in the Post-Development Stormwater Management Ordinance (for all construction) and the Sustainable Building Ordinance (for city-owned facilities only). Still, if the Atlanta BeltLine project is to live up to its billing as the country's premier "sustainable redevelopment" project, its primary instrument for guiding that redevelopment must be retooled with an intentional focus on sustainability and, more importantly, urban climate resilience.

CHAPTER 3. METHODS

Chapter 2 explored various indicators of urban climate resilience and the feasibility of including them within the scope of the present study. The latter half of this chapter presents in greater detail the two indicators selected (or more precisely, the two sets of related indicators), why they were chosen, and the methods employed in order to measure each. First, a brief introduction to the study area is presented in the following section.

3.1 Study Area

This analysis focuses on a study area of approximately 1,100 acres, whose centroid is about 1.8 miles northeast of the Five Points transit station in Atlanta's historic downtown. The area falls entirely within the BeltLine Planning Area (BPA), described by officials as a roughly half-mile buffer on either side of the 22-mile corridor. The 15,000 acres that comprise the full BPA encompass approximately 19 percent of the City of Atlanta's land area and 22 percent of its population.[125] In the BeltLine vision's nascent years this planning area was subdivided into 10 "Subareas" of varying dimensions, allowing for master planning at the neighborhood and district level. The planning rationale behind this spatial unit was that a half-mile buffer would capture a comfortable "walkshed" for a typical pedestrian. The 22-mile Atlanta BeltLine corridor and the 10 Subareas that comprise the BPA are shown in Figure 2 against the backdrop of Atlanta's city limits.

[125] Federal Highway Administration Center for Innovative Finance Support, 2019.

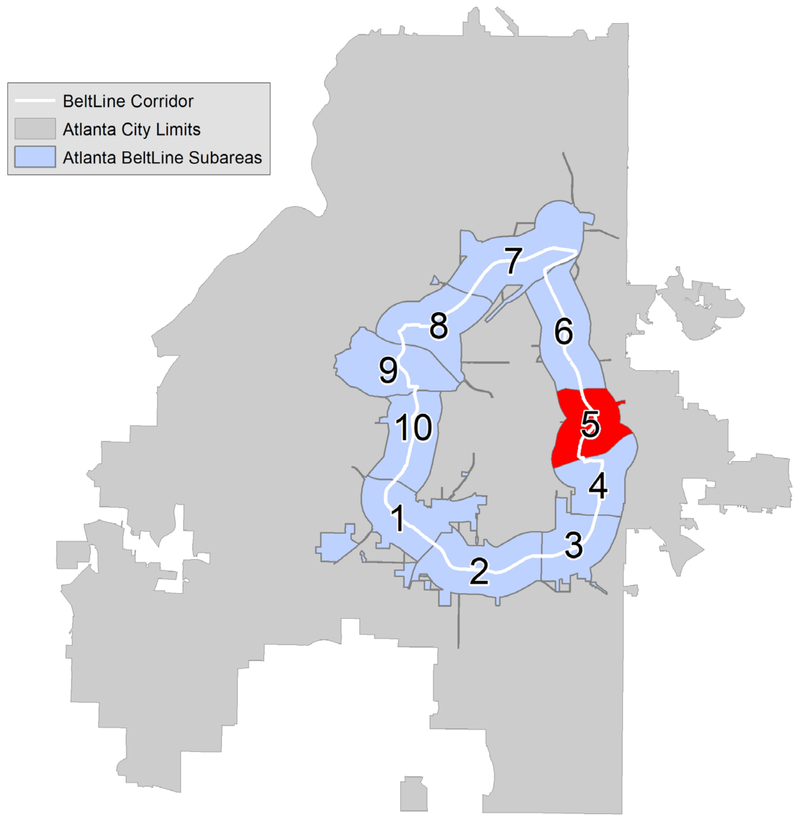

Figure 2: Atlanta BeltLine Subareas

For the sake of simplicity and applicability, the study area for this analysis is coterminous with Subarea 5, which contains the longest segment of the Eastside Trail's first phase. This 2.25-mile portion of the Eastside Trail, completed in 2012, remains the flagship product of the BeltLine project completed to date. Electronic trail counters recorded 1.8 million users on this section in 2018 – orders of magnitude greater than trail use on the newer Westside Trail last year.[126] Public perception tends to reflect this distinction: national media coverage invariably includes photographs from at least one of a handful of iconic perspectives along this portion of the trail. The "BeltLine" name itself serves as shorthand for this trail section in the minds of more casual visitors, despite

[126] Atlanta BeltLine Inc. 2019, "2019 BUILD Grant Application"

representing only one-tenth of the BeltLine mainline corridor. To date, it is the single most active nexus of private development around the Atlanta BeltLine corridor, its growth fueled by advantageous market conditions and several affluent adjacent neighborhoods that fared far better in the Great Recession than communities on Atlanta's south and west sides. Conveniently, Subarea 5 also falls entirely within a single watershed, at the headwaters of the Peachtree Creek, with its southern boundary roughly tracing the Eastern Continental Divide that runs along Atlanta's Dekalb Avenue. Thus, the study area is as hydrologically intuitive as it is socially and economically.

Subarea 5 is the second smallest of the BeltLine districts, representing just 7.5% of the BPA's land area. However, it has the highest estimated population density of the 10 subareas, by a wide margin: nearly 8,600 people per square mile in 2018, versus 6,200 in neighboring Subarea 6. It also experienced the greatest net population growth between 2000 and 2018, adding approximately 6,200 residents – an increase of nearly 75%.[127] Figure 3 delineates the boundaries of Subarea 5, the portion of BeltLine corridor that bisects it (which contains the Eastside Trail alignment), and adjacent neighborhoods.

[127] Atlanta Regional Commission, "BeltLineSubareas_Data_Updated" ArcGIS Online, updated April 16, 2020, https://www.arcgis.com/home/item.html?id=266f51623ecb48bc9c4333112c70e661.

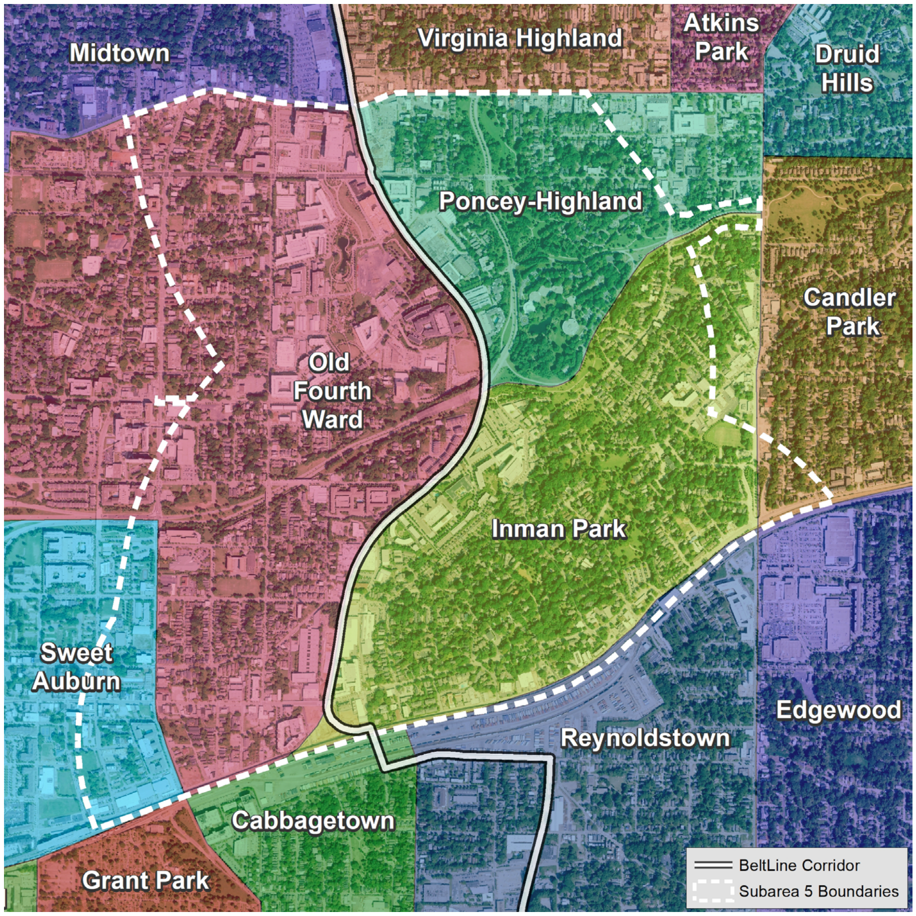

Figure 3: Subarea 5 and Adjacent Neighborhoods

3.2 Relevant BeltLine Outcomes and Indicators

From its inception, the BeltLine project has embraced an ambitiously broad vision for social, economic, and ecological change in order to enlist buy-in from as many local constituencies as possible.[128] Publicized goals and targets include: 33 miles of multiuse trails, 22 miles of light rail transit, and 46 miles of improved streetscapes; $10 billion in private economic development, 30,000 permanent jobs, and 5,600 “affordable” housing

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[128] Fulton 2016.

units priced below market rate; as well as 1,300 acres of new greenspace and 1,100 acres of brownfield remediation.[129]

Figure 4 reformulates and refines these stated project goals in terms that are more clearly relevant to urban resilience, resulting in nine "Outcomes" that the BeltLine may help influence at several scales. The figure illustrates in schematic form the relationships between:

- Outcomes that the Atlanta BeltLine project aspires to help achieve, either explicitly or implicitly;
- Mechanisms through which the BeltLine could influence these outcomes in Subarea 5 and elsewhere in the BeltLine Planning Area; and,
- The proxy indicators intended to measure progress toward those outcomes.

While each of the BeltLine project's overarching objectives can be related to social, ecological, or economic resilience in some fashion, the highlighted outcomes were selected for further investigation in this thesis. These two outcomes – diminished urban heat island effect and low-impact, compact development patterns – are particularly relevant to the project of enhancing urban climate resilience in the built environment. In the "Leverage" section, each box indicates a policy or design lever that may be brought to bear in pursuit of the accompanying outcome (and, upon which the BeltLine's implementing agency may feasibly exert influence). The "Indicators" section lists specific, measurable performance measures or proxies that are relevant to the levers above and can be used to evaluate

[129] Atlanta BeltLine, Inc., n.d., "Project Goals," https://beltline.org/the-project/project-goals/.

performance toward the accompanying outcome. This is not an exhaustive list but rather an illustration of relevant indicators that might be tracked using existing data sources – without requiring public agencies to invest in massive expansions in technical capacity or

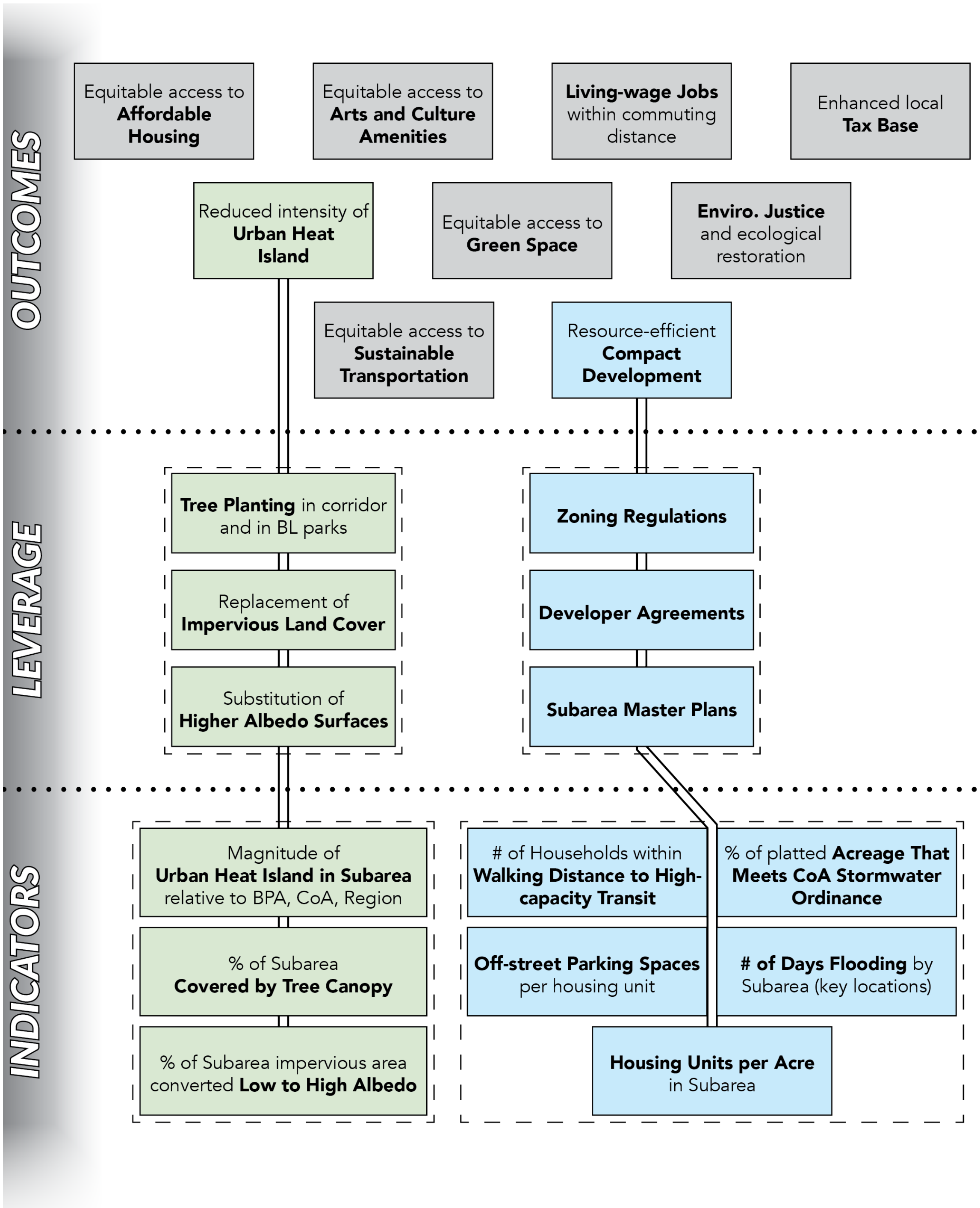

Figure 4: Beltline Resilience Indicators, Leverage Points, and Outcomes

costly research methods. The two selected groups of indicators intersect in a variety of ways with the Atlanta BeltLine's other stated project outcomes: for example, "Number of households within walking distance to high-capacity transit" obviously influences the Sustainable Transportation outcome, much as tree canopy enhancement will likely correlate to green space access.

Trees and tree planting have always been elemental to the BeltLine – even if implications for urban heat were implicit (or incidental) in the early days. (Gravel's 1999 thesis does not address the topic, nor does the 2004 "Emerald Necklace" study prepared by Alex Garvin, nor the 2005 Redevelopment Plan.) Although urban tree canopy and land cover conditions also impact on other project outcomes – such as equitable green space access and environmental justice & ecological restoration – for the purposes of this thesis these indicators are considered through the lens of urban heat. In this context, the benefits of interventions to enhance tree canopy and convert low-albedo, impervious land cover are numerous. They include reductions in building energy use and stormwater runoff; improved air and water quality; and, though less relevant at the neighborhood or city scale, carbon sequestration and climate change mitigation.[130] In Figure 4, selected indicators for the outcome of interest ("Reduced intensity of urban heat island") include two drivers of heat island formation that may be directly measured using land cover classification: "Percent of Subarea covered by tree canopy"; and "Percent of Subarea impervious surfaces converted from low to high albedo." A third, more outcome-oriented indicator, "Magnitude of urban heat island in Subarea" entails more sophisticated measurement of dynamic

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[130] EPA, n.d., "Using Trees and Vegetation to Reduce Heat Islands," https://www.epa.gov/heat-islands/using-trees-and-vegetation-reduce-heat-islands#2.

variables and requires that baselines also be established for the BeltLine Planning Area, city, and broader region. Only the first two indicators are considered in this analysis.

Figure 5 underscores the urgent importance of pursuing the other outcome of interest, resource-efficient growth.[131] The Atlanta Regional Commission (ARC) estimates that the 21-county region it oversees will grow 50% in the next three decades, swelling to 8.6 million residents by 2050 after absorbing the present population of metro Denver.[132] Fulton County alone, which contains the vast majority of Atlanta's municipal land area, is projected to pack on over 460,000 new residents. For its part, the City of Atlanta is planning

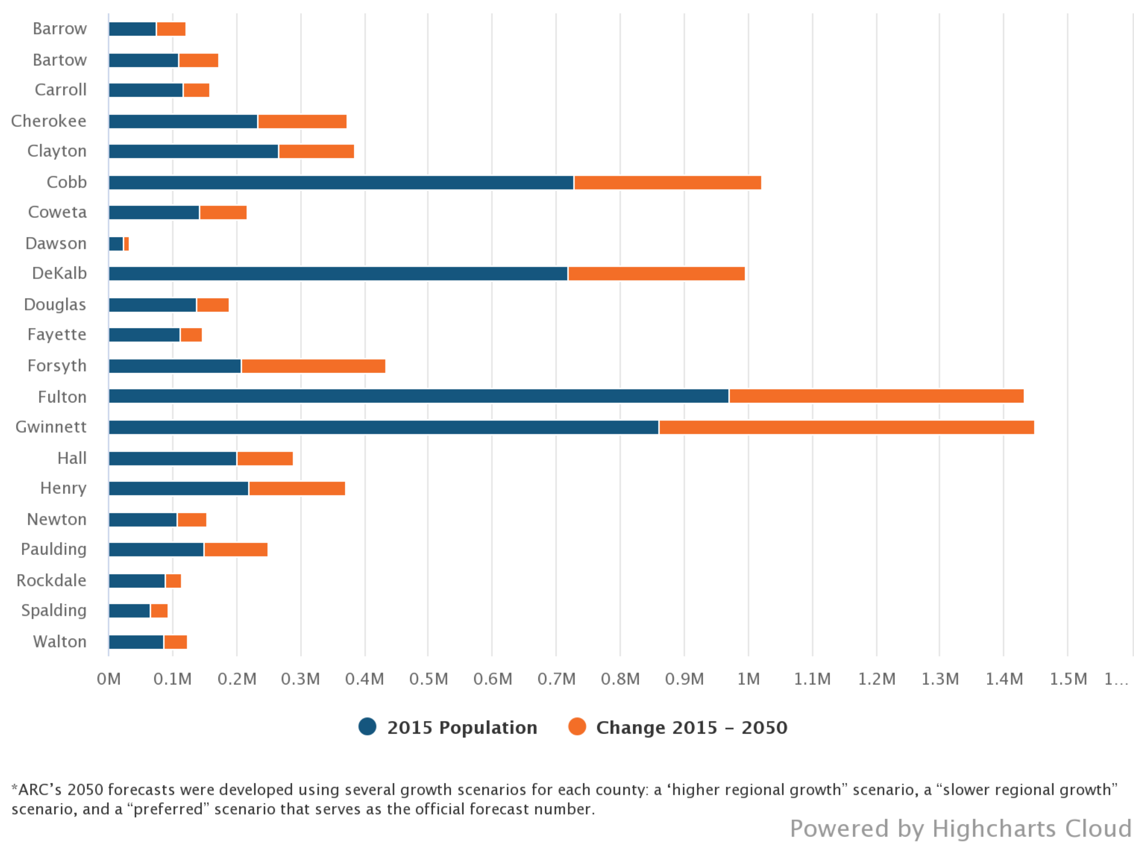

Figure 5: Atlanta Region Population Growth Forecast, 2015-2050, by County

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[131] Figure source: Atlanta Regional Commission
[132] Atlanta Regional Commission, n.d., "Population & Employment Forecasts," https://atlantaregional.org/atlanta-region/population-employment-forecasts/.

to accommodate a much higher portion of regional growth than it has for the past half century. The Department of City Planning predicts, perhaps unrealistically, that the city may "nearly triple" its existing population by as soon as 2040, reaching 1.2 million residents.[133] But, by even the most conservative estimates, forecasted population growth would place immense stress on the city's existing housing stock and infrastructure. Should housing supplies in Atlanta's relatively few walkable, bikeable, and transit-accessible districts dry up and become unaffordable for a large portion of new (or existing) residents, a greater portion of growth would be displaced to car-dependent outlying suburbs. This would pose obstacles to climate resilience at both the city and regional level, both in terms of mitigation (e.g., greater per capita greenhouse gas emissions) and adaptation (e.g., difficulty enacting policies for tree canopy enhancement across a fragmented patchwork of jurisdictions).

This scenario assumes that past and present trends continue in a relatively stationary pattern, fluctuating within a confidence interval in the absence of transformational disruptions imposed by climate change or economic upheaval. However, Figure 6 provides a sobering glimpse into another scenario, in which baseline estimates of population growth are compounded by large-scale, climate change-induced displacement from coastal population centers.[134] Recent research projected that by 2100, Atlanta could become the third-largest destination in the country (behind Austin and Orlando) for climate migrants

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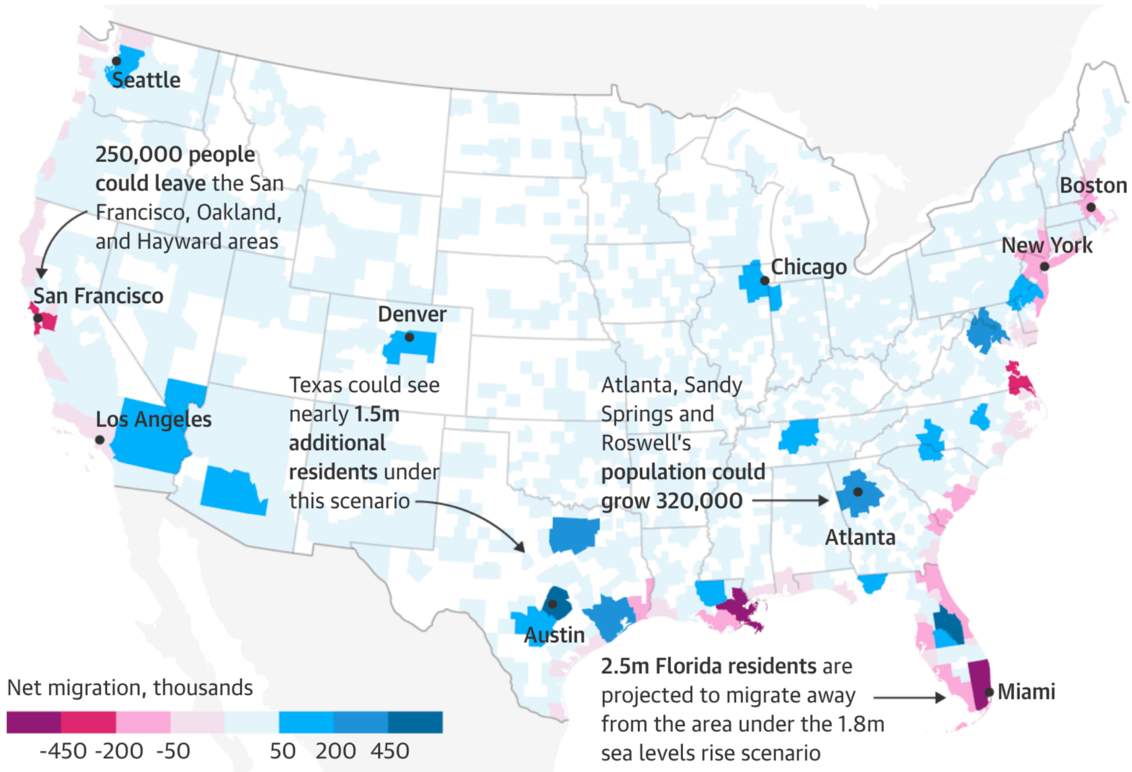
[133] City of Atlanta Department of City Planning, 2017, *The Atlanta City Design*, 122-127, https://www.atlcitydesign.com/.
[134] Figure source: *The Guardian*, appearing in September 2018 piece, "America's era of climate mass migration is here" "https://www.theguardian.com/environment/2018/sep/24/americas-era-of-climate-mass-migration-is-here.

displaced by sea level rise (SLR), driving as many as 320,000 additional people to the Atlanta region.[135,136]



Guardian graphic. Source: Nature climate change, Mathew E. Hauer

Figure 6: Key Origin & Destination Cities for SLR Climate Migration

3.3 Selected Indicators

This analysis investigated two groups of indicators that addressed the research question, “has the BeltLine made its surrounding built environment more climate resilient?” First, it considered land cover change in the rapidly redeveloping study area around the Eastside Trail between 2009 and 2017; specifically, the analysis sought to

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[135] Hauer 2017, 12.
[136] Hauer et al. 2020, 34.

measure changes in tree canopy coverage relative to changes in the surface area of light impervious and dark impervious ground cover.[137] The analysis then scrutinized the supply of land in the study area deemed suitable for sustainable redevelopment or "green growth" as defined by the LEED for Neighborhood Development (LEED-ND) methodology. Specifically, this entailed estimating changes between 2009 and 2017 in the number of land parcels that would meet "candidate parcel" criteria – a first hurdle to clear in a LEED-ND inventory, before proceeding to the much more labor-intensive process of confirming parcel eligibility.

How do these indicators relate to resilience in the built environment? Beyond simply correlating to more resilient or sustainable outcomes, each one helps indirectly measure an urban district's climate resilience in terms of its capacity to either withstand or avoid both acute shocks and long-term stresses. The two land cover indicators selected from Figure 4 (e.g., within the "urban heat island" column) intersect closely with ISO's urban resilience indicators, cited in Section 2.2. Greater tree canopy coverage has been shown to moderate urban heat and mitigate its adverse effects on human health at the neighborhood scale.[138] Similarly, both reducing impervious land cover and promoting urban tree canopy, in particular, have been shown to deliver a variety of benefits for stormwater runoff quantity and overall surface water quality.[139] The urban form indicators in Figure 4 (e.g., within the "compact development" column) relate more obliquely to

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[137] The threshold applied to distinguish between light and dark surface material was somewhat arbitrary due to differences in spectral characteristics between the 2009 and 2017 NAIP imagery. Nonetheless, most often the unsupervised land cover classification differentiated asphalt pavement and roofing materials ("dark" impervious) from concrete, white-painted, or otherwise "light"-colored impervious surfaces.
[138] Ziter et al. 2019, 7575-6
[139] Center for Watershed Protection 2017, 11-12

resilience outcomes but nonetheless help compose valuable proxy measurements. For example, indicators pertaining to transit access and provision or private parking help predict a range of outcomes from transportation emissions to economic inclusion; residential density has important implications for alleviating stress on built infrastructure and optimizing development patterns for low-carbon transportation.[140] Rather than directly measure this set of precise indicators – an endeavor that demands attention in future study – the methodology presented below in Section 3.3.2 sets its sights on a more diffuse but related proxy measurement. Specifically, this thesis seeks to quantify the "supply" of land in Subarea 5 with locational qualities that are conducive to the climate-resilient urban development patterns described above.

3.3.1 Land Cover and Tree Canopy

Here, the performance measure applied is *land cover composition (by percentage)* pre- and post-construction of the Eastside Trail and Historic Fourth Ward Park. Evaluation is based on 1-meter resolution aerial imagery in accordance with established GIS methodologies for unsupervised raster classification

This analysis demanded a particularly high level of remote sensing image fidelity due to the study area's limited scale and irregular shape. Whereas many tree canopy assessments utilize imagery from the National Land Cover Database (NLCD), whose 30-meter resolution is better suited for regional analyses, this thesis instead used 1-meter imagery from the US Department of Agriculture's (USDA) National Agricultural Imagery

[140] Temmer and Venema 2017, 4-5

Program (NAIP). The NAIP's four-band imagery is captured during the "leaf-on" season, typically around the same date and time of day in order to avoid inconsistencies in sun angles and resulting shadows. NAIP availability varies by state; in Georgia, imagery was collected approximately every two years between 2005 and 2017. However, four-band imagery with a near-infrared band only became available for Georgia in 2009, replacing traditional "natural color" (red, green, blue) images.[141]

Prior to 2009, almost all aerial imagery captured as part of USDA's NAIP program was captured in three-band "natural color" – red, blue, and green bands. Four-band "color infrared" (CIR) imagery became available for 19 states, including Georgia, in 2009. The addition of a fourth, near infrared band (wavelengths between 800 and 900 nm) allows the analyst to derive the Normalized Difference Vegetation Index (NDVI), a high-resolution indicator of plant health (USDA 2017).

For the sake of continuity – namely, in order to permit the direct comparison of NDVI layers over time – this analysis makes use of NAIP imagery captured in September 2009 rather than the previously available dataset from 2007, which was captured in three-band natural color. Consequently, the tree canopy analysis loses sight of the first four years following two critical policy signals in the nascent BeltLine project: the formal adoption of the BeltLine Redevelopment Plan and the creation of the BeltLine Zoning Overlay and BeltLine TAD. However, this omission is somewhat mitigated by the arrival of the Great Recession in 2007, which slowed most development in the city to abrupt halt. Atlanta

[141] USDA 2019, "NAIP Coverage 2002-2018," https://www.fsa.usda.gov/Assets/USDA-FSA-Public/usdafiles/APFO/status-maps/pdfs/NAIP_Coverage_2018.pdf.

experienced the most dramatic slowdown in new construction of any metro area from 2005 to 2009; single-family permits declined 92% in Fulton County during this period, compared to 74% nationwide.[142] Conversely, the study period from 2009 to 2017 coincides with the most significant in-town building boom in Atlanta's modern era: annual permits for new residential and commercial developments more than doubled between 2012 and 2017, plateauing around 700 in 2016.[143]A detailed description of the land cover classification methodology can be found in Appendix B. In short, this analysis employed an algorithm known as ISODATA (Iterative Self-Organizing Data Analysis Technique) to form "clusters" of pixels with similar spectral characteristics.[144] The technique can be performed on multi-band, multispectral imagery (e.g., representing wavelengths beyond the visible spectrum) in ArcGIS using the Iso Cluster tool. When applying this method to four-band NAIP imagery, the analyst is able to generate a normalized difference vegetation index (NDVI) layer that measures the difference between a ground cover's reflectance of near-infrared and red light, resulting in a standardized value between -1 and +1.[145] The NDVI provides a much more powerful instrument than the naked eye alone in detecting photosynthetic activity and thus, healthy vegetation. Incorporating texture analysis through the use of the Focal Statistics tool in the Spatial Analyst ArcGIS extension may further strengthen the ability of the classification algorithm to detect more nuanced differences in object shape and not simply color. Behee (2012) found that measuring texture roughness variations (a proxy for object height) using 7-by-7-meter neighborhoods proved especially

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[142] Immergluck 2013, i.
[143] Giarrusso 2018, 40.
[144] Giarrusso 2018, 16.
[145] Behee 2012, 21-26.

effective at distinguishing between tree crowns and smooth, or evenly illuminated, zones of low grass and shrub vegetation that might otherwise exhibit similar levels of photosynthetic activity.[146]

Whereas in "supervised" image classifications, the analyst guides the sorting process by identifying a sufficient number of representative "training sites" for the processing software in advance, the Iso Cluster tool uses unsupervised classification wherein the software classifies land cover types into a large number of classes based on spectral characteristics.[147] When performing unsupervised classification, it is best practice to initially use a conservatively high number of classes, perhaps 50 or 100, and draw down the number of classes through subsequent rounds of reclassification using human judgment and the analyst's knowledge of the study area.[148] The analyst sorts these 50 classes into a smaller set of meaningful categories – in this case, trees, grass, bare soil, lighter and darker impervious surfaces (e.g., white painted roofs and asphalt shingles, respectively), and shadows or water bodies. The analyst then extracts any areas classified as water/shadow, masks those zones with the NDVI, texture difference layers, and individual NAIP bands, and performs the Iso Cluster tool once more to explode those regions into more granularly distinguished sub-classes (typically, 10) for more careful examination and reclassification. Differences in spectral characteristics between the 2009 and 2017 NAIP imagery for the

146 Ibid, 64-65.
147 Cooperative Extension System 2019, "What's the difference between a supervised and unsupervised image classification?" https://mapasyst.extension.org/whats-the-difference-between-a-supervised-and-unsupervised-image-classification/.
148 ESRI n.d., "How Iso Cluster works," https://desktop.arcgis.com/en/arcmap/10.6/tools/spatial-analyst-toolbox/how-iso-cluster-works.htm.

study area also made it necessary to extract other individual classes and reclassify them in order to ensure consistency across the final two classifications.

The available NAIP imagery for the two study data points posed several challenges. Most notably, while analysis was simplified by the fact that the study area fell entirely within a single NAIP image, obviating the need for a raster mosaic, the two images were misaligned by as much as 50 feet. Attempts to georeferenced the 2009 imagery to 2017 – which aligned precisely with the Fulton County tax parcel boundaries – were unsuccessful. Inconsistencies in the spectral qualities of the two images also complicated comparison of the land cover classifications. Although both were captured in late September, the 2009 NAIP flight evidently took place earlier in the day, introducing much longer shadows to the north and west of taller trees and built structures. As a result, 2.5% more grid cells were classified by the unsupervised Iso Cluster tool as shadows and had to be reclassified by hand. Lastly, inconsistent contrast across the 2017 NAIP image made it challenging to distinguish between grass and bare soil land cover, which likely inflated the estimated soil percentage compared to 2009.

This analysis disaggregated land cover changes by several spatial units: land parcels, a superimposed fishnet grid of equal-area cells, and zoning classification. The single-family zoning districts, denoted R-1 through R-4, were of particular interest. Recent studies of Atlanta’s urban tree canopy have drawn attention to the pernicious effect of single-family infill redevelopments, which tend to replace relatively modest older houses with sprawling new homes, covering a greater portion of the log and often necessitating the removal of established trees. Giarrusso’s 2018 update on the state of Atlanta’s urban tree canopy speculated that these larger-footprint new builds “may be the biggest threat to the city's urban tree canopy."[149] The report estimated that if half of single-family properties were built out to their maximum allowable lot coverage, the city's tree canopy would shrink by 18%.[150] This trend is plainly evident in gentrifying in-town neighborhoods like Old Fourth Ward, which lies west of the Eastside Trail in Subarea 5. Because 76% of the city's tree canopy is found on properties zoned for single-family residential, this phenomenon must be closely monitored.[151]

3.3.2 Supply and Utilization of "Green Growth" Parcels

This analysis uses LEED-ND eligibility at the parcel level as an indicator of the locational characteristics necessary to support the low-carbon, "green urbanism" prescribed in sustainable development literature. New Urbanist researchers have documented the frustrations of using ready-made walkability metrics such as Walk Score as a proxy for desirable urban form. Walk Score's composite scoring formula weighs density of existing economic activity more heavily than urban form measures (e.g., block size); moreover, it has been shown to erroneously identify parking lot aisles as city blocks, inflating walkability scores around big box retailers and malls.[152] When Talen *et al.* (2013) found weaker-than-expected correlation between LEED-ND-eligible parcels and favorable Walk Scores, they speculated that whereas "LEED-ND focuses on development potential based on sustainable urban form, Walk Scores capture the extent to which existing amenities can be reached by foot."[153]

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[149] Giarrusso 2018, 41.
[150] Ibid, 40-41.
[151] Ibid, 30; see Table 4.
[152] Steuteville 2016; Steuteville 2019.
[153] Talen et al. 2013, 27.

Recently, the City of Atlanta performed a land suitability analysis of this type in their "SHIFT ATL" initiative. The GIS exercise iterated further on the recommendations of *The Atlanta City Design* by establishing an evidence-based, fine-grained baseline of car dependence across the city. Working at the level of the Neighborhood Statistical Area (NSA) – an idiosyncratic spatial unit assigned by the Atlanta Regional Commission – SHIFT ATL scored 102 districts across the city based on their "car-free livability" under current circumstances. It overlaid nine citywide data layers that captured: walkable and bikable buffers around high-frequency transit and groceries, intersection density, business type variety, proximity to bike share hubs, and topographic slope. Referring back to the range of "Growth Areas" and "Conservation Areas" delineated in *City Design*, the study recommended that "our most intense, long-term efforts to drive car-free livability" be directed toward higher-scoring neighborhoods that overlap with all designated Growth Areas as well as less intense "Urban Neighborhoods." "These NSAs are the most ideal places to focus densification, multi-modal transportation projects, and in which to de-emphasize travel by car," the Department of City Planning concluded.

This particular analysis draws upon the body of literature introduced in Chapter 2 that studies more comprehensive sustainable community assessment systems – specifically, LEED-ND. Some of these studies have evaluated the efficacy of LEED's neighbourhood development scorecard by scrutinizing existing certified communities.[154] Others have used sustainability indicators built into the LEED-ND certification scheme to gauge a jurisdiction's potential performance at the citywide level in Phoenix and Lisbon,

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[154] Smith and Bereitschaft 2016.

Portugal.[155, 156] This latter group sought to enrich the LEED-ND methodology with context-specific GIS to conduct "a form of land suitability analysis" at the city scale that could identify "priority urban areas and parameters for strategic planning."[157,158]

Whereas the Lisbon study looked at 10 prerequisites across all three overarching sections of the LEED-ND scorecard, Talen et al. (2013) limited their scope to the five prerequisites within the Smart Location and Linkage (SLL) section. The authors focused on the Smart Location prerequisite (coded SLLp1), "the most critical determinant of location eligibility," which provides four pathways for parcel eligibility based on infill or redevelopment status, transit accessibility, and land use diversity. The ensuing geospatial analysis produced an "inventory of LEED-ND location-eligible land whose carrying-capacity is the share of community growth capable of superior triple-bottom-line performance."[159]

The Phoenix study derived its GIS-based methodology from a 2012 guide produced by Criterion Planners on behalf of USGBC.[160] The original document described a four-step process: define a study area serviced by existing infrastructure, inventory "candidate parcels," test those parcels for compliance with the Smart Location prerequisite (SLLp1), and screen compliant parcels for the presence of certain sensitive ecological resources that would place constraints on their eligibility (these additional prerequisites are coded SLLp2-

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[155] Talen et al. 2013.
[156] Pedro, Silvaa, and Pinheiro, 2018.
[157] Talen et al. 2013, 23.
[158] Pedro, Silvaa, and Pinheiro, 2018.
[159] Talen et al. 2013, 21.
[160] Two of the authors on Talen *et al.* (2013) listed their affiliation with Criterion Planners, and an excerpt of their Phoenix case study was appended to the USGBC document in September 2012.

5).[161] “The location eligibility method applies the nine tests to the candidate parcel batch in sequence, and once a parcel passes a test it is removed from the batch and designated SLLp1-compliant.”[162] The resulting inventory divides the study area’s parcels into three groups: “location-eligible without environmental constrains,” “constrained by SLLp2-5 resources,” and ineligible parcels. This latter pool is also worthy of further evaluation, the guide insists: “In effect, the methodology creates a deficiency list that can be used as a corrective plan to move parcels over time from ineligibility to eligibility."[163]

The data requirements for this LEED-ND parcel inventory methodology are relatively straightforward; an overview can be seen in Figure 7.[164] High-resolution land cover imagery is the most critical element because a parcel’s eligibility depends in large measure on how much of its area meets the LEED-ND definition of “previously developed.”[165] The Phoenix case study assembled a citywide mosaic of 2.4-meter resolution Quickbird imagery, upon which the authors performed object-based classification to distinguish between pervious (soil, trees, grass, and water) and impervious (buildings, swimming pools, and other) land cover. Vector data requirements, however, could present challenges depending on the sophistication of publicly available geospatial data in a jurisdiction. These requirements include data on water and wastewater service boundaries, parcel boundaries, streets, transit stops, and surface water bodies – all likely to come from a local jurisdiction or its metropolitan planning organization – along with

[161] Criterion Planners, *A Methodology for Inventorying LEED-ND Location-Eligible Parcels in a Local Jurisdiction* (USGBC, September 1 2012), 2, https://www.usgbc.org/resources/methodology-inventorying-leednd-locationeligible-parcels-local-jurisdiction.
[162] Ibid, 7.
[163] Ibid, 22
[164] Figure source: Talen et al. 2013, 25
[165] Ibid, 3

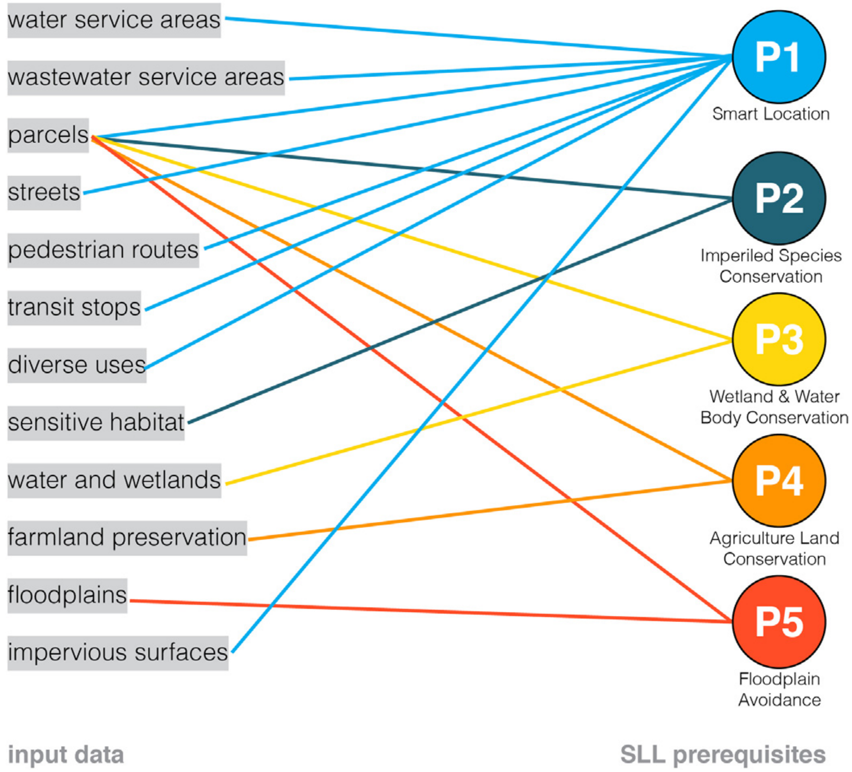


Figure 7: Data Layer-Prerequisite Relationship

federal or third-party data related to sensitive habitats, wetlands, floodplains, and agricultural land. Each of these vector features must include certain attributes. For example, parcels must include (or be joined with) data on land value and “improvement” value (e.g., buildings) to determine parcel candidacy; streets must be coded as local, collector, or arterial; and street segments must be coded as having or lacking sidewalks.

This thesis deviates from the methodology described above in several respects:

- Most notably, it performs and compares historical inventories at two points in time – 2009 and 2017 – rather than taking a snapshot of present-day existing conditions in a jurisdiction.

- It utilizes NAIP imagery of Atlanta, freely available at higher resolution (1 meter) than the Phoenix case study's Quickbird and shot in September of both study years.
- The land cover analysis presented herein discards the swimming pool classification and instead deliberately groups impervious surfaces into dark-colored (e.g., asphalt paving and roof shingles) and light-colored (e.g., concrete) materials. The albedo, or surface reflectivity, of a material has been shown to exert an outsized influence on its thermal behavior.[166] Land-based strategies to reduce urban heat island effect are a key component of urban resilience and climate adaptation and thus are an important consideration for this study.

This exercise tests one possible approach to measure the impact of public investment in pedestrian and transit infrastructure. How the BeltLine's physical infrastructure and policies interact to influence urban form, particularly in the context of climate adaptation and resilience, is one aspect of the project that remains woefully under-explored. In urban districts like Subarea 5 with high concentrations of underutilized parcels that possess certain characteristics of sustainable urban form – namely, zoning allowances that can support density and mix of uses – do these investments lead to development patterns that reflect and strengthen these characteristics? Will the resulting development and adaptive redevelopment deliver urban form that complements this infrastructure through lower per capita greenhouse gas emissions or energy and water consumption? Can

[166] Urban Climate Lab 2016.

a universal suitability proxy, like LEED-ND, predict resilience outcomes at the parcel level and beyond? Or are more context-specific, evidence-based metrics necessary to do so?

From the outset, it is clear that the stripped-down criteria applied in this analysis provide a somewhat crude proxy measure. Still, this method benefits from being based on a well-established certification system with a widely applicable methodology. It is important to note that this analysis stops short of conducting a full LEED-ND inventory of the study area. As demonstrated by past explorations of LEED-ND as a planning support tool, such an inventory proves so intensive in both staff time and technical capacity that it is unfeasible for most local governments.[167] (Municipalities can reap major benefits by touting certain sites or districts as "LEED-ND-ready" based on preliminary analysis of key indicators for which data is readily available, such as intersection density. Undertaking more technically exhaustive analysis is likely to deliver only marginal returns in terms of attracting private investment.) Instead, this thesis analyzes the study area based on those eligibility criteria that are most salient for public policy – where land use planning and investments in physical infrastructure and transit can wield the greatest influence on the standard's performance metrics.

Regardless of the questionable efficacy of applying LEED-ND as a readymade planning support tool, the purpose of the LEED-ND analysis in the following chapter is to quantify and locate the supply of "green growth"-supportive parcels and acreage within a district. The analysis looked at how this supply changed over a decade that coincided with

[167] Talen et al. (2013) estimated that their Phoenix case study demanded over 500 hours of labor.

major investments in BeltLine train and park infrastructure – e.g., where that supply was utilized.

CHAPTER 4. RESULTS

4.1 Tree Canopy and Land Cover: 2009 and 2017

Results of the unsupervised Iso Cluster land cover classification are presented below along two different dimensions. The distribution of land cover types – classified into groups of bare soil, tree canopy, grass, dark impervious surface, and light impervious surface – is first measured in terms of raw surface area across the Subarea in 2009 and 2017. These results, presented as classified raster data, were *then* spatially interrelated to three sets of vector data – a “fishnet” grid of 40-by-40-meter cells; individual land parcel geometry; and zoning categories – in order to investigate other relationships. Findings from each test are presented in turn below.

4.1.1 Classified Land Area

Results from the 2009 and 2017 land cover classifications appear in Table 2 and are visualized in Figure 8. (Full-sized graphics are reproduced in APPENDIX A.) The distribution of land cover types in Subarea 5 remained relatively consistent across the study period: tree cover occupied about one-third of all land; impervious surfaces accounted for slightly under half; the remainder, nearly 20%, was classified as grass or base soil.

Table 2: Land Cover Composition, 2009 vs. 2017

Land Cover Type	2009	2017	Change (%)
Soil (%)	6.5	7.4	+0.9
Tree Canopy (%)	36.3	33.0	-3.3
Grass (%)	11.5	11.5	0
Dark Impervious (%)	24.6	25.7	+1.1
Light Impervious (%)	21.1	22.4	+1.3

Tree canopy exhibited the greatest change, declining 3.3%; the total area covered by tree canopy fell from 401 acres in 2009 to 365 in 2017. Dark and light impervious surface area increased 1.1% and 1.3%, respectively; together they accounted for 532 acres across the Subarea. Visual inspections of the two maps side by side reveals several notable focal points of land cover change, particularly at points along the Eastside Trail that saw townhome or multifamily development activity during the study period. The redevelopment of flood-prone surface parking lots into Historic Fourth Ward Park converted a substantial area of asphalt to pervious land cover, with landscaped tree canopy clearly visible in satellite imagery by 2019. (Notably, this additional canopy was of higher

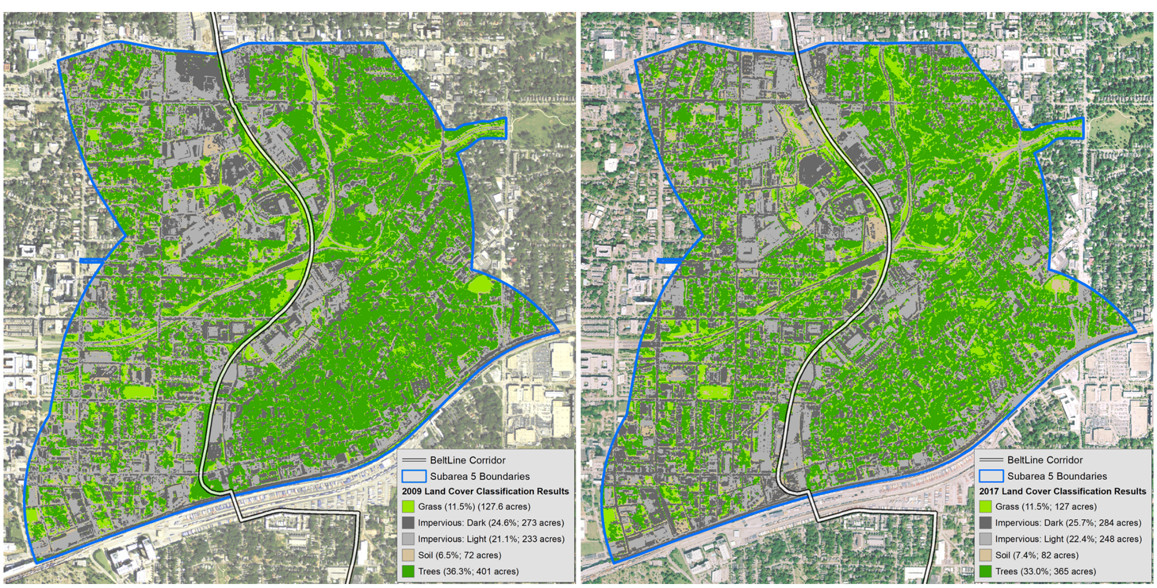


Figure 8: Land Cover Classification, 2009 vs. 2017

quality and permanence than some of the aforementioned “lost” canopy, much of which had been nominally identified as tree cover by the classification technique but was actually kudzu or other low-quality invasive species.) There were also instances where the redevelopment or underutilized parcels or adaptive reuse of existing industrial buildings along the BeltLine resulted in the replacement of asphalt paving or roofing materials with lighter-colored impervious surfaces.

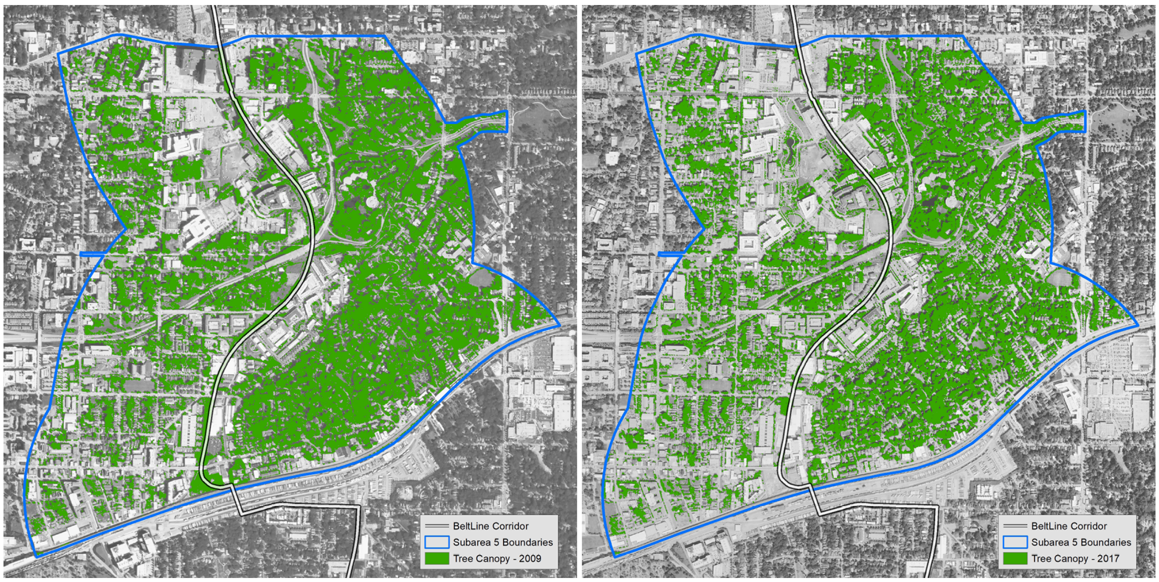


Figure 9: Extracted Tree Canopy Cover, 2009 vs. 2017

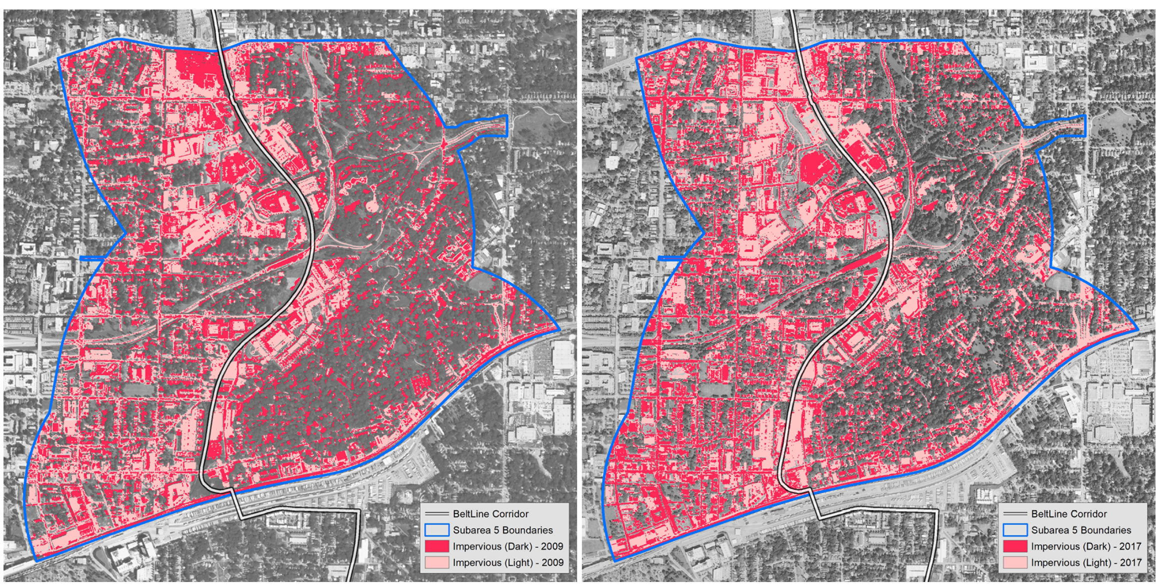


Figure 10: Extracted Impervious Land Cover, 2009 vs. 2017

These patterns become more discernable once the key land cover types are isolated through extraction as separate masks. Figure 9 illustrates tree canopy cover in 2009 and 2017 while Figure 10 isolates light and dark impervious surfaces. Land cover conversion during the study period is illustrated in Figure 11 and Figure 12, which – through a series of extractions, reclassifications, and raster calculations – visualize changes in tree canopy and impervious surface cover, respectively. These representations help validate the initial observations and quantify them with acreage totals by year for each land cover type.

Figure 11 and Figure 12 also confirm, among other things, that the greatest concentrations of canopy loss were found on sites that saw redevelopment during the study period:

- At the southern terminus of the Eastside Trail, between Irwin Street and Dekalb Avenue, where the Studioplex expansion and Edge mixed-use development were constructed;
- Near the center of Subarea 5 – parcels between North Highland Avenue and Freedom Parkway – where luxury townhomes replaced canopy alongside the trail;
- On four acres of formerly wooded land immediately to the west of Historic Fourth Ward Park, where the Camden Fourth Ward apartments were erected in 2013; and
- Immediately alongside the trail itself, which is to be expected given that its construction necessitated clearing the width of both the trail and transit rights-of-way.

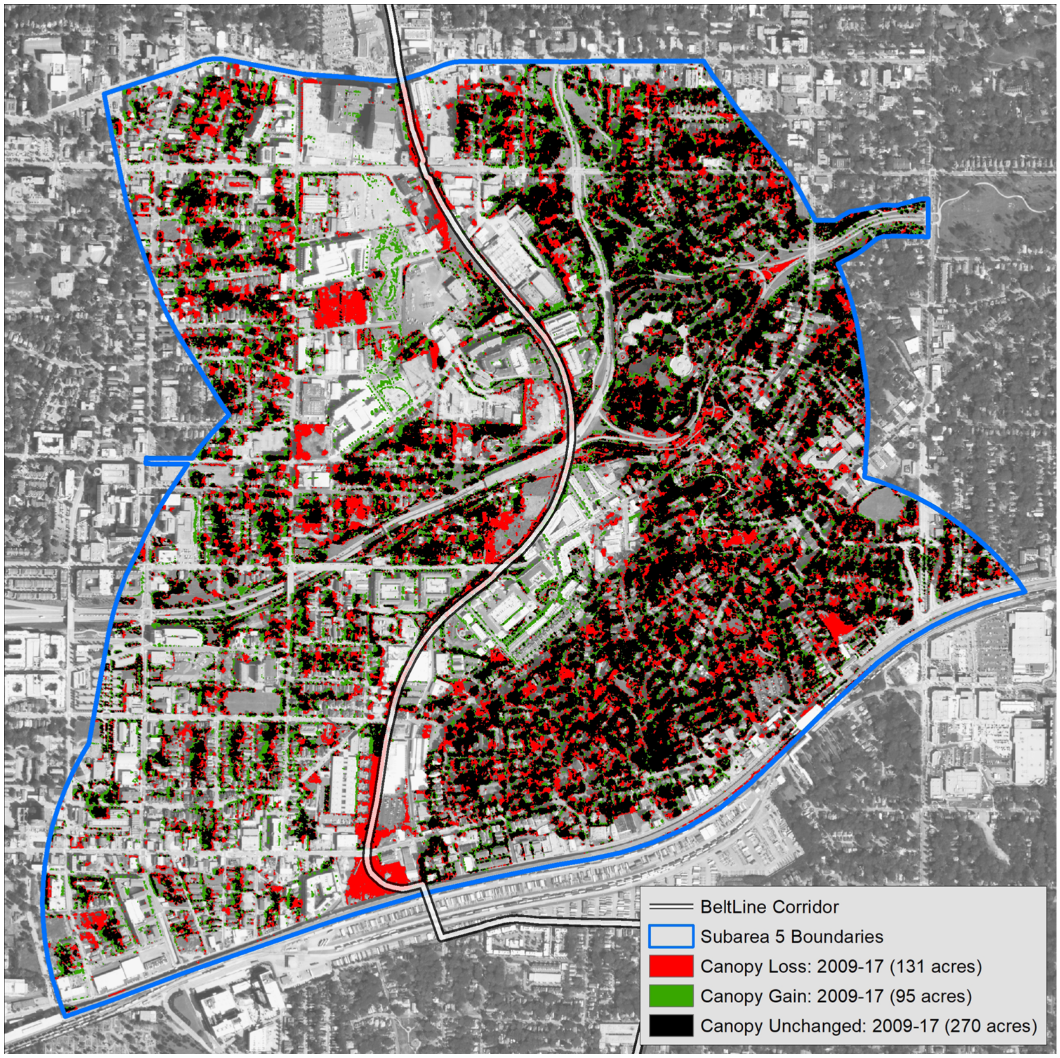


Figure 11: Tree Canopy Cover Change, 2009 to 2017

It is also evident from Figure 11 that additions to the subarea's tree canopy are more decentralized and distributed than its subtractions. The most conspicuous concentrations of new canopy growth can be found throughout Historic Fourth Ward Park and in the tree-planted streetscapes of planned unit developments that rose between Lake Avenue and North Highland Avenue, in the Inman Park neighborhood. Figure 11 also indicates more subtle growth patterns in the largely single-family residential neighborhoods further from the Eastside Trail – typically seen radiating from areas of unchanged canopy, which appear in black. This growth at the margins seems intuitive but should be interpreted with caution due to the confounding effect of spectral differences between the 2009 and 2017 imagery; the larger, less fragmented blocks of land cover change appear to be more reliable.

Figure 12 more clearly pinpoints locations where impervious surfaces were altogether removed or converted from one type to another. Most notable are the substitution of surface parking lots with pervious surfaces at Historic Fourth Ward Park and the fact that, where redevelopment of existing structures or impervious surfaces was observed, dark

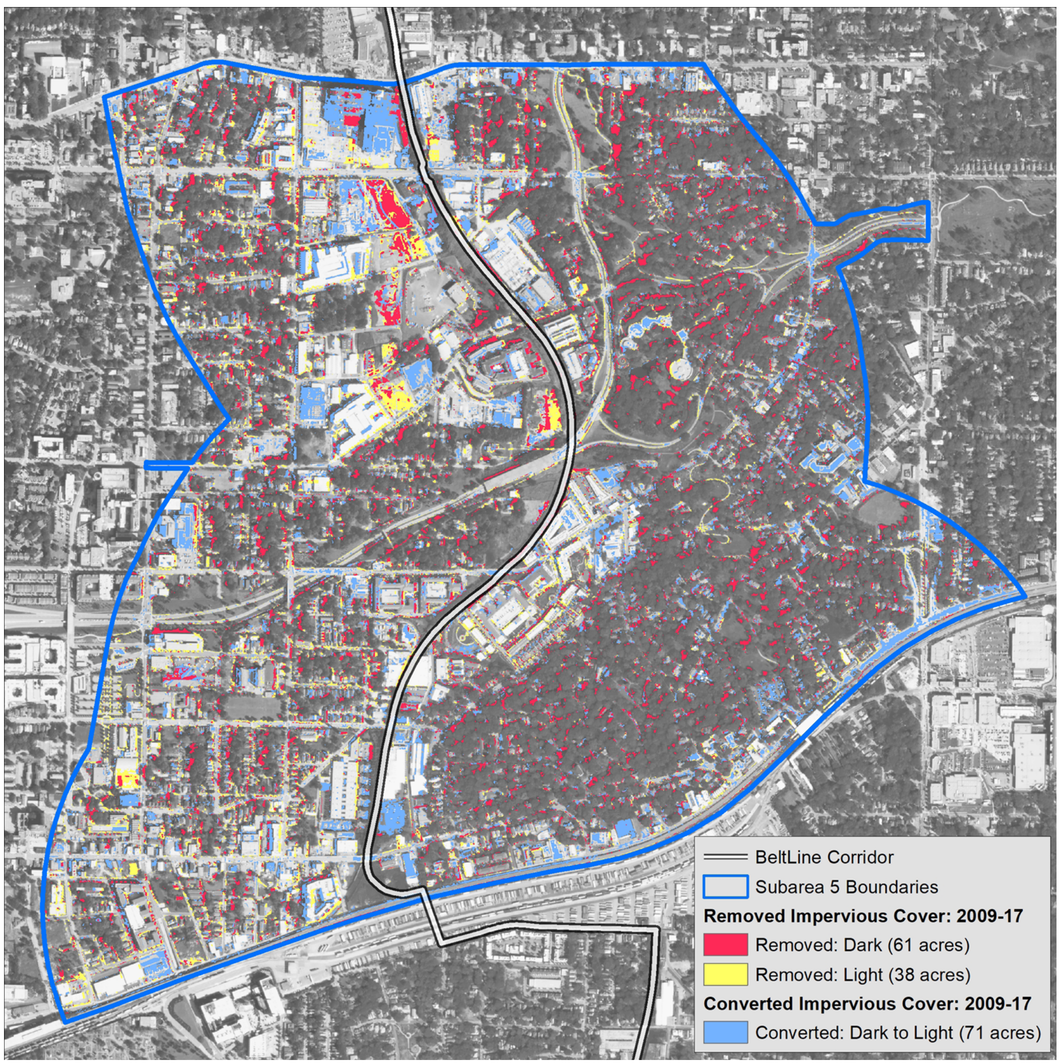


Figure 12: Removed and Converted Impervious Surface, 2009 to 2017

asphalt parking lots or roofing materials tended to be replaced with lighter-colored roofs. Outside of these large, contiguous areas – and particularly within single-family residential neighborhoods – the figure should be interpreted with caution. It is very likely that some portion of these "removals" simply represents areas of undisturbed impervious surfaces that became obscured by tree canopy growth above them.

Less encouraging is the implication drawn from Figure 13, which maps newly added impervious surfaces, that darker impervious surfaces – not lighter or pervious land

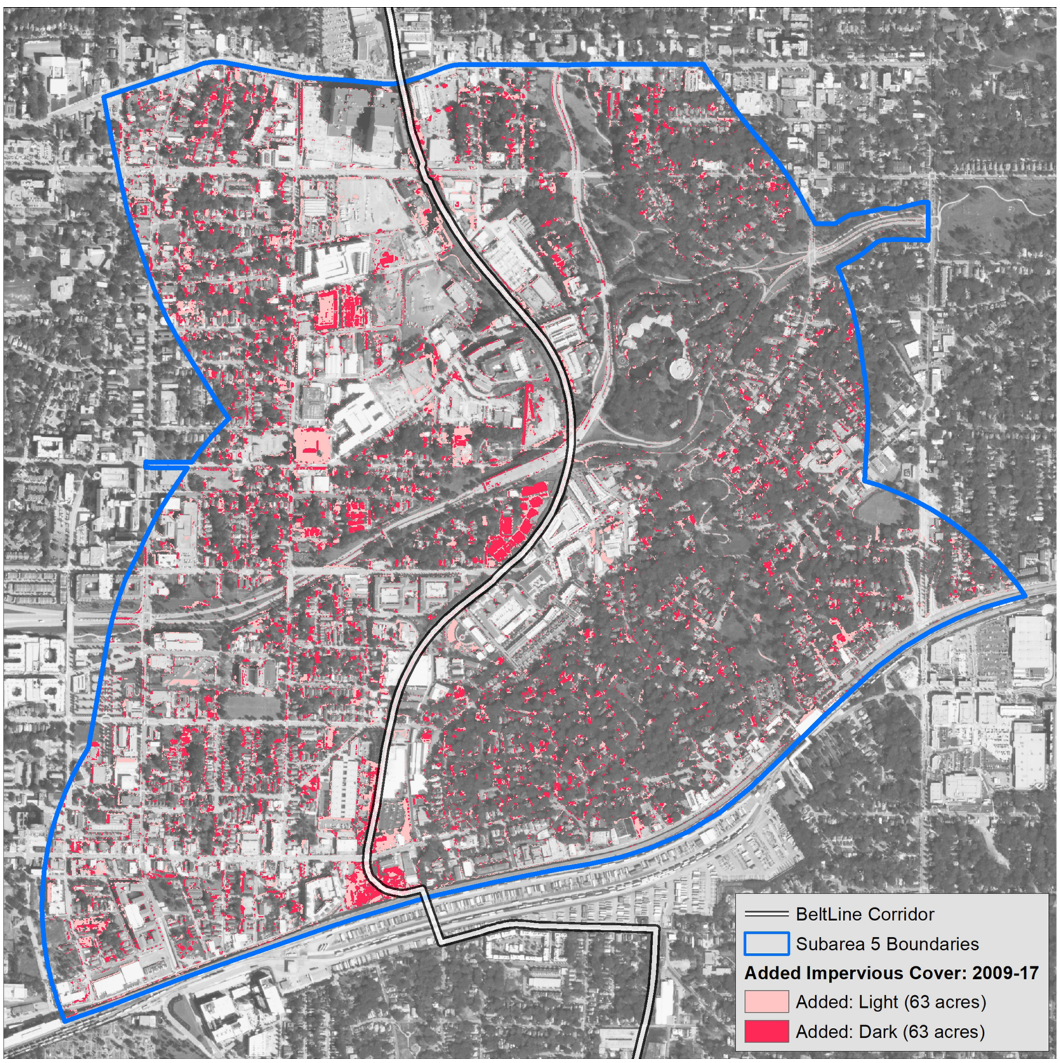


Figure 13: Added Impervious Surface, 2009 to 2017

cover types – were the dominant replacement once large, vegetated sites were cleared for new development. This was the case in three notable sites that were either BeltLine-adjacent (The Edge; Highland Park Townhomes) or abutted Fourth Ward Park (Camden Fourth Ward). Across Subarea 5, more impervious land cover was added (126 acres) than removed (99 acres) from 2009 to 2017, resulting in a net increase in the portion of Subarea covered with impervious surfaces – from 45.7% to 48.1%. Nonetheless, half of this added impervious cover was classified as light-colored.

4.1.2 Fishnet Grid

The fine-grained, 1-meter resolution of this data – coupled with the fragmented nature of urban tree canopy – made it difficult to perceive changes in land cover at the Subarea scale, even after smoothing techniques were applied. To aid in visualization, the author imposed a 40-by-40-meter grid upon the raw unsupervised classification results and calculated land cover composition for each of the 2,960 resulting cells. The results for tree canopy coverage specifically are presented in Figure 14; white borders indicate cells in which tree canopy constitutes over 75% of land cover area. At the beginning of the study period, 11.4% of cells met this threshold. By the end, only 7.0% did so. Meanwhile, the portion of majority-impervious cells increased from 20.9% to 25.5%, driven entirely by growth in cells composed of over half *dark* impervious (8.9% to 13.8%). There were no obvious regions of growth for these high-canopy cells, whereas losses appeared concentrated to the west of the Eastside Trail in the rapidly redeveloping Old Fourth Ward neighbourhood. While the number of cells with no more than 13% tree cover – the lowest-canopy class – remained relatively steady, there were some cases where cells graduated

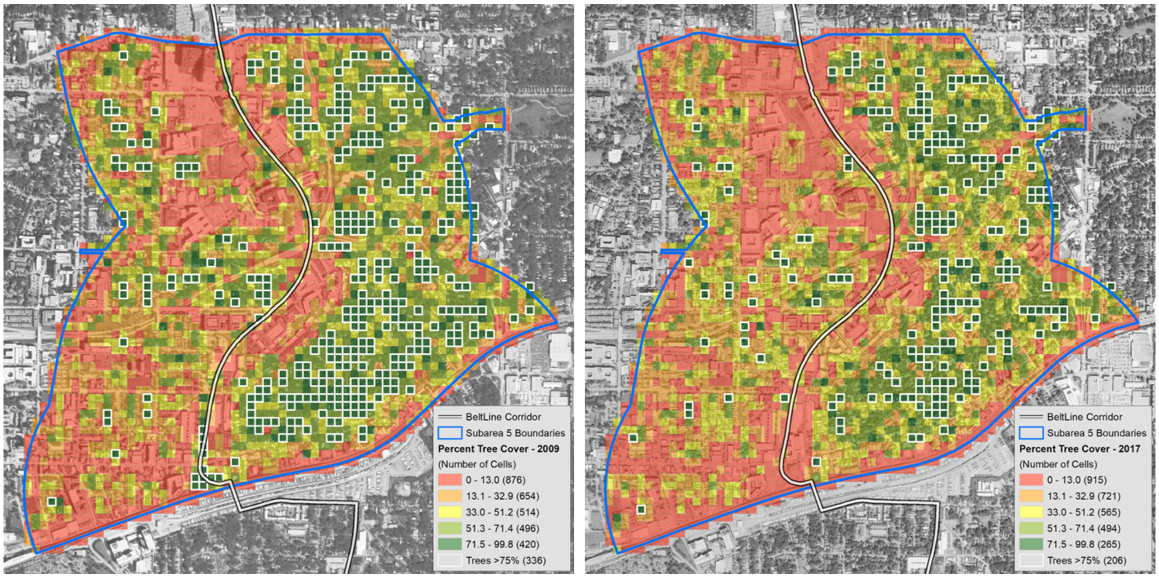


Figure 14: 40-by-40-m Cells by Percent Tree Canopy Coverage, 2009 vs. 2017

from this class to higher bins, for example as Historic Fourth Ward Park began to see canopy growth. It should be noted that some signs of generalized canopy losses, particularly the diminishment of tree cover in the well-established Inman Park neighbourhood in the southeast quadrant of Subarea 5, is likely an artifact of spectral inconsistencies between the 2009 and 2017 satellite imagery. These discrepancies were partially mitigated through multiple rounds of cleaning and reclassification, but not fully corrected.

To complement these high-level observations on change across the Subarea, Figure 15 helps isolate clusters of significant tree canopy losses or gains – only about 600 cells that saw a change of at least 14% from 2009 to 2017 are represented here. Three areas of contiguous tree canopy gain stand out here: the interior of Historic Fourth Ward Park, street trees throughout a master-planned section of Inman Park, and the spacious public right-of-way flanking Freedom Parkway and The Carter Center.

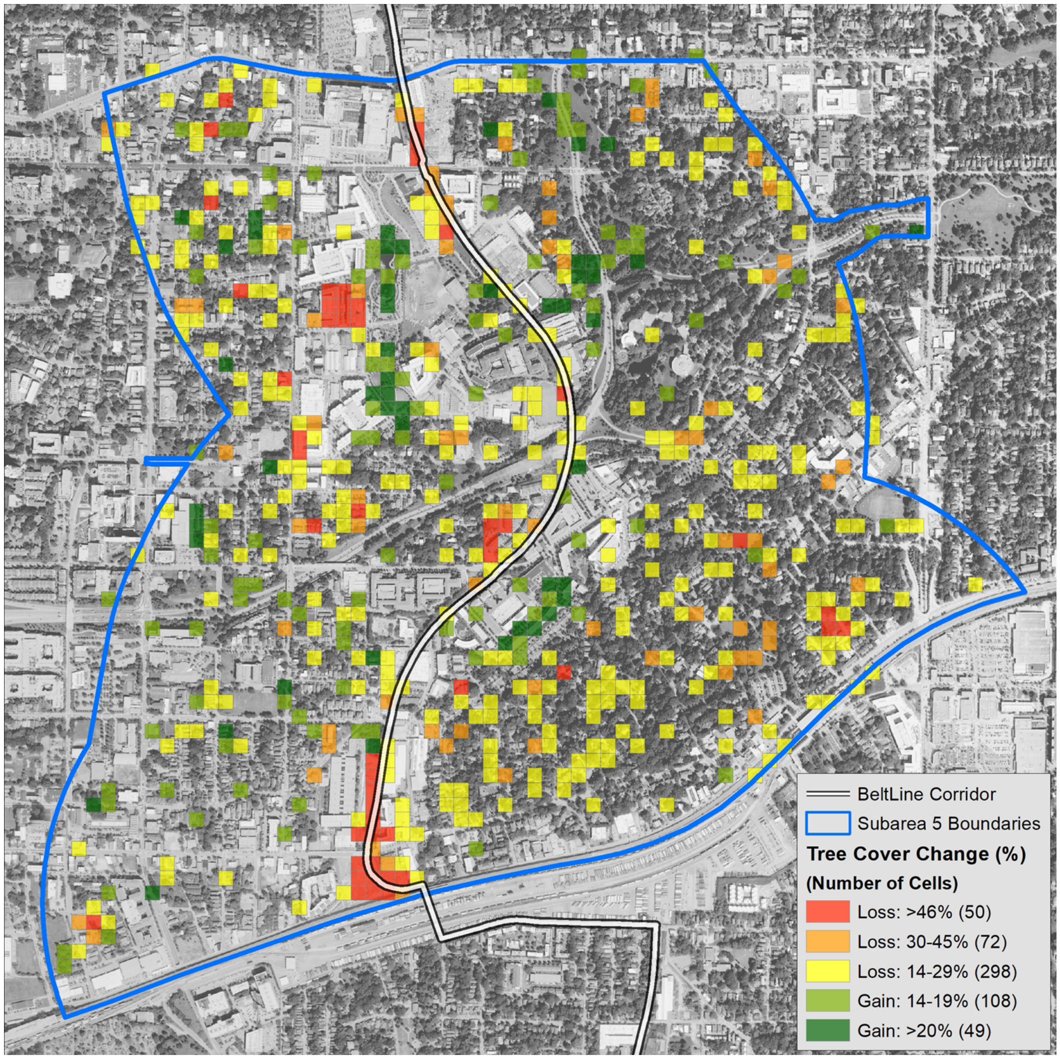


Figure 15: 40-by-40m Cells by Percent Change Tree Canopy, 2009 to 2017

4.1.3 Tax Parcel Boundaries

From a policy perspective, parcel geometry is perhaps the most useful spatial unit by which to examine land cover changes in the study area. Whereas the boundaries of the fishnet grid are arbitrarily constructed and zoning districts do not reliably reflect existing conditions, parcels imply a level of intentionality and accountability that carry great legal and political consequences for landholders. This dimension allows the analyst to remove public rights-of-way and marginal or extraneous lands and focus on areas likely best suited to carry out interventions to plant trees, remove impervious hardscape, or otherwise alter land cover.

This portion of the tree canopy analysis also poses the best opportunity to interrelate land cover results with the LEED-ND inventory exercise found in the second half of this chapter. In fact, determining land cover composition for each parcel and classifying accordingly is an important step in the process of determining whether it meets criteria to be a LEED-ND "candidate parcel." Once the dataset has been cleaned, a user-generated unique identifier for each parcel allows for tabular joins; spatial joins or visual inspection can fill in gaps in instances where this process fails.

Figure 16 shows all parcels in Subarea 5 classified by percent tree canopy coverage in 2009 (left) and 2017 (right). Note that parcels are divided into six classes based on Jenks natural breaks for each year, and thus the break points vary rather significantly; the number of parcels in each bin can be found in parentheses. Unlike previous maps, parcels outside

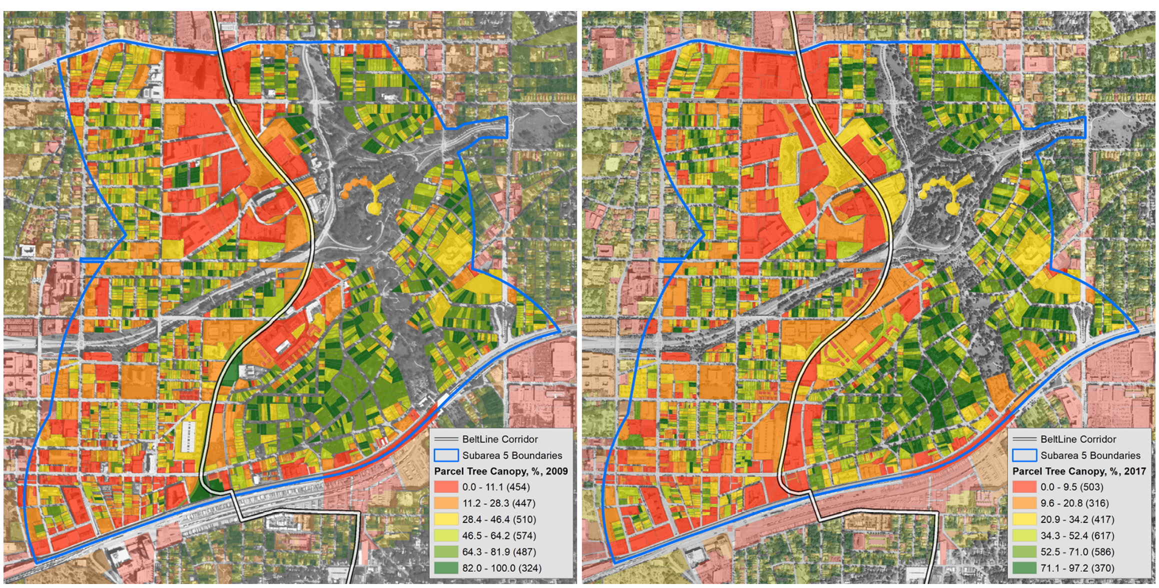


Figure 16: Parcels by Percent Tree Canopy Coverage, 2009 vs. 2017

of the Subarea 5 boundaries are included, masked for clarity, in order to help visualize how theoretical and physical edges (e.g., BeltLine Planning Area boundaries versus rail corridor or urban green belt) generate different patterns of continuity or discontinuity. Changes in parcel geometry during the study period due to assemblage and subdivision also make visual comparison somewhat difficult. Still, the graphics reinforce the same general spatial impressions gleaned from previous figures:

- Old Fourth Ward park helped mitigate tree canopy deficits in the midst of rapid redevelopment;
- Trail-adjacent development, notably new construction of townhomes and mixed-use projects, erased or fragmented pockets of tree canopy along the trail;
- Conversely, canopy gains are visible in older BeltLine-adjacent planned developments in places like Inman Park, where street trees and other distributed landscaping have had time to grow.

For the sake of simplicity and standardization, Figure 17 depicts percentage change from 2009 to 2017 only for parcels larger than a quarter-acre – about 500 properties in total. This figure overlays 2017 parcel boundaries over 2017 NAIP imagery to aid in identifying the effects of significant new development or greenspace that appeared during the study period. Among these, around 28% likely saw canopy gains and only 20 parcels (4%) saw gains of 13% or more. Conversely, about a third experienced modest to severe canopy losses, including nine parcels that lost between half and 88% of their canopy coverage (denoted in red in Figure 17). Once again, the prevailing sense is that BeltLine-adjacent parcels saw significant canopy losses associated with trail construction or new development, whereas older BeltLine-proximate projects tended to recover canopy and Historic Fourth Ward park generated substantial new growth. A handful of projects stand out for their near-total land cover conversion, whereas non-residential corridors like Dekalb Avenue (Subarea 5's southern boundary) and Boulevard (to the west) experienced less significant change and in some places modest increases in canopy.

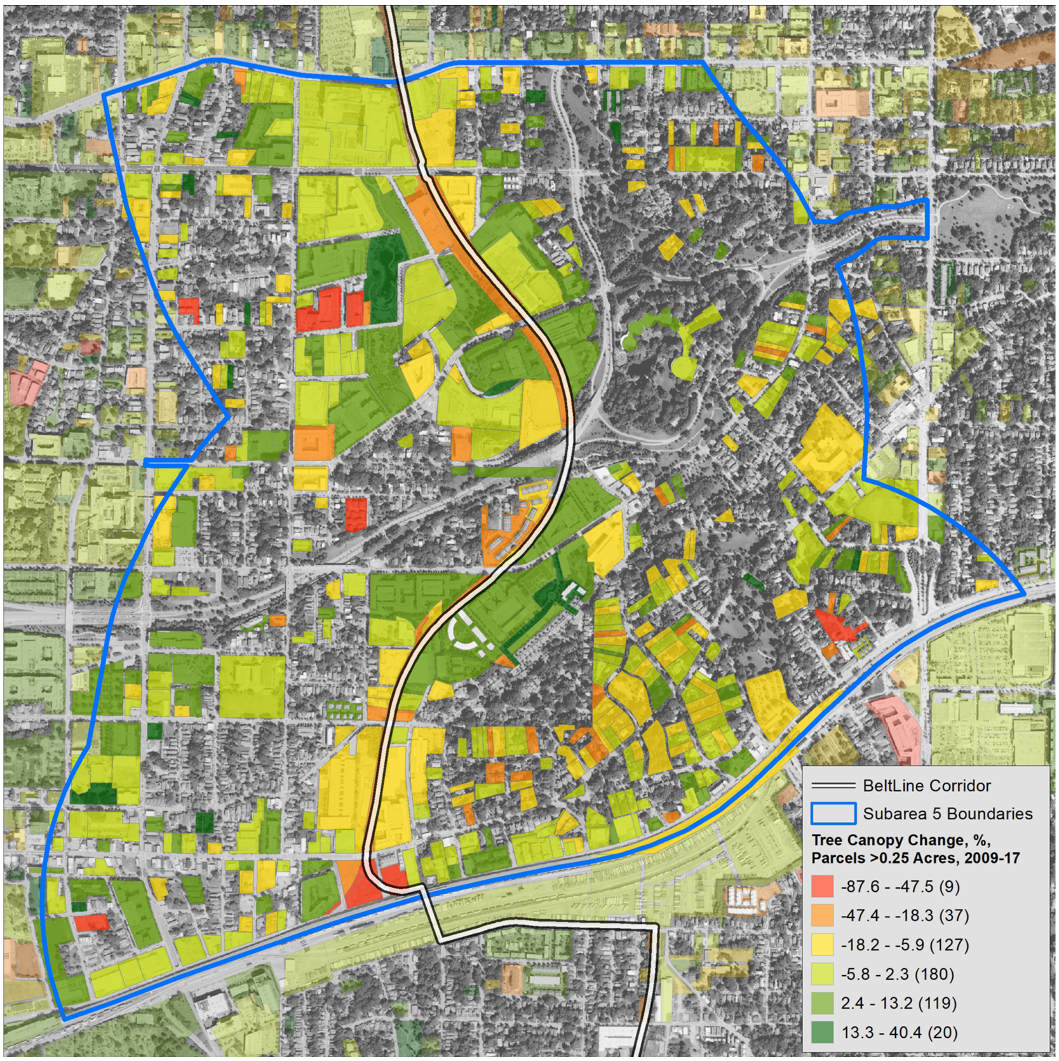


Figure 17: Parcels ≥ 0.25 Acres by Percent Change Tree Canopy, 2009 to 2017

4.1.4 Zoning Category

Lastly, this portion of the thesis considered tree canopy and land cover in the context of zoning typology. The author identified 26 types of zoning *districts* – e.g., R-4, I-1, MRC-2 – that were present in Subarea 5 as of mid-2019.[168] To generate a more succinct and intuitive typology, these district types were then grouped them into 12 thematic classes

Table 3: Zoning District Taxonomy; Number of Instances in Subarea

Commercial	C-1	21
	C-2	24
	C-3	4
	C-4	1
Historic & Cultural	HC-20C	7
Industrial	I-1	11
	I-2	8
Live-Work	LW	3
Multifamily Residential	MR-3	5
	MR-4	10
	MR-5	2
	RG-1	4
	RG-2	7
	RG-3	12
	RG-4	6
Neighborhood Commer..	NC	2
Planned Development	PD-H	4
	PD-MU	8
Quality of Life / Mixed-Use	MRC-1	4
	MRC-2	5
	MRC-3	19
Residential Limited Co..	R-LC	3
Single-Family Residenti..	R-4	8
Special Public Interest	SPI-5	7
	SPI-6	5
Two-Family Residential	R-5	17

[168] "Atlanta Zoning Districts – Complete Listing, adapted from the City of Atlanta Zoning Ordinance." City of Atlanta. n.d. https://www.atlantaga.gov/home/showdocument?id=2173.

(e.g., Commercial, Industrial, Single-Family Residential, Quality of Life / Mixed-Use, etc.). The full taxonomy is shown in Table 3: the first column identifies the author-defined classes; the second column indicates the zoning districts that comprise each; the third column denotes the number of separate districts for each within Subarea 5. For example, a block zoned R-5 but bisected into separate polygons by several parcels zoned NC would result in two "instances" of R-5 and one of NC. (Acreage is a more appropriate measure of each zoning classification's relative presence; subsequent figures and tables include these values for the broader categories.)

Performing the Tabulate Table geoprocessing tool once again – this time using zoning districts as the zonal dimension, instead of grid cells or parcels – produced the 2017 land cover results found in Table 4. Categories are sorted in descending order of acreage to convey that four categories have an outsized influence on land cover composition across the Subarea. Two-Family Residential (R-5 zoning, 305 acres), Multifamily (187 acres),

Table 4: Composition of Key Land Cover Types by Zoning Category, 2017

Zoning Classifications	Acres	Tree Canopy 2017	Impervious (Light) 2017	Impervious (Dark) 2017
Two-Family Residential	309.6	48.8%	12.7%	21.2%
Multifamily Residential	186.8	37.5%	19.4%	20.5%
Quality of Life / Mixed-Use	128.7	11.2%	39.7%	33.9%
Commercial	117.2	15.7%	35.1%	35.5%
Industrial	87.2	13.0%	32.0%	33.6%
Historic & Cultural	77.9	21.4%	19.4%	40.2%
Planned Development	62.9	23.5%	34.0%	26.0%
Special Public Interest	62.4	54.1%	6.4%	7.4%
Single-Family Residential	53.2	54.1%	10.2%	18.3%
Residential (Limited Commercial)	10.5	37.0%	26.1%	21.9%
Neighborhood Commercial	9.2	19.9%	34.0%	12.1%
Live-Work	1.1	17.0%	31.2%	25.1%

Selected land cover percentages for 2017 for Tree Canopy, Impervious (Light), Impervious (Dark) broken down by Zoning Classifications (accompanied and sorted by class acreage).

Quality of Life/Mixed Use (129 acres), and Commercial (117 acres) together account for two-thirds of all land area. Additional columns indicate the percentage of tree canopy, light impervious, and dark impervious surface in each zoning category.

To relate these numbers to the 2009 baseline, Figure 18 depicts percentage change in tree canopy and *combined* impervious cover (light and dark) for each zoning category – with the exception of Live-Work, which was eliminated due to its inconsequential size and anomalous results. While the changes are relatively modest, it is striking that almost every category experienced tree canopy loss in concert with impervious surface gains. Also worth noting is that the greatest canopy losses appear to be in key zoning categories with large footprints: two-family and single-family residential districts each lost over 5% of their tree

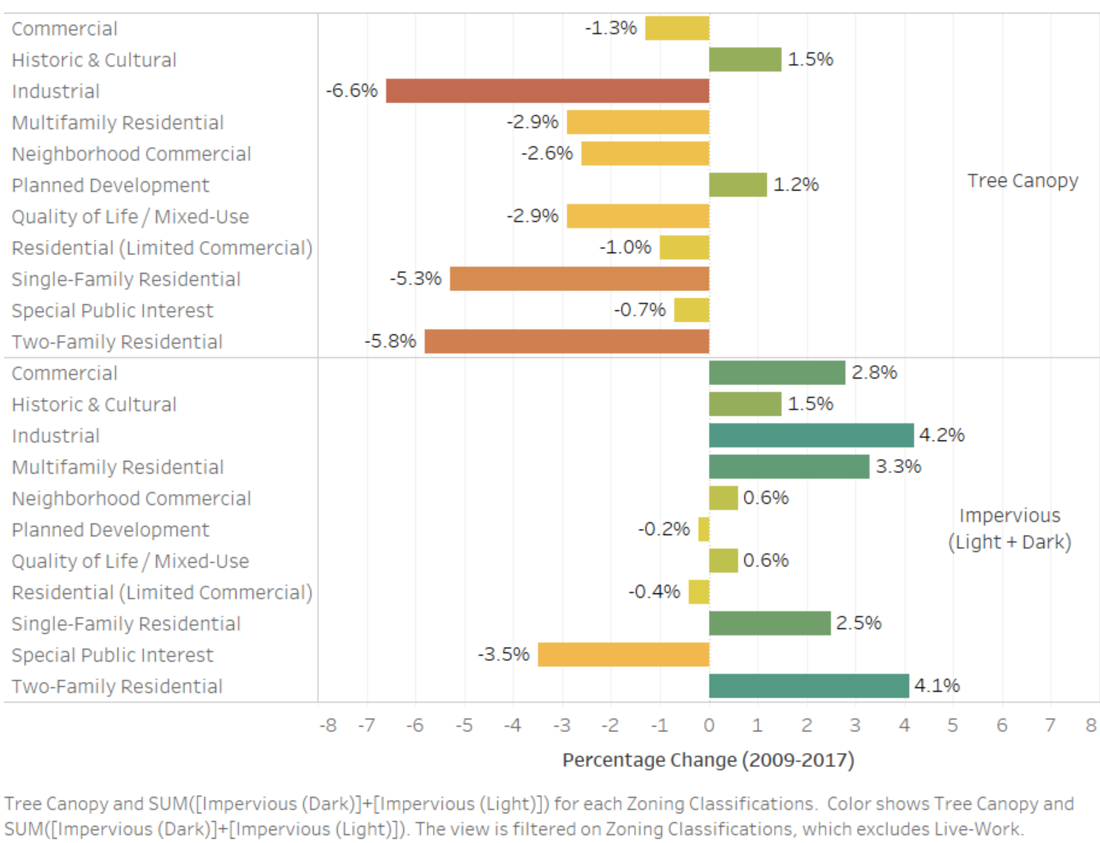
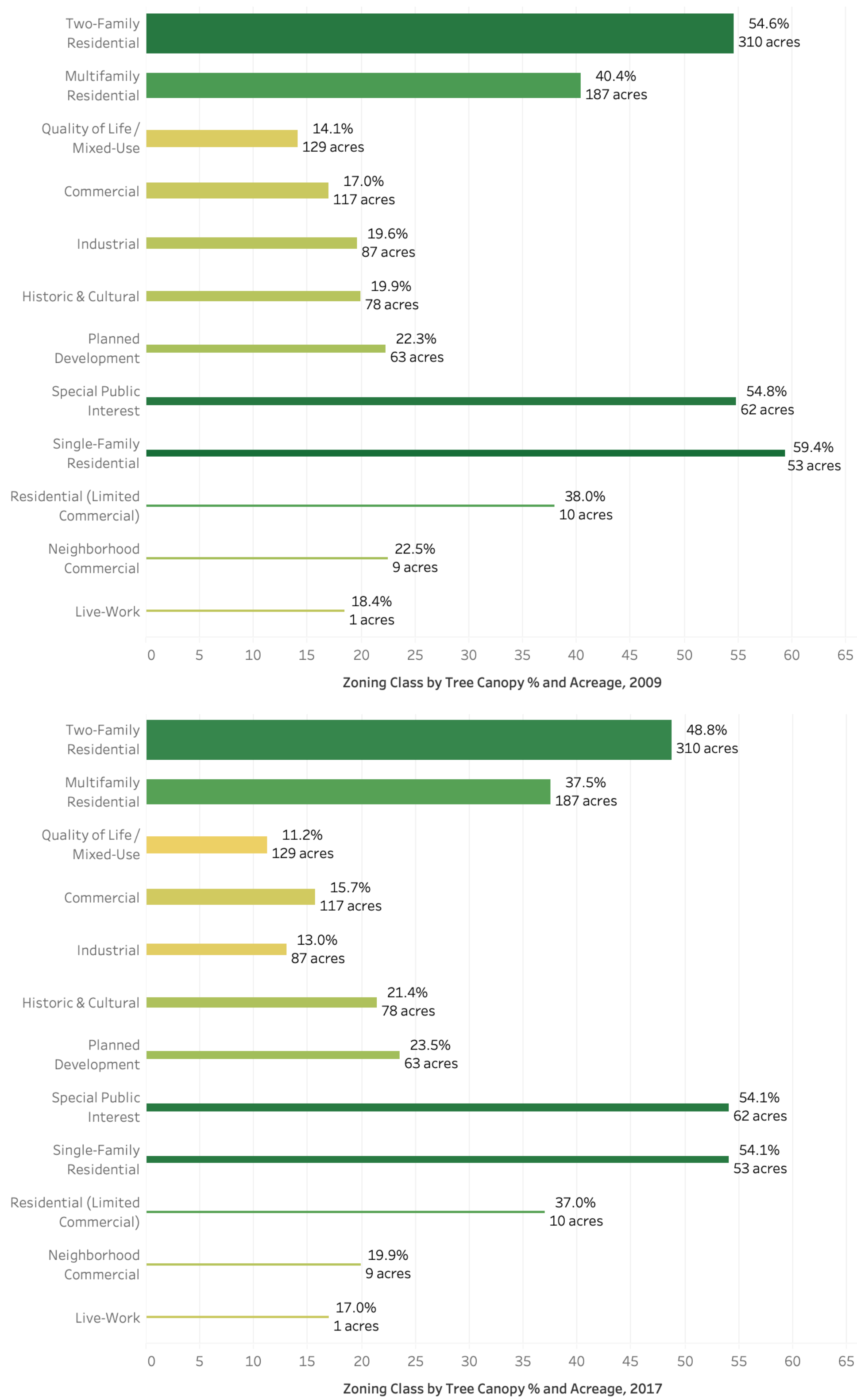


Figure 18: Land Cover Percent Change by Zoning Category, 2009-17

canopy. Figure 19, which interrelates percentage tree canopy coverage and category acreage, underscores why this finding is troubling. Due to its huge acreage, Two-Family Residential zoning represented an estimated 41% of all tree canopy in Subarea 5 in 2017, about 150 acres, according to results of the unsupervised classification conducted previously. Consequently, the estimated 5.8% decrease in canopy coverage within this zoning category had a far more severe impact than a 6.6% decrease within the Industrial category – e.g., 18 acres of lost canopy versus 5.7. Figure 20 helps visualize this relationship between acreage and land cover percentages for the various zoning categories; Subarea 5's overall land cover composition will be most sensitive to changes within the categories that occupy the largest blocks.



Sum of Tree Canopy 17 for each Zoning Classifications. Color shows sum of Tree Canopy 17. Size shows sum of Acres. The marks are labeled by sum of Tree Canopy 17 and sum of Acres.

Figure 19: Zoning Category by Tree Canopy and Acreage, 2009 vs. 2017

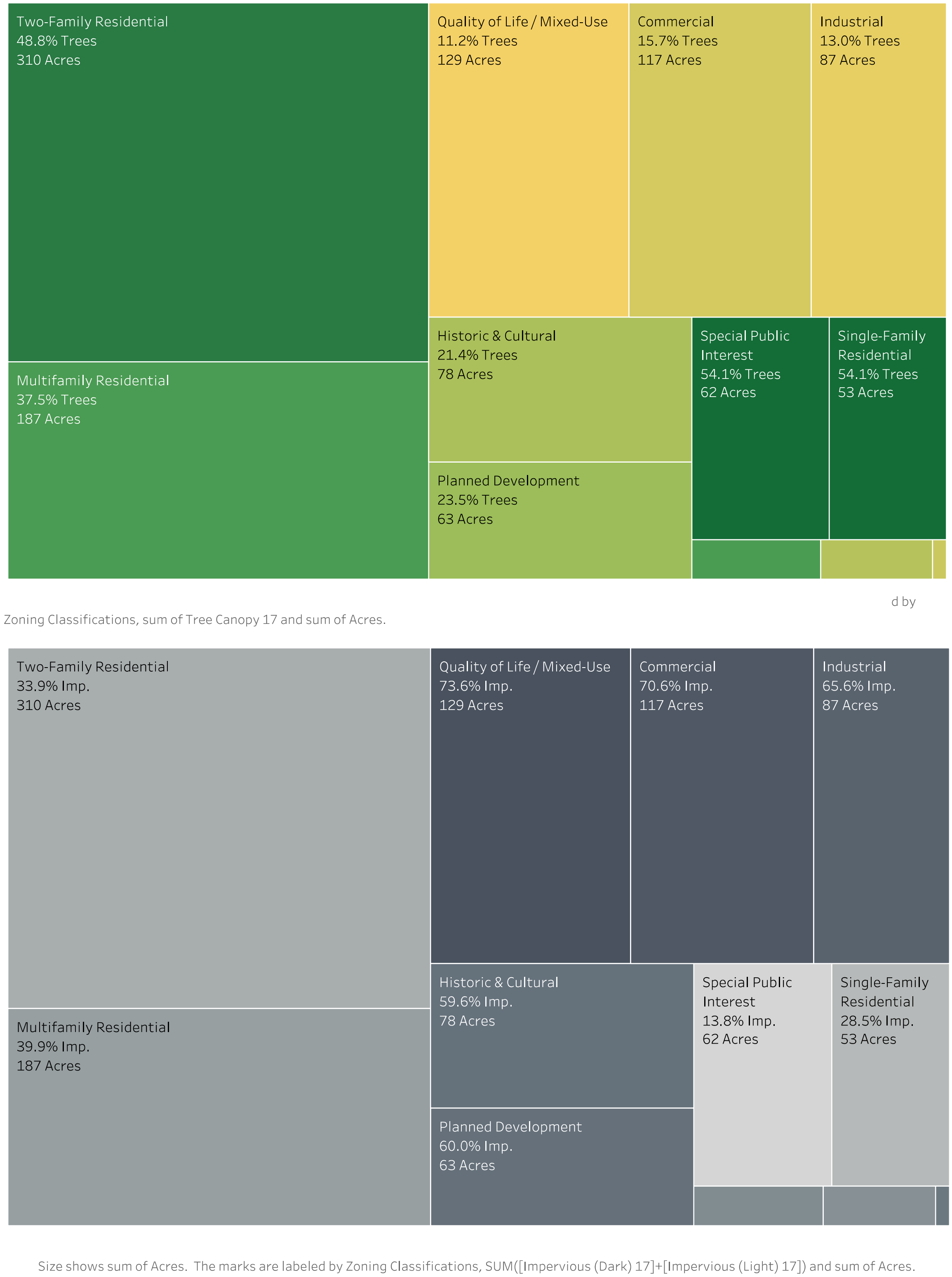


Figure 20: Zoning Categories by Percent Tree Canopy (Top), Combined Impervious Cover (Bottom), and Acreage, 2017

While this approach produces intriguing results, they must be interpreted with some caution due to the potentially confounding influence of re-zonings during the study period. Unable to obtain GIS data on zoning classifications from 2009, the author was forced to overlay present-day zoning conditions on the historical land cover raster. The City of Atlanta regularly publishes an updated shapefile of ongoing and completed rezoning cases that includes dates and previous zoning categories, so one could feasibly work backwards to reconstruct a historical map. A review of that case data revealed 55 confirmed re-zonings between 2007 and 2017, a conservatively broad timeline that likely captures any relevant parcels entering the development pipeline by late 2009. Summary statistics on those cases may be found in Table 5.

Table 5: Rezonings by New District Type, Subarea 5, 2007-2017

Zoning District Type	Rezonings To	Total Acreage
Quality of Life / Mixed-Use	34	50.2
Multifamily Residential	10	4.7
Planned Development	4	12.5
Commercial	3	0.7
Historic & Cultural	1	0.4
Industrial	1	0.6
Single-Family Residential	1	0.2
Two-Family Residential	1	0.3

It is possible that changes in zoning could skew land cover comparisons over the study period – for example, the addition of an asphalt-covered former industrial tract to a category could artificially deflate another category's tree canopy coverage without it losing a single tree. Indeed, this phenomenon may be partly responsible for the land cover composition of mixed-use "Quality of Life" districts, which had the lowest tree canopy coverage (11.2%) and highest combined impervious surface coverage (74%) among all zoning categories. It's likely no coincidence that this category saw the greatest number of re-zonings – 34 cases representing about 50 acres – in the process likely inheriting canopydeficient, formerly industrial properties targeted by developers and planners for mixed-use resurrection. On the other hand, Table 5 lends greater weight to the finding of noteworthy tree canopy loss in the R-5 zoning district given that only one property in Subarea 5 was rezoned into this category between 2007 and 2017. It also suggests that rezonings likely had a negligible effect on data continuity between 2009 and 2017 for almost all of the aggregated zoning categories tracked in Table 3. This question could be further interrogated by overlaying zoning maps from 2009 and 2017, removing areas that underwent rezoning in the intervening years, and tabulating new results that control for discrepancy in this regard.

These geographies also offer unique opportunities to monitor the extent to which zoning regulations can influence land cover composition over time, e.g., whether properties rezoned to categories that carry more stringent landscaping requirements or parking limits will experience tree canopy gains. Possible effects of the BeltLine Zoning Overlay should be accounted in subsequent investigations, as its regulations may somewhat flatten differences in land cover outcomes between different underlying zoning classifications that might otherwise see fuller expression outside of the Overlay. As more parcels redevelop and become subject to the Overlay (existing conditions are grandfathered in), this effect may become more noticeable.

4.2 LEED-ND Eligibility Analysis: 2009 and 2017

The results of the LEED-ND candidate inventory are presented in a series of summary tables below. This section will refrain from subjecting the reader to an exhaustive procedural description of the GIS process that generated these results; brave souls may find this process laid bare in minute detail in APPENDIX C. To reiterate the introduction to this chapter and previous discussion of LEED-ND literature, the purpose of this exercise is to identify land parcels in Subarea 5 that would meet “candidate parcel” criteria. This step represents a first hurdle to clear in a LEED-ND inventory before proceeding to the much more labor-intensive process of confirming parcel eligibility. Unlike previous studies cited in the Literature Review and Methods chapters, this thesis also set out to measure change over time in the number of parcels, their acreage, and their location for a single study area. Finally, it sought to diagnose *why* those parcels that had changed candidate status did so – whether these conversions were indicative of progress toward the outcomes of dense urbanism espoused by LEED-ND, or if there was little correlation with these outcomes (which might point to shortcomings in the methodology itself).

4.2.1 Data Preparation and Exclusions

This analysis tested a set of four exclusion criteria consistent with the methodology laid out by Criterion Planners (2012):

- Parcels under 0.5 acres designated for single-family residential use (“Small SFR”)

- Parcels with appraised *improvement* value greater than *land* value, e.g., deemed likely “developed” and thus less susceptible to redevelopment (“Appraisal”)
- Public right-of-way, parks, and other tax-exempt public lands (“Public, Undevelopable”)
- Schools, hospitals, places of worship, cemeteries, operating utilities, and certain other special uses (“Ineligible Use”)

The vast preponderance of time spent on this process was devoted to topological cleaning, e.g., identifying and eliminating duplicate parcels, condo subparcels, and otherwise extraneous geometry. “Parcels within parcels,” typically small, symbolic polygons represented within the larger parcels that correspond to actual physical property boundaries, posed by far the biggest issue to correct in this stage. About 1,700 of these subparcels were removed from the two attribute tables in this cleaning stage. Once complete, calculating exclusions based on attributes coded by the Fulton County Tax Assessor was a fairly routine procedure. The results of this series of exclusions can be found in Table 6, disaggregated by year.[169] It is important to note that, whereas the stepwise methodology described by Criterion Planners eliminates a parcel as soon as it meets its first exclusion criterion, this analysis ran each exclusion test on every parcel. The author reasoned that these results would prove more useful for diagnostic purposes and would remain consistent regardless of the order in which exclusions are tested.

[169] As Table 6 demonstrates, total parcel counts and acreage vary slightly from 2009 to 2017; year-specific figures are used for normalization in subsequent tables.

Table 6: Subarea 5 Parcels by Status and Exclusion, 2009 vs. 2017

ALL PARCELS WITH CENTROID IN SUBAREA 5		2009	2017
	Total Parcels	2,797	2,839
	Total Parcel Acreage	791.3	776.7
Development Status:			
	Developed (>50%)	872	1,142
	Small Developed (<1 acre, >10%)	1,359	1,268
	Vacant (All Others <50% Developed)	565	429
Exclusions:			
	Small SFR (<0.5 acres)	2,054	2,154
	Appraisal (Impr. > Land Value)	1,636	2,048
	Public, Undevelopable	97	89
	Ineligible Use	46	38
	Place of Worship	36	31
	School	5	3
	Hospital	3	2
	Cemetery	1	1
	Utility (Operating)	1	1
	Parcels with Exclusions	*2,378*	*2,514*
	Parcels without Exclusions	*419*	*326*
	Candidates after Manual Exclusions	***407***	***314***

After applying the prescribed steps and removing a handful of additional parcels ("manual exclusions"[170]) that were overlooked in the data cleaning stage, 407 candidate parcels remained in 2009 and 314 in 2017. Figure 21 indicates, in red fill, where in the study area parcels were eliminated in 2017 based on each exclusion test. About 85% of 2009 parcels and 88% of 2017 parcels met at least one exclusion criterion; roughly three in four parcels were excluded as small single-family in each year, whereas the "Public" and "Ineligible Use" exclusions only applied to a combined 5% of parcels in both years. The only noteworthy change was in the portion of parcels that met the "Appraisal" exclusion, which increased from 59% in 2009 to 72% in 2017. This could suggest that the

[170] See discussion of Table 8 for important notes on these exclusions and their effect.

subarea had densified with infill development during the study period; however, it could just as easily be the result of lag time in property value assessments.

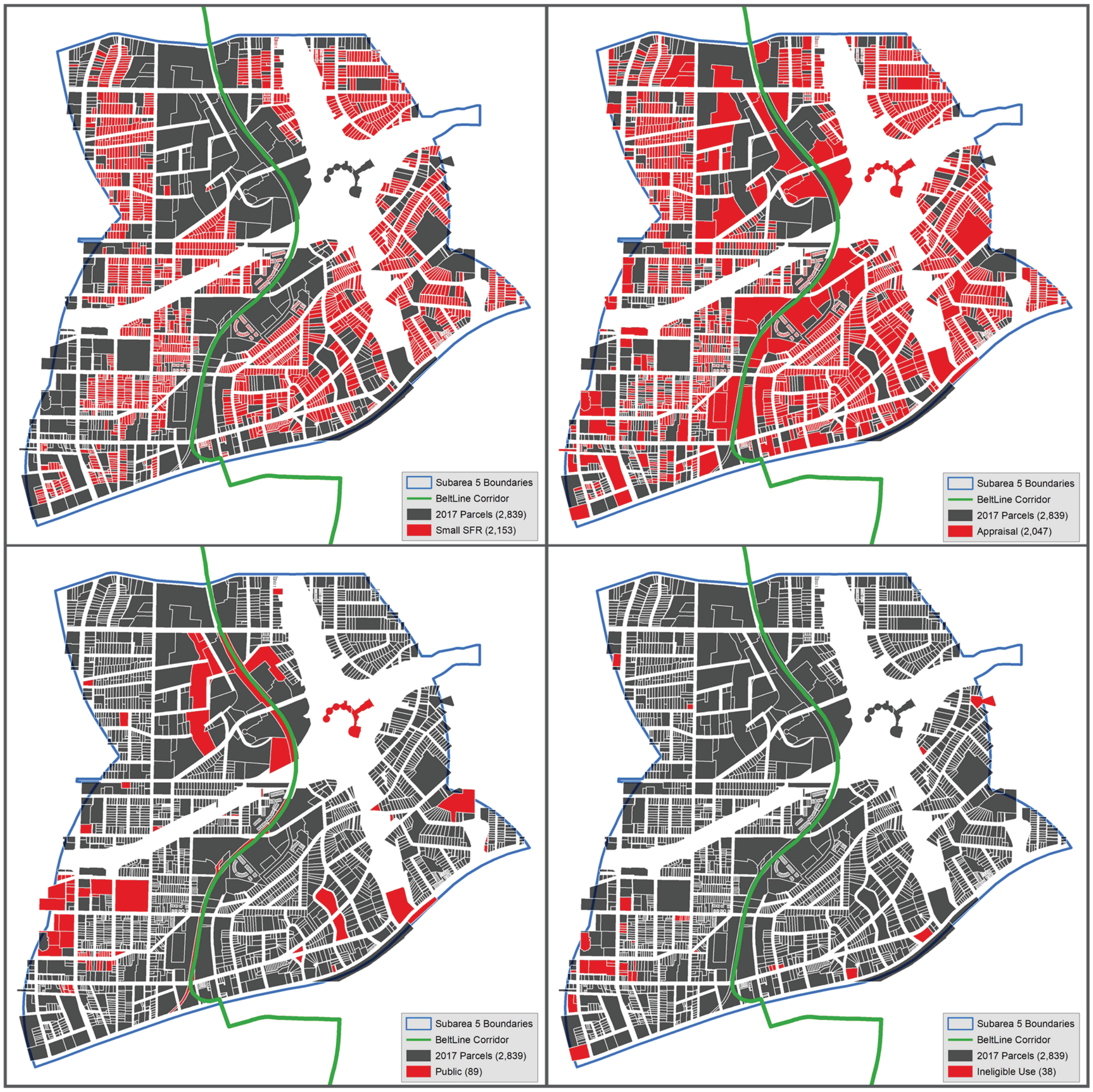


Figure 21: Excluded Parcels in Subarea 5, 2017, by Exclusion Criteria

4.2.2 Candidate Parcels

Figure 22 maps the locations of the 407 candidate parcels in 2009 and 314 in 2017; candidate parcels appear in green. Table 7 breaks down the percentage of total parcels and acreage that were identified as LEED-ND candidates in their respective year. The findings suggest that the portion of candidate parcels fell from 14.6% to 11.1% of all parcels in Subarea 5 (a difference of 3.5%) between 2009 and 2017. Alternatively, candidate *acreage* – in essence, the supply of land capable of supporting “green growth” throughout Subarea 5 – fell by 8.9%, over 70 acres. This may indicate that the shrinking number of candidate

Table 7: Candidates by Percent of Total Parcels and Acreage, 2009 vs. 2017

CANDIDATES AFTER EXCLUSIONS	2009	2017
Vacant without Exclusions	114	80
Redevelopable without Exclusions	293	234
Total Number Candidate Parcels	**407**	**314**
Percent of Total Parcels	*14.6%*	*11.1%*
Total Acreage Candidate Parcels	**211.1**	**137.8**
Percent of Total Acreage	*26.7%*	*17.7%*

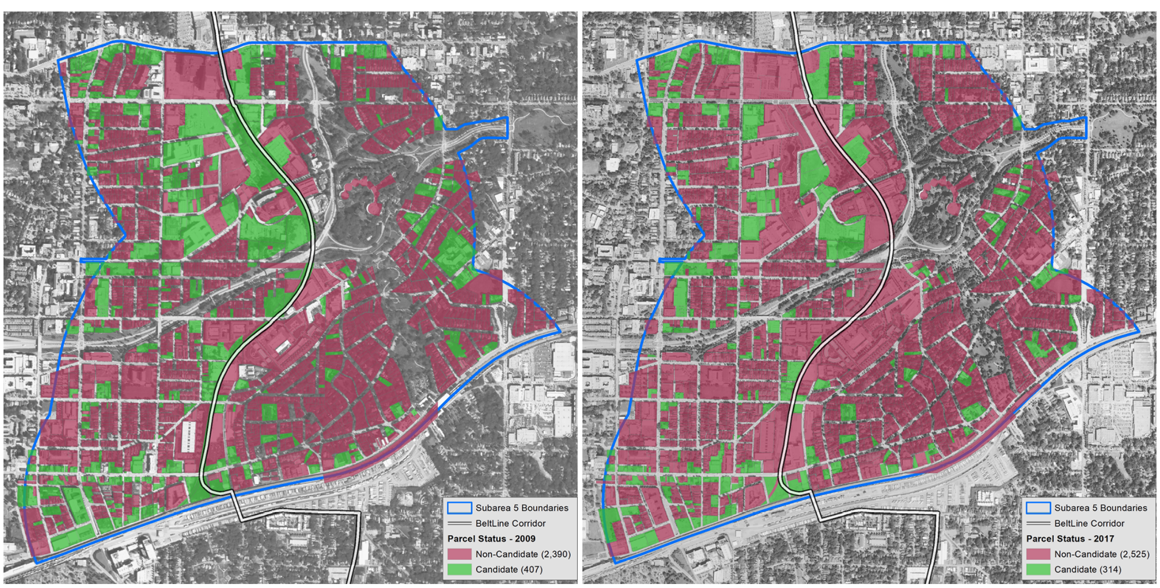


Figure 22: Subarea 5 Parcels by Candidate Status, 2009 vs. 2017

parcels was largely the result of 1-acre-or-larger parcels (e.g., not infill single-family homes) redeveloping in the intervening years.

This finding requires an additional caveat regarding the aforementioned "manual exclusions." Validating the final candidate set by hand removed a dozen additional parcels from both the 2009 and 2017 candidate sets. Manual exclusions resulted in notable reductions in candidate parcel acreage: 14 acres removed in 2009 and 32 in 2017. This had the effect of further exaggerating the degree to which candidate acreage was consumed or utilized over the eight years in question. That difference between the percentage of land suitable for candidacy in 2009 versus in 2017 – a utilization rate, in effect – rose from 6.6% to 8.9% as a result of this last round of exclusions. Stated differently, the margin between candidate acreage in 2009 and in 2017, originally roughly 7% (29% to 22%), grew to roughly 9% (27%-18%) after manual exclusions. What accounted for this difference? Mostly, the removal from the 2017 candidate set of 675 Ponce de Leon Ave, an immensely valuable 16-acre mixed-use redevelopment, which had been erroneously coded as a candidate parcel following merger of overlapping parcels on the site.

Candidate parcels were classified as either "vacant" or "redevelopable" based on the appraisal values for land and improvements encoded for each parcel in the Fulton County tax digest attribute table. Parcels with an improvement value of 0 were coded as vacant while those with land values surpassing improvement values were deemed redevelopable, applying the rationale provided in Talen et al. (2013) that this condition was a sufficient proxy indicator for "developed-but-under-built parcels."[171] (Bear in mind that

[171] Talen et al. 2013, 26.

all other parcels, e.g., those with non-zero improvement values greater than land values, would have necessarily satisfied the "appraisal" exclusion.)

As indicated in Table 8, redevelopable parcels outnumbered vacant parcels by about 3-to-1 among candidates in both years. However, there was a slight shift in the distribution of candidate acreage toward the redevelopable group. This shift appears to be true across all Subarea 5 parcels – candidates and non-candidates – based on an alternate classification of development status based on impervious land cover rather than appraisal value.[172] According to percentages generated from Table 9: Development Status, All Subarea Parcels, 2009 vs. 2017, the portion of parcels classified in this manner as

Table 8: Number of Candidate Parcels and Total Acreage, 2009 vs 2017

CANDIDATE PARCELS AND ACREAGE		2009	2017
	Total Candidate Parcels	407	314
	Total Candidate Acreage	**211.1**	**137.8**
Candidate Parcels by Category:			
	Vacant (Improvement Value = 0)	114	80
	Redevelopable (Land > Impr. Value)	293	234
	Percent Candidate Parcels Vacant	*28.0%*	*25.5%*
	Percent Cand. Parcels Redevelopable	*72.0%*	*74.5%*
Candidate Acreage by Category:			
	Vacant (Improvement Value = 0)	61.0	32.9
	Redevelopable (Land > Impr. Value)	150.1	105.0
	Percent Candidate Acreage Vacant	*28.9%*	*23.9%*
	Percent Cand. Acreage Redevelopable	*71.1%*	*76.1%*

[172] Each parcel was coded "developed," "small developed," or "vacant" based on data tabulated from the unsupervised land cover classification described in the previous section. Classification scheme is described in greater detail in APPENDIX C.

"developed" increased 9% (from 31% to 40%) while vacant parcels fell 5% (20% to 15%). Two trends may be at play here: it appears that physically vacant parcels truly were developed in significant number during the study period (outpacing, it should be added, any demolitions that may have followed the Great Recession). However, it is possible that many parcels, as a result of rising property values, simply graduated to "redevelopable" status the moment their appraised land value surpassed improvement values. This effect should be accounted for in future analyses of this type that compare parcel characteristics over time. This is particularly true when studying gentrifying neighborhoods in the context of volatile housing markets.

Table 9: Development Status, All Subarea Parcels, 2009 vs. 2017

DEVELOPMENT STATUS BY IMPERVIOUS COVER:	2009	2017
Developed (>50%)	872	1,142
Small Developed (<1 acre, >10%)	1,359	1,268
Vacant (All Others <50% Developed)	565	429

4.2.3 Change in Parcel Status

The rest of this chapter will consider how and why the candidate parcel set changed between 2009 and 2017. Nearly one-third of parcels included in the original candidate pool were no longer candidates by 2017; their locations are denoted in the lighter shade of purple in Figure 23. These numbers are also tabulated in Table 10. In addition to the 69% (279 parcels) that remained LEED-ND candidates in 2017, another 35 parcels achieved candidate status in 2017 by passing each exclusion test. However, this analysis disregards these "new" candidate parcels and focuses instead on tracking what became of Subarea 5's

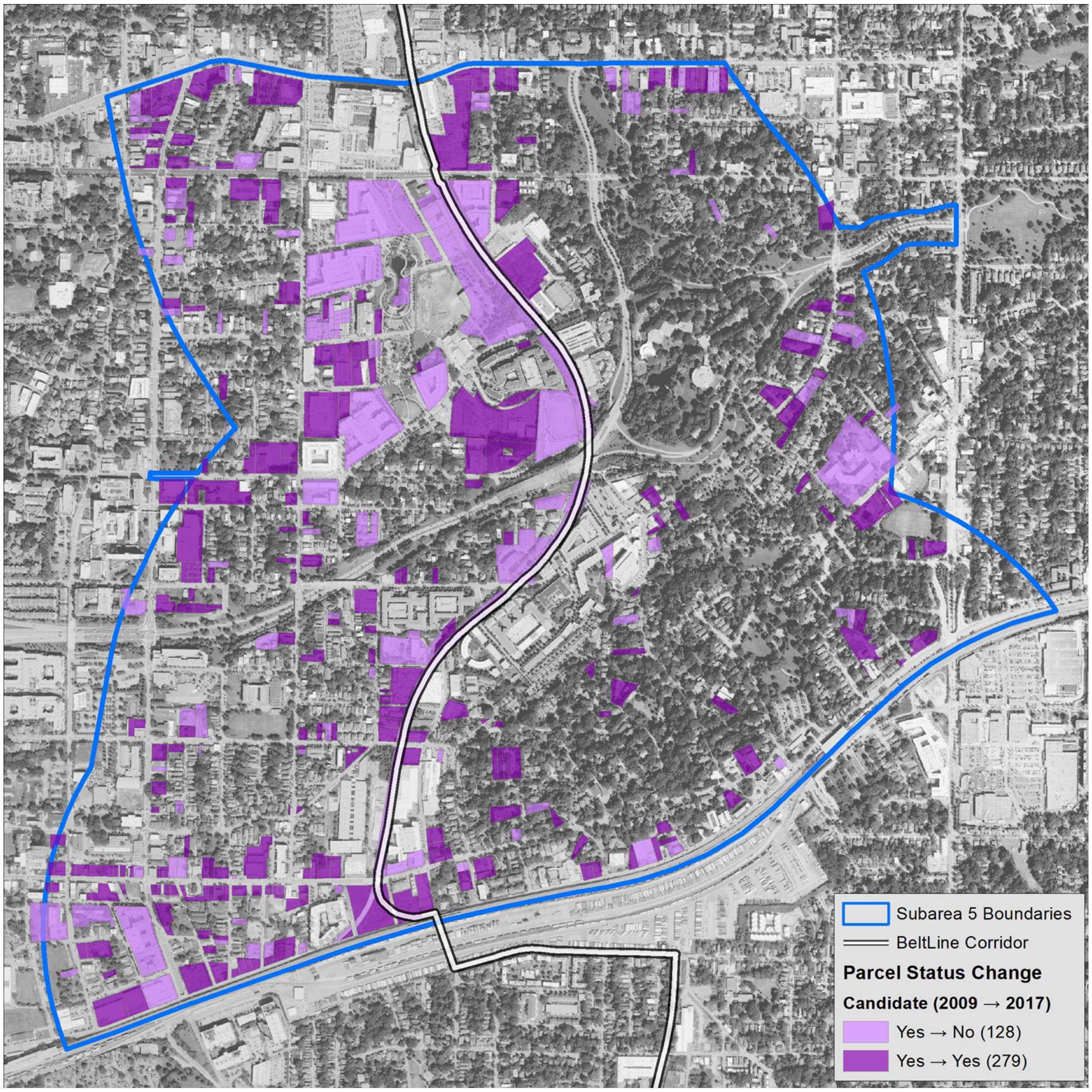


Figure 23: Status of 2009 Candidate Parcels in 2017

supply of redevelopable land in the years leading up to, during, and shortly following the Eastside Trail's arrival.

Returning to Figure 23, several spatial patterns emerge when looking at the distribution of both classes of parcel. Many of the converted parcels ("Yes → No") – including several of the largest – appear tightly concentrated around the Eastside Trail and Historic Fourth Ward Park. (It is worth noting that although only one-third of parcels exited the candidate pool during the study period, they represented almost half of the total original candidate acreage (100 of 211 acres) and over 10% of the platted acreage subarea-wide.) Conversely, parcels that remained in the candidate set ("Yes → Yes") tended to be clustered around several key commercial corridors: Dekalb Avenue, North Highland Avenue, and Ponce de Leon Avenue, in particular. These could represent vacant lots, disused storefronts, or instances where land uses have not kept up with what rising property values deem "highest-and-best use."

Table 10: Candidate Parcel Status Change, 2009 to 2017

PARCEL STATUS CHANGE, 2009 – 2017	
Total Candidate Parcels, 2009	407
Parcels Remained Candidates	279
Parcels Converted from Candidate to Non-Candidate	128
Percent Parcels Remained Unchanged	*68.6%*
Percent Parcels Changed to Non-Cand	*31.4%*

4.2.4 Reasons for Change

In 2009, there were 407 parcels in the final candidate pool. By 2017, 128 of these parcels were no longer candidates.[173] Most often, this suggested that redevelopment had taken place in the intervening years: specifically, 89 of these parcels (70% of this subset) together representing about 56 acres (56% of subset acreage) fell into this group. These parcels had either been excluded in 2017 because their improvement value had surpassed land value, or visual inspection of satellite imagery showed clear evidence of redevelopment. Another 12 parcels representing 35 acres had been converted to

[173] In 38 instances where parcels could no longer be joined across the two time frames based on Parcel ID alone – typically indicating cases where assemblage or subdivision had created new parcels – the new parcel geometry that replaced them was no longer a LEED-ND candidate)

undevelopable greenspace, public uses, or ineligible uses like places of worship – most notably, this patchwork of parcels had been stitched together to form the BeltLine Eastside Trail and Historic Fourth Ward Park. A much smaller subset – 27 parcels representing just 9 acres – had either been excluded in 2017 under the "small single-family residential" exception or met an uncertain fate that could not be determined from tax records and imagery alone.

Table 11: Reason for Parcel Status Change, 2009 to 2017

REASON FOR STATUS CHANGE, 2009 - 2017		
Total Parcels Converted, 2009 to 2017	**128**	
Likely Redeveloped	89	*69.5%*
Excluded as "Small SFR"	16	*12.5%*
Converted to Public or Ineligible Use	12	*9.4%*
Unknown Reason	11	*8.6%*
Total Acreage Converted, 2009 to 2017	**100.4**	
Acreage Likely Redeveloped	56.4	*56.2%*
Acreage Excluded as "Small SFR"	2.9	*2.9%*
Acreage Converted to Public/Ineligible Use	35.1	*35.0%*
Acreage Unknown Reason	6.0	*6.0%*

The results of this classification are summarized in Table 11 and mapped in Figure 24: Reason for Parcel Status Change, 2009 to 2017. In short, 79% of parcels and 91% of acreage that exited the LEED-ND candidate pool between 2009 and 2017 did so as a result of private redevelopment or new public infrastructure. These two categories predominate in the area around the Eastside Trail and Historic Fourth Ward Park; indeed, the trail and distributed park parcels represent the majority of candidate acreage converted to greenspace in the Subarea. Conversely, 21% of parcels representing just 9% of platted acreage became ineligible either for unknown reasons or due to conversion to small single-

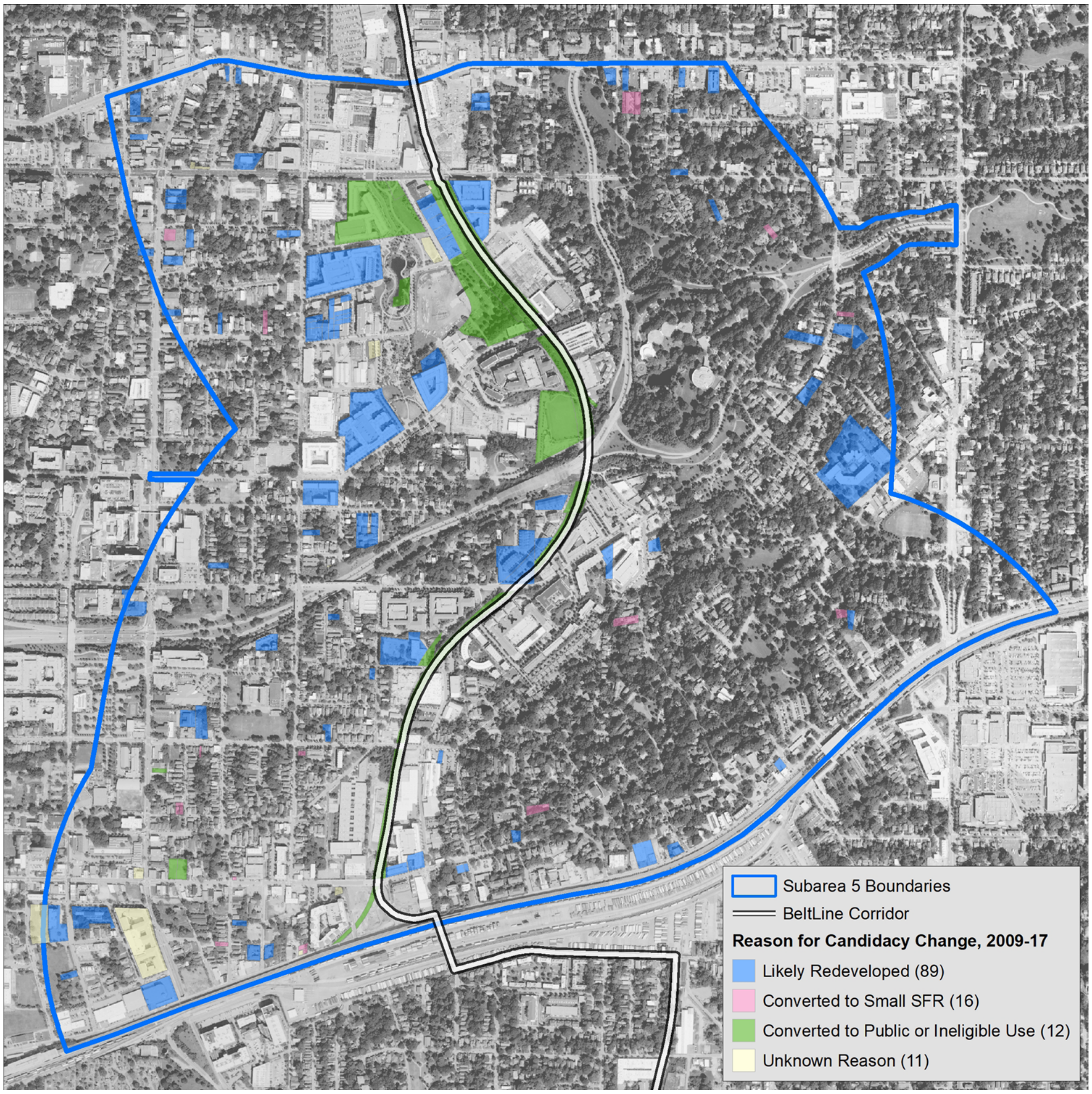


Figure 24: Reason for Parcel Status Change, 2009 to 2017

family lots. This is an encouraging finding insofar as it suggests that it is helpful to look at land removed from the LEED-ND candidate pool over a time period – particularly, when measured in acres rather than number of parcels alone – as a proxy for "utilization" of green growth land supply.

CHAPTER 5 examines a selection of 19 notable parcels, either adjacent to or within close proximity of the Eastside Trail and Historic Fourth Ward Park – that were confirmed to have undergone redevelopment between 2007 and 2019. Each of these parcels was converted from vacant or underutilized land – applying LEED-ND’s definitions – to new development or adaptive reuse. In the process, they significantly densified the urban fabric of the Subarea. Apartment projects alone added over 3,200 residential units at a density of about 54 units/acre.

CHAPTER 5. DISCUSSION

This chapter and the one that follows will attempt to synthesize the results of what are, at present, essentially separate analyses of land cover and land suitability, conducted in isolation with few shared linkages apart from a common study area. This effort should be judged a success only if it contributes meaningful policy guidance that is at once intuitive, rigorously researched, and feasible to implement – both practically and politically. The following sections will discuss, among other things, methodological issues that may hamper scalability and considerations that may add value to future research. It will also attempt to resolve questions around planning theory posed in the literature review. Chapter 6 will more explicitly address policy implications and lay out key recommendations based on the finding presented in this document.

5.1 Tree Canopy and Land Cover Analysis

This analysis did not investigate the ecological qualities of the new tree canopy growth that was observed in Subarea 5 during the study period; nor did it examine the quality of vegetation lost to site development or trail construction. Commenting on the results of the unsupervised land cover classification in Section 4.1.1, the author speculated that canopy gains throughout the subarea were of higher quality and permanence than much of the vegetation that had been lost, particularly along the BeltLine corridor. For example, despite the use of texture analysis and multiple rounds of reclassification, there were instances where kudzu and other low-quality vegetation remained classified as tree canopy in the baseline imagery from 2009. Conversely, new trees added to rights-of-way and site landscaping during study period were deliberately selected from a palette of native or noninvasive exotic species and were likely accompanied by maintenance agreements – thus vastly enhancing their likelihood of reaching maturity undisturbed. Future research on tree canopy in the BeltLine Planning Area should incorporate a more sophisticated tree inventory methodology that can account for number of trees and distribution of species in order to estimates carbon sequestration, heat mitigation, and other benefits.

Several technical and methodological obstacles hampered the effectiveness of the tree canopy and land cover analysis conducted on Subarea 5. Spectral inconsistencies between the NAIP imagery captured in 2009 and 2017 posed significant challenges that could not be remedied by substituting imagery due to the infrequency of NAIP flights (once every two years in Georgia). Correcting for these discrepancies required lengthy, tedious intervention on the part of the analyst, in the process introducing opportunities for biases and subjective interpretation to influence research outcomes. The shortcomings of the unsupervised ISODATA (iterative self-organizing data analysis technique algorithm) land classification method tended to compound these issues. Subsequent comparative land classifications of this nature should implement more methodical validation of sample sites from each class and each year for the sake of statistical rigor. Applying a supervised classification method, in which the analyst "trains" the image processor to recognize representative spectral patterns, could help address these issues, but also poses scalability challenges. Alternatively, object-based classification has been shown to produce superior results than both pixel-based methods – both supervised and unsupervised[174] – and should be considered in future analyses of small study areas such as the BeltLine Subareas.

[174] Weih, Jr. and Riggan, Jr. 2010, 4.

Comparing the parcel-level distribution of land cover types raised two additional concerns about this methodology: differentiation between land cover types degrading due to “over-classification”; and the inadequacy of 1-meter imagery for parcel-level analysis. Spectral differences between the 2009 and 2017 NAIP images seemed to prevent the Iso Cluster tool from reliably distinguish between similarly colored surfaces – barring exceptional differences in texture. And while the NAIP imagery’s 1-meter resolution would be more than sufficient for measuring land cover changes across the city or region, it proved too coarse-grained to reliably estimate land cover percentages for smaller residential parcels. Because single-family residential parcels were of keen interest in this study, the imagery was determined to be less than ideal for this application. Subsequent studies on the subject should utilize higher-resolution satellite imagery from private providers, such as DigitalGlobe. Quickbird, WorldView-1, and WorldView-2 products, for example, have been demonstrated to provide adequate precision for such granular tasks as estimating parcel-level impervious surface coverage for the purpose of assessing stormwater fees.[175]

For the purposes of this thesis, the land cover types of greatest interest were tree canopy and impervious surfaces. Differentiating light and dark impervious land cover yielded interesting results, but it’s unclear how effectively they can guide science-based interventions in the built environment, particularly in the context of localized heat island effect. The image classification only considers color and texture and is agnostic to surface materials – and their thermal performance. For example, the tool struggled to differentiate

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[175] Pacifici and Navulur 2011.

conventional shingles from glass skylights, roof-mounted HVAC equipment, and cars parked on the top levels of parking garages. Much in the same way that this methodology incorporated texture analysis to help distinguish land cover types along an additional dimension, future research could integrate surface temperature data to validate image-based identification of light and dark impervious surfaces based on differences in thermal characteristics. Applications of thermal infrared remote sensing for land surface temperature estimates in conjunction with object-based image analysis (OBIA) for impervious surface identification, for example, have been shown to provide powerful methodologies for monitoring urban heat island effect.[176]

5.2 LEED-ND Inventory

Section 4.2 attempted to quantify and locate the supply of “green growth”-supportive parcels and acreage within Subarea 5. The analysis looked at how this supply changed over a decade that coincided with major investments in BeltLine train and park infrastructure – e.g., where that supply was utilized. Because the inputs and criteria that drive achievement of LEED-ND candidate status are only incidentally related to urban resilience – existing land use, vacancy status, parcel size – measuring this supply does not, on its own, provide meaningful insight into resilience outcomes. Far more important will be a final step, beyond the scope of this thesis, to systematically examine the characteristics of the development that took place in these green growth parcels. Did these projects achieve the desired outcome of low-impact, compact development? The set of indicators proposed

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[176] Wei, Chunzhu and Blaschke, Thomas. 2018. "Pixel-Wise vs. Object-Based Impervious Surface Analysis from Remote Sensing: Correlations with Land Surface Temperature and Population Density." *Urban Science.* 2:1: 12. https://doi.org/10.3390/urbansci2010002.

in Figure 4 would help answer that question on a parcel-by-parcel basis and, in the aggregate, provide measures by which to evaluate performance at the district scale.

5.2.1 Summary Findings

If LEED-ND strives to take stock of the supply of green growth within a jurisdiction, then there are two ways in which a transportation-focused redevelopment project like the Atlanta BeltLine can advance that objective. The project can stimulate redevelopment and adaptive reuse of existing eligible sites, thereby increasing the utilization of parcels less burdensome to public services and infrastructure (and likely less carbon-intensive across their lifecycles) than new construction on greenfield sites. Or, a project like the BeltLine can directly manipulate urban form in ways that bring greater numbers of parcels into eligibility – in effect growing that supply pool itself.

Researchers and policymakers should devote future study to the latter phenomenon, as their findings can inform scenario planning and weigh priorities related to growth and preservation of existing assets that strengthen community resilience. More broadly, it can help local and regional officials gain a better grasp of their jurisdiction’s budget of sustainable growth opportunities in an era where sprawl-plagued cities will be forced to grapple with their own carrying capacity. Regrettably, this represents a blind spot of the analysis at hand, which neglected “new” candidate parcels in favor of tracking the fate of the 2009 candidate set. Future research of this type should more deliberately identify parcels that, with minor planning interventions, may become LEED-ND candidates and, more meaningfully, become more likely to achieve the objectives of sustainable urbanism. As briefly mentioned in the previous chapter, future studies should also carefully consider potentially confounding effects from rising property values and devise strategies to decouple metrics of sustainable performance from unrelated background effects of gentrification.

As indicated in Chapter 3, the author ultimately chose not to conduct a full LEED-ND inventory of the study area, in part because such an endeavor would likely entail hundreds of person-hours. More importantly, it would provide little utility as a public policy prescription because few localities possess the staff bandwidth and in-house technical capacity required to feasibly scale up such an effort in a comprehensive and equitable manner across their jurisdiction. Instead, the author focused on identifying the pool of candidate parcels that might be cautiously promoted as "LEED-ND-ready." These parcels have cleared the greatest hurdle by passing a series of preliminary exclusions designed to weed out undeveloped existing single-family lots, certain public interest uses, and parcels generally deemed to be adequately "developed." In Subarea 5, the candidate parcels represented a modest portion of total parcels – 14.6% in 2009 and 11.1% by 2017 – and about a quarter of platted land area – 26.7% and 17.7%, respectively. These percentages are notably higher than those found in analyses of broader study areas due to the dense concentration of redevelopable brownfields and former industrial properties in Subarea 5. (The elimination of duplicate geometry and "parcels within parcels" resulting from condos, townhomes, and other planned unit communities also inflates these percentages.)

Moreover, findings from previous studies suggest that the majority of candidate parcels will satisfy one of the eligibility pathways provided under the SLL prerequisite. About 71% of candidate parcels in Phoenix achieved at least "constrained" eligibility; in

Lisbon, almost all tested parcels did so by virtue of the pedestrian-scale density built into the ancient city. Assuming similar “pass rates” as the Sun Belt peer city for candidate parcels in Subarea 5, approximately 289 of the 407 candidate parcels would achieve eligibility, as would about 223 of the 314 in 2017.

This exercise did expose several shortcomings of relying on tax parcel data for cross-sectional analysis of small study areas. Most obviously, whereas the vast majority of the BeltLine Planning Area and City of Atlanta lie within Fulton County, a small portion of Subarea 5 intrudes into the adjacent county of Dekalb. This introduced discrepancies and blind spots due to inconsistencies in how the two tax assessment entities coded the attribute tables for their publicly available parcel shapefiles. However, in the Fulton County portion of Subarea 5 – where the vast majority of redevelopable parcels are found – more problematic still was the lag time between new construction and its reflection in tax appraisal. For example, two five-plus-acre parcels in the study area’s core were misidentified as LEED-ND candidates in 2009, even though gleaming new apartment buildings conspicuously occupied their surface in satellite imagery from September of that year. Further review of building permits suggested that the new redevelopments at 660 Ralph McGill Blvd and 525 Glen Iris Dr began construction in 2008 but did not deliver until mid-to-late 2009. As of January of that year, at which point the Fulton County Board of Assessors was likely expected to finalize tax bills, the combined land value of the two parcels officially outstripped the value their built improvements by a wide margin, $4.5M to $69,000.

This instance demonstrates the level of tedious spot checking – and close familiarity with the study area – required to verify inventory results to any sort of rigorous standard of accuracy.[177] Future applications of this methodology could partially mitigate against this issue by using tax parcels for the following year. However, given the inconsistencies in the timing and magnitude of property tax increases – themselves often dictated by local political circumstances rather than rote formula – such small samples of tax parcel data may prove unreliably detached from conditions observed in real-time.

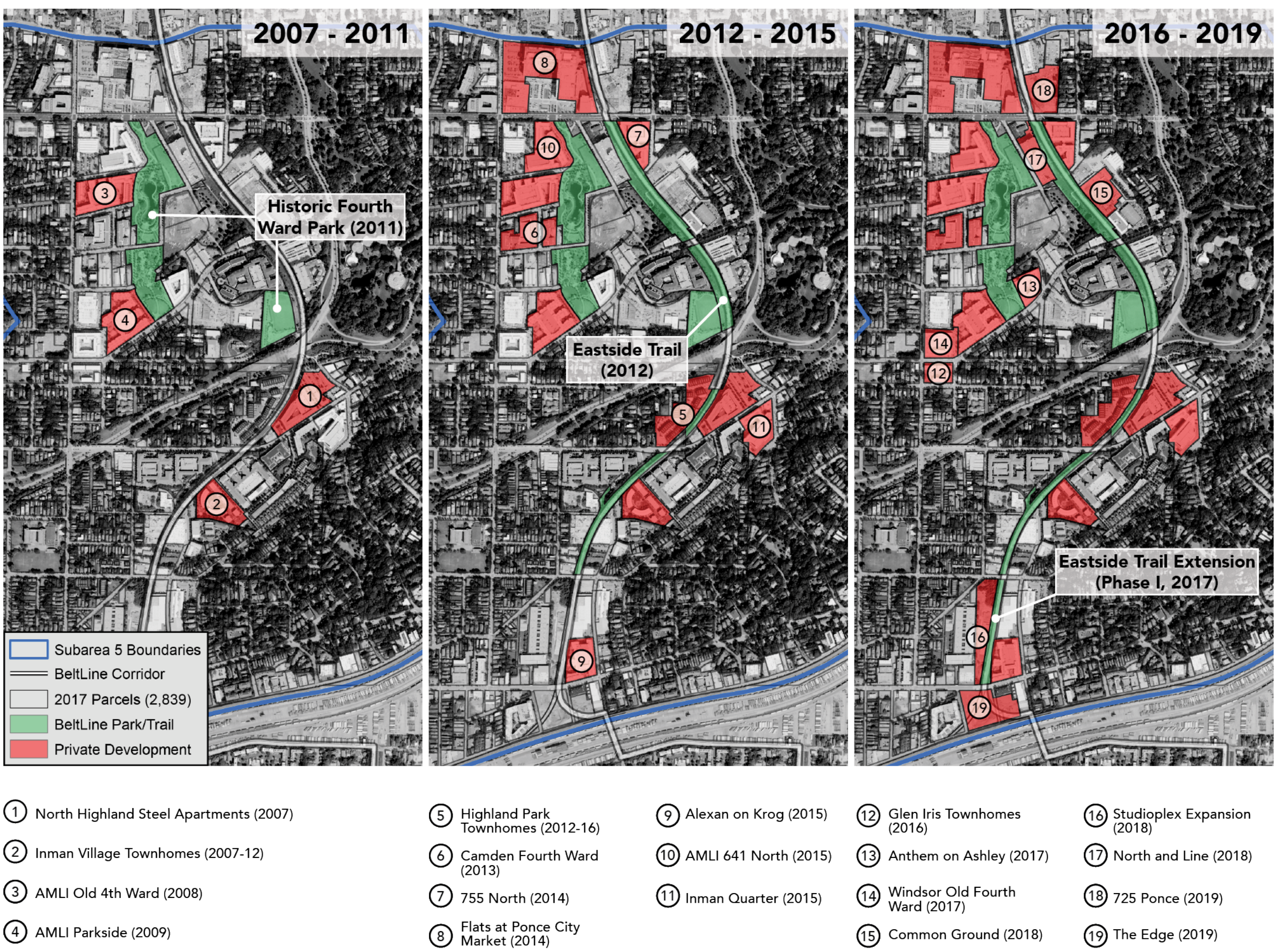
5.2.2 Selected Developments

This analysis also sought to estimate the cumulative impact of key infill projects developed on or near the Eastside Trail over the study period. In order to capture noteworthy activity in the study area that could reasonably be deemed related to the trail and future transit – either in anticipation of its construction or once trail infrastructure was in place – the study period was extended to cover construction between 2007 and 2019. Based on a review of construction activity in the study area since 2000, five years before the BeltLine Redevelopment Plan was formally approved, this timeline appeared to adequately account for protracted development timelines and the for the near-complete suspension of building activity during the Great Recession. Multifamily and mixed-use construction appeared to resume at a blistering pace in 2014, two years after the opening of the Eastside Trail.

Figure 25 illustrates the sequencing of BeltLine trails and parks, overlaid in green, alongside 19 major private developments – in red, a mix of new construction and adaptive reuse – built in Subarea 5 between 2007 and 2019. In addition to townhome communities

[177] The two buildings in this example represented xx acres and 301+337 units of multifamily housing – whose omission could significantly skew results of small jurisdictional sustainability assessments.

and mixed-use office/commercial space, the list of projects includes 13 multi-family developments that together represent 3,456 rental apartments on 60 acres of land, achieving a density of nearly 60 units per acre. The figure is intended to convey two main points: that development activity in the subarea during this decade was highly spatially correlated to and clustered around BeltLine infrastructure; and that development activity tends to ramp up well in advance of such infrastructure's final delivery in a pattern of speculative anticipation.



Data Sources: City of Atlanta Accela, Google Earth, Fulton County Board of Accessors,

Figure 25: Selected Developments and BeltLine Infrastructure, 2007-2019

This paper does not presume to attribute this activity entirely to the BeltLine, much less to say that it would not have occurred *if not for* the Eastside Trail and Historic Fourth Ward Park. To be sure, there are other market factors that would have made these neighborhoods ripe for redevelopment during the years in question: proximity to job centers, existing retail amenities and services, and adjacency to affluent in-town neighborhoods. Still, the pattern of large-scale infill development that appears to cluster around anticipated or newly delivered BeltLine infrastructure certainly suggests that the trail segments and greenspace played a large role in driving this dense residential and mixed-use development.

CHAPTER 6. CONCLUSION

6.1 Research Question, Revisited

Has the Atlanta BeltLine made the surrounding built environment more resilient to the rapidly accelerating effects of climate change? The evidence presented herein is inconclusive. Setting aside for a moment the question of causation and looking simply at outcomes, has the built environment become measurably more resilient? And setting aside the fatal assumptions of stationarity and equilibrium baked into sustainability, has the built environment been made more "sustainable" in measurable ways? Insofar as the performance measures identified in this study are concerned, the study area certainly appears to have achieved progress in both dimensions. Subarea 5, for the most part, appears to have densified in appropriate places, namely, formerly industrial properties and polluted brownfields within walking distance of BeltLine trail and future transit. Areas of both concentrated and distributed canopy have been preserved while hardwood saplings planted throughout planned developments and alongside the Eastside Trail steadily accumulate biomass.

Still, by certain other measures of urban climate resilience and sustainability it is less clear whether the area improved its performance over the past decade. For example, the fishnet grid results presented in Section 4.1.2 suggested that while net tree canopy coverage remained stable across the subarea during the study period, this coverage may have become more fragmented or concentrated: the number of canopy-rich cells shrank considerably. This is troubling in light of evidence that tree canopy distributed throughout areas where people actually live and work delivers greater benefits for urban heat mitigation than the same acreage of tree cover that is confined to more sparsely populated areas.[178] Moreover, indicators related to stormwater management, building energy consumption, and broader lifestyle-related carbon intensity were omitted from this analysis but should be investigated further at a fine-grained, neighborhood scale. Improvements in energy use intensity achieved by upgrading an aging building stock are likely at least somewhat undermined if new homes are substantially larger than the structures they replaced or contain fewer units. Similarly, the benefits of smaller carbon footprints associated with dense, walkable, transit-connected urban form may be rendered moot by the phenomenon of "carbon gentrification," wherein more affluent newcomers lead more carbon-intensive lifestyles than legacy residents.[179]

Moreover, in this same vein, it remains to be seen whether localized carbon footprint reductions resulting from urban densification around the BeltLine would generate a net benefit at the *regional* scale. For example, if demographic inversion"[180] in BeltLine neighborhoods displaces working-class residents to distant, car-dependent suburbs while more affluent newcomers continue to commute by car, a net increase in greenhouse gas emissions would likely result. In a sense, by treating the study area as a closed system, this thesis is guilty of the same nearsightedness it had lamented in its opening passages on site planning orthodoxy – simply at a different scale. Neither the site nor the district behaves in a vacuum, and thus a full assessment of urban climate resilience requires a fuller accounting of impacts at the jurisdictional and regional levels. For now, however, the

[178] Stone and Rogers, 2001, 193-195
[179] Rice et al., 2020, 152-154
[180] Alan Ehrenhalt describes this phenomenon in his 2013 book, *The Great Inversion*

potential for the kind of perverse outcomes cited above underscores that the BeltLine's goal of promoting affordable, mixed-income communities is inextricably tied to its aspirations for climate-resilience communities. Just as their objectives are mutually supportive, so too does failure in one area jeopardize the other.

The good news is that, as a theoretical framework, resilience remains better equipped than sustainability to deal with issues of boundary delineation thanks to its emphasis on dynamic systems. Moreover, the framework's roots in disaster risk reduction make it more practical to operationalize resilience-based initiatives across jurisdictional scales (local, state, and federal) than legal mechanisms for environmental protection or – even more inaccessible to sub-national actors – international climate action. To be sure, applying urban climate resilience carries inherent limitations and pitfalls, particularly around defining precise goals and metrics and ensuring equity. Planning scholars have spent the past decade cautioning that resilience interventions must be carefully designed – and vigilantly monitored – in order to avoid assigning "winners and losers" through the inequitable distribution of benefits.[181,182] Still, the concept's explicit focus on governance and decision-making processes provides an appropriate platform through which to adjudicate questions of social equity and justice.[183]

[181] Leichenko 2011, 166.
[182] Meerow and Newell, 2016.
[183] Kim and Lim 2016, 5.

6.2 Observations on Methodology

In the process of investigating the research question and its implications for policy and practice, this analysis led the author to several methodological insights that may prove useful to future research. These are briefly summarized below – and discussed at greater length in CHAPTER 5 and the latter two Appendices.

6.2.1 Satellite Imagery Dataset

Spectral inconsistencies between the NAIP imagery captured in 2009 and 2017 posed significant challenges. Because it was not possible to substitute more suitable imagery – NAIP flights are only conducted every two years in Georgia – the author's only recourse was to address these discrepancies, with limited success, through several rounds of reclassification and filtering. Moreover, NAIP's 1-meter resolution proved inadequate for parcel-level analysis, particularly in the case of small residential parcels. Subsequent studies on the subject should utilize higher-resolution satellite imagery from private providers, such as DigitalGlobe.

6.2.2 Land Cover Classification Method

Certain qualities of the ISODATA (iterative self-organizing data analysis technique algorithm) land classification method tended to compound the limitations of NAIP imagery for this application. Despite the incorporation of textural analysis, the unsupervised algorithm struggled to reliably distinguish between similarly colored surfaces in the many cases where exceptional differences in texture were absent. Future research into land cover change over time at the district scale – in this case, an area less than two square miles –

may address these issues somewhat by employing a supervised classification method or object-based image analysis (OBIA).

It is also unclear whether simply distinguishing between light- and dark-colored impervious surfaces, without revealing more nuanced insights into thermal performance, can guide evidence-based interventions to mitigate urban heat. The land classification method employed here only considers color and texture and is agnostic to surface materials; for example, it struggled to differentiate skylights from asphalt shingles. Much in the same way that this methodology incorporated texture analysis to help classify land cover types along an additional dimension, future research could integrate surface temperature data to validate image-based identification of light and dark impervious surfaces based on differences in thermal characteristics.

6.2.3 LEED-ND as "Green Growth" Proxy

This analysis evaluated LEED-ND candidacy rather than eligibility, which greatly simplified the methodology but also sacrificed its ability to address the research question. Because the inputs and criteria that drive achievement of LEED-ND candidate status are only incidentally related to urban resilience, this test provided a weak proxy for "resilient urban form." Measuring the supply and spatial distribution of these candidate parcels does not, on its own, provide meaningful insight into resilience outcomes. In fairness, this analysis only looked at one of several components of LEED-ND eligibility, the "Smart Location and Linkage" group. Evaluating changes in Subarea 5 from 2009 to 2017 using prerequisite criteria from the "Neighbourhood Pattern and Design" or "Green Infrastructure and Buildings" groups could prove more effective at measuring climate resilience. However, it may prove more fruitful still for future research to forego attempting to repurpose schemes designed for certification purposes and instead design more context-specific criteria or scoring composites by which to empirically evaluate resilience in the built environment.

Whether using LEED-ND criteria or a bespoke metric, if the purpose of an analysis is to take stock of the supply of green growth within a jurisdiction, then there are two ways to gauge the impact of a project like the BeltLine. First, a project can stimulate redevelopment and adaptive reuse of existing eligible sites, thereby increasing the utilization of parcels less burdensome to public services and infrastructure than new construction on greenfield sites. Alternatively, public infrastructure its amenities can directly manipulate urban form in ways that bring greater numbers of parcels into eligibility – in effect growing that supply pool itself. This latter phenomenon fell outside the scope of the present analysis, but researchers and policymakers should study it further. Instead, this thesis focused on the "utilization" dimension, but stopped short of examining the characteristics of the new development that sprang up on those green growth parcels, which would have more directly measured achievement of low-impact, compact development. In future analysis, the set of indicators proposed in Figure 4 can help evaluate performance on a parcel-by-parcel basis and, in the aggregate, at the district scale. These indicators address objectives like avoiding overprovision off-street parking, expanding access to high-capacity transit, and mitigating stormwater runoff, and each can help measure climate resilience in the built environment.

6.2.4 Parcel Dataset

This exercise also highlighted idiosyncrasies in tax parcel data that may interfere with cross-sectional analysis of small study areas. Particularly evidence was the lag time between new construction and its reflection in the tax appraisal field of the Tax Parcels shapefile published by Fulton County. Future applications of this methodology can partially mitigate against this issue by using parcel data for the following year – e.g., in this instance, using 2010 and 2018 datasets – to capture revised tax assessments.

6.3 Policy Recommendations

The results and discussion presented in previous chapters highlight several opportunities for evidence-based policy reform. Atlanta BeltLine, Inc. (ABI) and the City of Atlanta's Department of City Planning (DCP) are the most logical agents to champion these changes; implementation will require sustained coordination with Department of Watershed Management, the city and county development authorities, and the Georgia Department of Transportation (GDOT), among others.

Goal #1: Adopt climate resilience as an explicit objective of the Atlanta BeltLine; articulate its connections to equity and sustainability; and develop performance measures and indicators for tracking achievement. Sustainability is implicitly embedded in the BeltLine's mission and explicitly embedded in the Atlanta BeltLine, Inc. mission statement. However, it has often been neglected as a distinct programmatic element; ABI leaders seem to accept as an article of faith that other programmatic elements adequately achieve sustainable outcomes as co-benefits. This is especially problematic at a time when sustainability is regarded in some community circles as either abstract (separate and apart from more immediate material goals like provision of affordable housing, living-wage jobs, and adequate transit service) or, worse still, as a frivolous pet project for the affluent. In light of these challenges, rather than investing great energy in making a persuasive case for sustainability, BeltLine leadership may find it more effective to pivot to a broader framework of urban climate resilience. This framework is inclusive enough to accommodate ecological sustainability while also situating the concept in terms that resonate with the lived experiences of low- and middle-income Atlanta communities. It is also far more responsive to the conditions of nonlinearity, tipping points, and transformational change presently observed not only in climate science but also in political and economic discourse.

Fortunately, the themes of climate adaptation and community resilience offer persuasive entry points for relating ecological sustainability to more tangible challenges and community objectives – and demonstrating how policies and practices can advance each goal simultaneously. To ensure that this expression of commitment translates to meaningful resources and funding, however, ABI must: identify and justify its desired outcomes; develop performance measures; and transparently track progress toward quantifiable targets that are publicly disclosed. Each of these steps will help build public support and trust while ensuring accountability. The organization's recent work on equity and inclusion, which entailed clearly articulating desired project outcomes and publishing a set of performance measures by which to assess performance,[184] offers a model for this type of exercise. Because this programmatic area represents a cross-cutting boundary

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[184] Atlanta BeltLine, Inc., n.d., "Equity and Inclusion: Measuring Our Progress," https://beltline.org/the-project/project-goals/equity-and-inclusion/#measuring-our-progress.

object of its own – much in the same way that urban climate resilience can marshal collective action across a diverse set of disciplines – it is perhaps an appropriate area to house (or at least incubate) the BeltLine's climate resilience work.

Figure 4 in Section 3.2 sought to take a first step toward this goal by mapping project outcomes, the policy and design levers ABI might utilize to pursue them, and key indicators through which to evaluate performance toward doing so. For example, tree planting in BeltLine corridor and parks, combined with new zoning provisions to promote the use of high-albedo surfaces roofing and paving on private property, are levers for alleviating urban heat island effect; metrics for tracking their impact may be direct (e.g., surface temperatures across a Subarea) or indirect (e.g., tree canopy coverage). Moreover, the figures and tables in Chapter 4 may serve as templates for reporting key indicators for each of the BeltLine Subareas – both vector and raster data (e.g., parcel and grid cell; and land cover by area, respectively). In the present study, these templates have been used to report and visualize key land cover figures (e.g., tree canopy and impervious surface) and changes over time in the supply of "green growth-supportive" land (employing the LEED-ND candidate parcel methodology). In the future, the data analysis and presentation formats employed here will require some refinement and elaboration to be made suitable for the kind of more granular metrics related to urban form characteristics (e.g., dwelling unit density, intersection density, or off-street parking provision) that Figure 4 highlights. However, by measuring several related indicators at the scale of a single subarea, this analysis sought to provide a proof of concept that might be practicable across the entire BeltLine Planning Area.

While it is enticing to contemplate expanding the scope of this work into a more holistic framework for evaluating climate resilience in the BeltLine geography, the fact remains that even this analysis had to be substantially scaled back from its initial scope. Ultimately, it only investigated parcel-level LEED-ND *candidacy*, a proxy far removed from meaningful performance metrics. This suggests that a full inventory of LEED-ND-eligible parcels, even for one of the BeltLine Planning Area's smallest subareas, is so technically burdensome as to prove unfeasible without large-scale investments in staff time and expertise. It would likely prove more efficient and effective to either develop a BeltLine-specific composite score to use in assessing achievement of "resource-efficient compact development." Similar to what City of Atlanta has done with SHIFT ATL, a climate-resilience composite for the BeltLine could integrate metrics such as: number of households within walking distance of high-capacity transit; number of off-street parking spaces per housing unit; and percentage of platted acreage that meets requirements of the City's stormwater ordinance. Alternatively, ABI could use a resilience-minded proprietary platform for plug-and-play scenario planning, such as Peter Calthorpe's UrbanFootprint. These tasks could be conducted in-house or added to the scope of work for planning consultants who carry out the remaining Subarea Master Plan updates; or a combination thereof.

Goal #2: Introduce, as part of Atlanta BeltLine Design Guidelines, a resilience scorecard that shall, following a phase-in period, establish mandatory performance standards. Using criteria from the LEED-ND methodology to identify parcels more likely to support "green growth," this analysis found that about 15% of Subarea 5's parcels and 27% of its land area were LEED-ND "candidates" in 2009 – representing a land supply budget of roughly 211 acres. By 2017, an estimated 22% of these candidate parcels on 56 acres had been redeveloped.

However, the findings presented in Section 4.2 could not tell us anything about the character of the new development that emerged on those acres. This shortcoming in methodology underscores that there is no existing channel through which public officials can track and assess climate resilience indicators – and not just conventional metrics of economic development – for new development. By instituting a "scorecard" system for private development projects planned within the BeltLine Zoning Overlay, ABI officials could create such a channel for data collection while at the same time instituting a framework capable of "ratcheting up" expectations for performance over time.

This thesis raised doubts about the effectiveness of applying a planning support system based on LEED-ND criteria to evaluate climate resilience performance in the built environment around the Atlanta BeltLine. Moreover, Section 2.4.5 highlighted the limitations of the BeltLine Zoning Overlay as a policy lever to drive performance on indicators that correlate to resource-efficient, compact development. The Overlay deals mostly with sidewalk standards, façade fenestration, curb cut placement, screening of parking and dumpsters, and other cosmetic issues related to walkability and safety. The BeltLine's Design Review Committee (DRC), an advisory body spawned by City legislation in 2015, is empowered to help guide development around the BeltLine Planning Area by reviewing and issuing recommendations on proposed development during the

Special Administrative Permit process.[185] However, its recommendations are non-binding and pertain only to the limited strictures of BeltLine Zoning Overlay. These constrains could be relaxed by either expanding the scope of the Zoning Overlay or expanding the powers of the DRC.

In the meantime, however, design guidelines offer a more politically feasible starting point for promoting climate-resilient urban form in the BeltLine subareas. These guidelines can establish a credible evidence base to justify requests for concessions from private property owners, be they DRC applicants or potential developers of BeltLine-controlled sites. They will likely be developed by a third-party consultant and thus will not demand extensive time commitments from subject-matter experts on staff. And they will serve as a conduit for climate-resilient design practices rather than an expensive standalone product dedicated to relatively novel concepts that, at this stage, likely have little political purchase among ABI leadership. Such a scorecard might draw inspiration from the Toronto Green Standard, a two-tiered model consisting of baseline requirements as well as a more ambitious level of environmental performance that developers may voluntarily pursue. Technical specifications within the standard could be brought to bear on questions of "green building" best practices, stormwater management, and tree protection and replacement, among other issues. Moreover, requirements or voluntary criteria laid out in the standard would provide important performance measures to track data on performance over time.

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[185] City Council of Atlanta, Georgia, 2015, 14-R-4377, "A Resolution Authorizing the Creation of the Atlanta Beltline Design Review Committee," adopted March 2.

Whatever form they take, a system for evaluating climate resilience must be designed with intention and transparency. Policymakers must remain mindful that encoding a diverse set of resilience indicators into a "black box" composite scoring mechanism may obscure internal conflicts between counterposing objectives that must be addressed. To revisit the example offered by Feldmeyer et al. (2019) in their explanation of the importance of data transparency to such applications, whereas impervious surfaces are undesirable in the contexts of stormwater management, air quality, and urban heat islands, they are necessary for infrastructure redundancy and disaster preparedness and response.[186] In this specific policy instance, a resilience scorecard must anticipate and reconcile conflicts between strategies to pursue climate resilience in the BeltLine Planning Area through compact "green urbanism," on one hand, and "green" land cover on the other. A well-designed solution will find ways to optimize for both – or, at least, to minimize distortions in scoring.

Goal #3: Systematize GIS monitoring of land cover characteristics at the parcel level. This goal is a prerequisite if local jurisdictions and agencies aspire to ever scale up incentives for voluntary green infrastructure practices on private property or enforcement of standards related to them. Other cities in fiscal and political climates as diverse as Denver,[187] Durham,[188] and San Antonio[189] have successfully implemented parcel-level land cover mapping and open data systems in order to assess stormwater utility fees in an

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[186] Feldmeyer et al., 13
[187] "Mapping Denver's Impervious Surfaces," n.d., ArcGIS, https://arcg.is/1fyDLn.
[188] City of Durham, n.d., "Stormwater Utility Fee," https://durhamnc.gov/814/Stormwater-Utility-Fee.
[189] City of San Antonio, n.d., "Interactive Impervious Cover Map," https://www.sanantonio.gov/PublicWorks/Projects/Storm-Water-Fee/What-is-Impervious-Cover/Interactive-Impervious-Cover-Map.

equitable and evidence-based manner. (An example of San Antonio's GIS web app can be seen in Figure 26.) Political pitfalls notwithstanding, there may be some appetite within city government to revive Atlanta's stormwater utility fee. The City's 2016 *Green Infrastructure Strategic Action Plan*, re-released under the current mayoral administration, lists creation of a stormwater utility among a lengthy policy wish list; the document does not clearly delineate prioritization or phasing, however.[190] Alternatively, it may be easier for Fulton County to develop such a system, as it already maintains a public-facing GIS interface for property tax records. Regardless of which agent takes ownership of the initiative, the goal – online GIS infrastructure capable of tracking parcel-level data on impervious cover and tree canopy, generated through regular land cover classifications – can be achieved at little political cost because it is, on its face, a benign proposition.

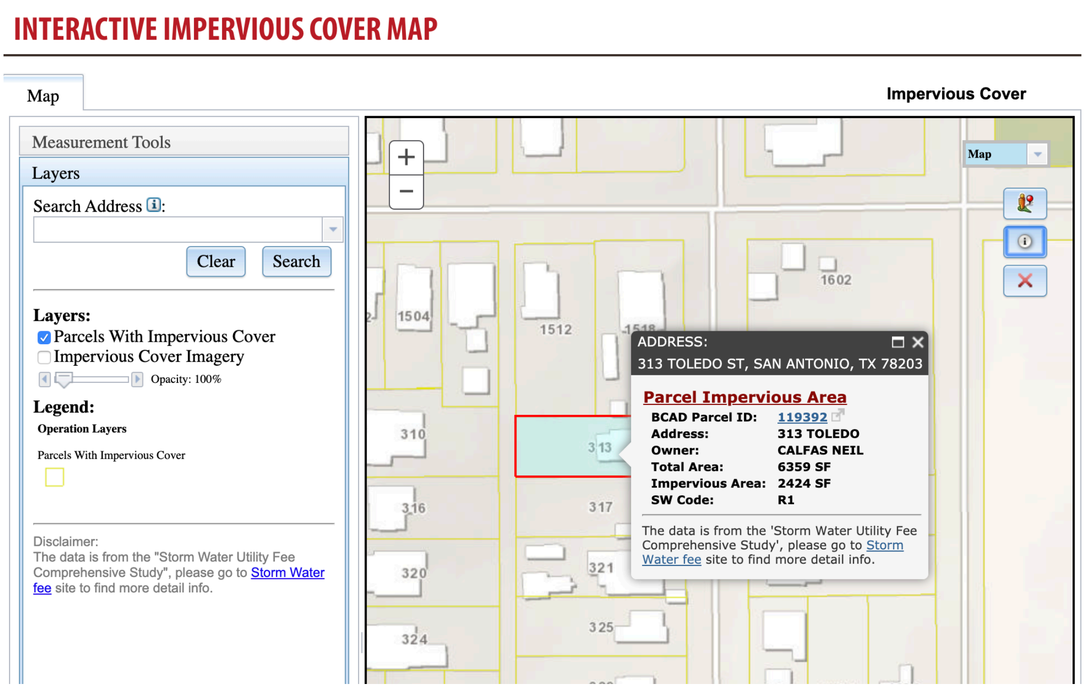

Figure 26: Example of Parcel-Level Land Cover Mapping, San Antonio

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[190] City of Atlanta Department of Watershed Management, 2018, *City of Atlanta Green Infrastructure Strategic Action Plan*, https://drive.google.com/file/d/1u65BWi5qBFA-iYQmdBLm9wAVE7yHJnyf/view.

Nevertheless, it is a critical first step toward implementing more ambitious policies around tree protection and stormwater management.

This thesis identified challenges and pitfalls associated with performing land cover analysis on the BeltLine subareas. Tracking parcel-level change over time was especially problematic when using 1-meter imagery (with inconsistent spectral characteristics) for a relatively dense, urban district. A long-term land cover and tree canopy monitoring initiative can address these issues by purchasing higher-resolution Quickbird imagery for the BeltLine Planning Area each year during the leaf-on season. These GIS resources can be made more powerful still by incorporating temperature data, combining a network of ground-level sensors installed throughout the 22-mile BeltLine corridor with satellite remote sensing data.[191] This additional data would help directly measure urban heat island formation at the Planning Area and Subarea scales and may provide a powerful companion to the land cover classifications.

Goal #4: Apply a "payment for performance" principle to incentivize tree planting on individual parcels. This analysis estimated that tree canopy coverage shrank 3.3% in Subarea 5 between 2009 and 2017 while impervious surface area grew by 2.4%. This shift coincided with a sustained surge in development activity as the city's housing market recovered from the Great Recession – a surge spurred largely by the anticipation and, later, arrival of BeltLine infrastructure. It is critical to note that Subarea 5 appears to

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[191] For a local model, see the Urban Climate Lab's Georgia Tech Climate Network, a collection of 24 temperature and relative humidity sensors installed across the urban campus in order to identify hotspots and examine interactions between vegetation, cool materials, and land cover: http://www.urbanclimate.gatech.edu/HOBO.html.

have experienced a net conversion of tree canopy to impervious surfaces *in spite of* BeltLine green infrastructure, most notably a 17-acre park built atop what had been a sea of asphalt. This finding underscores the importance of policies that explicitly seek to protect and enhance tree canopy in BeltLine Subareas, particularly in neighborhoods where planners anticipate large-scale redevelopment activity. These policies can mediate conflicts between the BeltLine's competing objectives of compact development and heat-mitigating land cover, where such conflicts arise, to ensure that both goals are pursued in concert.

Fortunately, an overhauled Tree Protection Ordinance (TPO) appears on track for adoption by Atlanta City Council in 2020.[192] According to the draft documents presented in 2019, under the revised TPO a tree's value will be determined by a base calculation (following a third-party valuation method) that is then mediated by local "Context Factors"

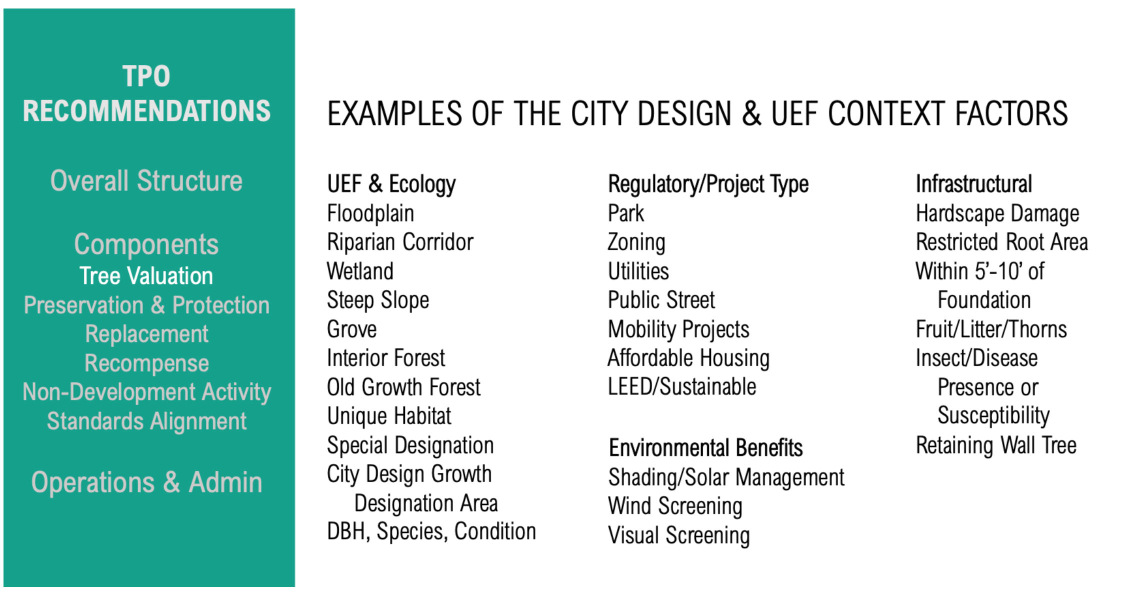

Figure 27: Examples of Context Factors Proposed in Tree Protection Ordinance

[192] Ruch 2020.

reflecting broader policy objectives (see Figure 27).[193] The draft document is noncommittal on the question of development standards for tree replacement, acknowledging a number of possible policy approaches including “incentives for planting in areas that need trees” and varying requirements by zoning category.

These strategies could be synthesized in a way that emphasizes public health benefits and incentivizes additional planting while also holding property owners accountable for delivering results. The City could first set standards for each zoning categories, prioritizing planting in residential and “quality of life” (e.g., mixed-use) zones. Property owners would pay recompense fees into the Tree Trust Fund in instances where the proposed site plan would result in a net loss of canopy under the context-conditioned valuation formula. Following construction, however, owners who are able to hit benchmarks for tree canopy gains over ensuing years could receive annual payments from the Tree Trust Fund. The BeltLine could be instrumental in implementing this policy in one of two ways: its planning area geography could provide a proving ground for early adoption, incubating the policy in its fluid stages and insulating it from legal challenge in the process, as it has done for the city’s Inclusionary Zoning policy. Or, the City could apply this approach citywide but emphasize it to greatest effect within the BeltLine Planning Area, either through more stringent baseline requirements or more enticing incentives.

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[193] Figure source: Atlanta Department of City Planning, community meeting presentation, November 19, 2019

Successful examples of this performance-based model can be found everywhere from international climate finance (the Paris Climate Agreement endorses results-based payments to tropical forest countries for avoided deforestation) to stormwater management (Philadelphia, Portland, Cleveland, and Washington, DC incentivize “green infrastructure” practices and reductions in impervious surface through credits that reduce landowners’ stormwater bills).[194] Because Atlanta, unlike these other cities, does not assess a stormwater utility fee, parcel-based payments for tree canopy enhancements could provide an alternative pathway through which to pursue similar goals.

These payments, at least initially, would likely be very modest due to the absence of a well-capitalized funding source (like a stormwater utility fee) and uncertainty around the scale of revenue the City’s Tree Trust Fund will generate once the revamped TPO takes effect. The City and relevant nongovernmental partners could explore avenues for further scaling up funding for this type of payments for ecosystem services in the future, perhaps by issuing an environmental impact bond (EIB). (Atlanta made headlines within the conservation finance community in 2019 after closing a $14 million EIB to fund green infrastructure projects in the historically troubled Proctor Creek watershed.[195]) It is unclear whether direct payments to landowners would be feasible under this type of financing vehicle – or, for that matter, whether it would be more efficient to simply expand green infrastructure practices on publicly owned land.

[194] Valderrama and Levine, 2012, 28.
[195] Lewis 2019.

6.4 Final Thoughts

This project started with a breathlessly ambitious, interdisciplinary scope that the author hoped might generate revelatory discoveries about the Atlanta BeltLine's performance as a tool for sustainability and resilience, as well as findings applicable to other sustainable redevelopment projects. Humbled by the enormity of that task, it evolved into something more modest: an analysis of two valuable lenses through which to approach these concepts: tree canopy and land cover, and urban form – and an attempt to draw meaningful connections between their findings and interrogate their underlying methods and assumptions. In spite of its imperfections, the author sincerely hopes that future scholars in planning and other disciplines may draw some utility from its successes and failures. More immediately, he hopes that the technical and policy recommendations advanced in this chapter resonate with decisionmakers in Atlanta and elsewhere, and with the planners and researchers whose expertise informs policymaking.

For students of planning and urban design, the author's best advice is this: approach these subjects with humility, self-reflection, and a commitment to justice. This is especially true for planning in the present era, a daunting backdrop of scarcity politics and its insidious implications,[196] inescapable neoliberal austerity that privatizes gains and socializes losses, and distrust or total disengagement between working class communities and the technocratic professions. By persuasively articulating connections to material aspirations and anxieties that loom in the minds of everyday people, perhaps planners may find more

[196] For a timely treatment of the "new politics of scarcity," see Mehta, Huff, and Allouche (2019).

success in expanding popular constituencies capable of advancing the goals of urban climate resilience.

APPENDIX A. SELECTED FULL-SIZE FIGURES AND TABLES

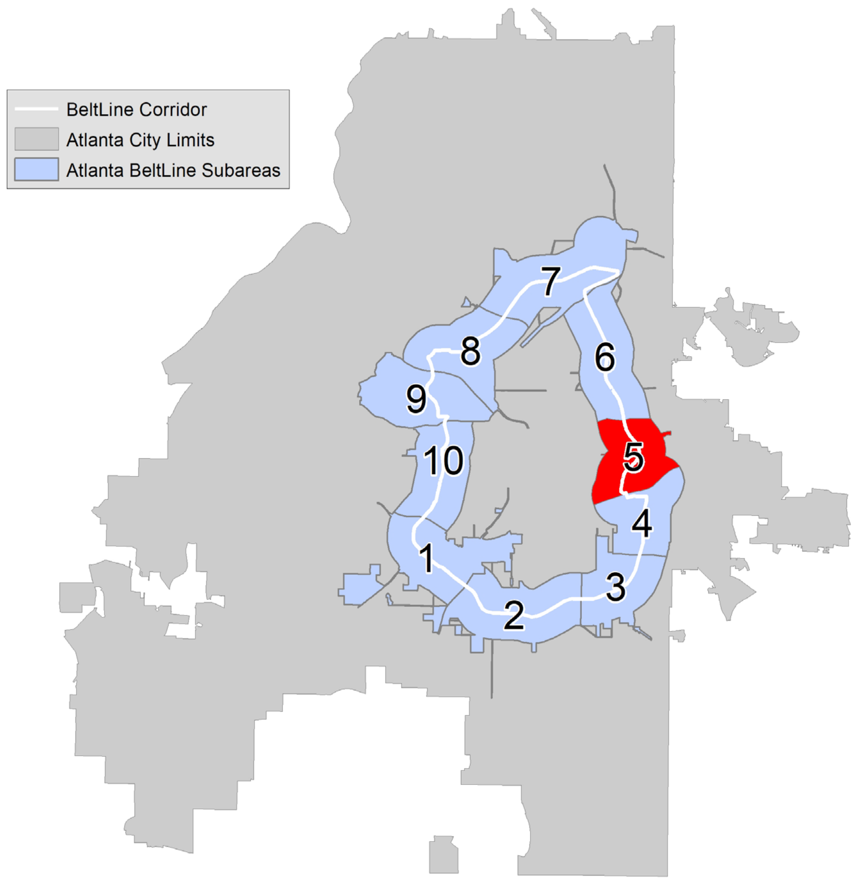


Figure 2: Atlanta BeltLine Subareas

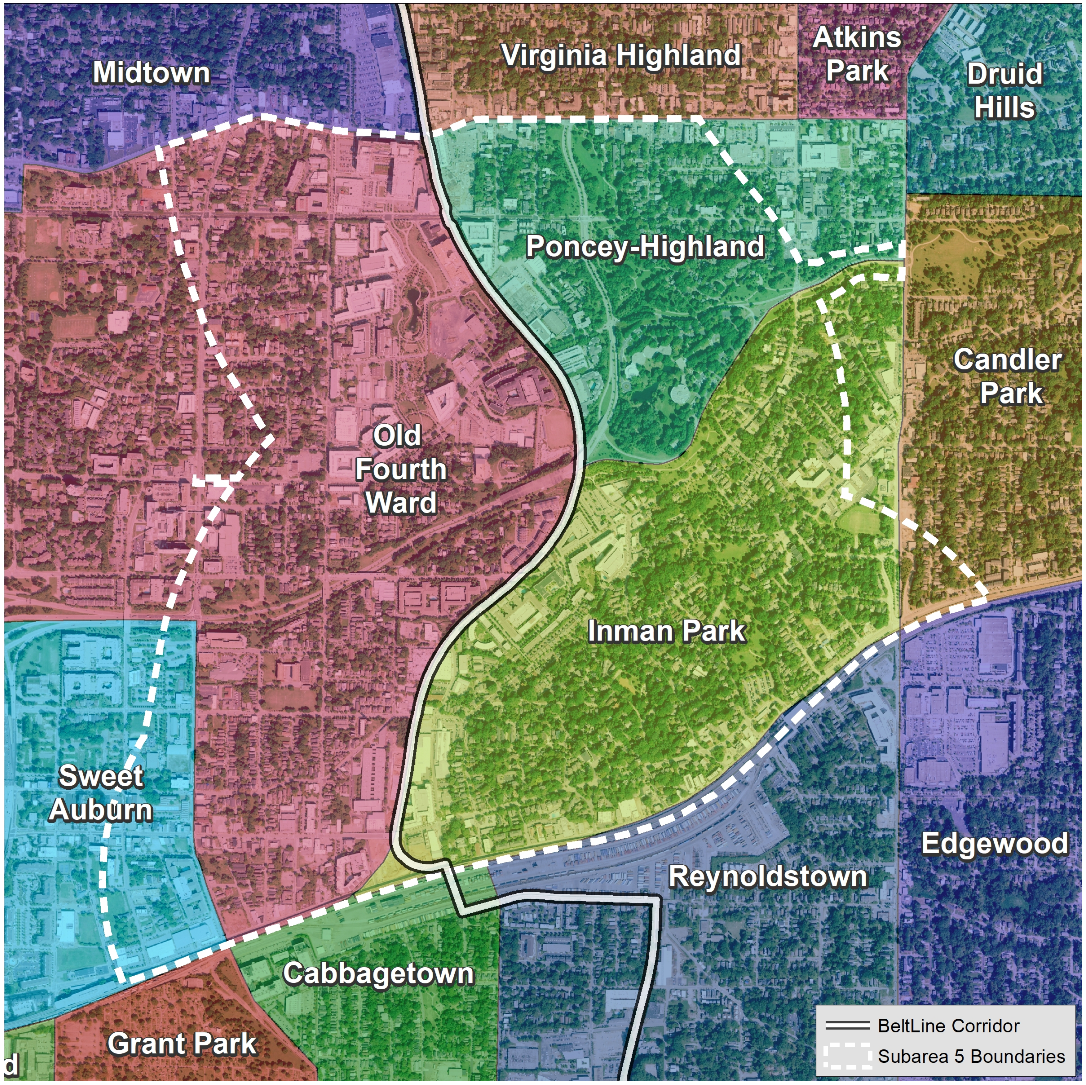


Figure 3: Subarea 5 and Adjacent Neighborhoods

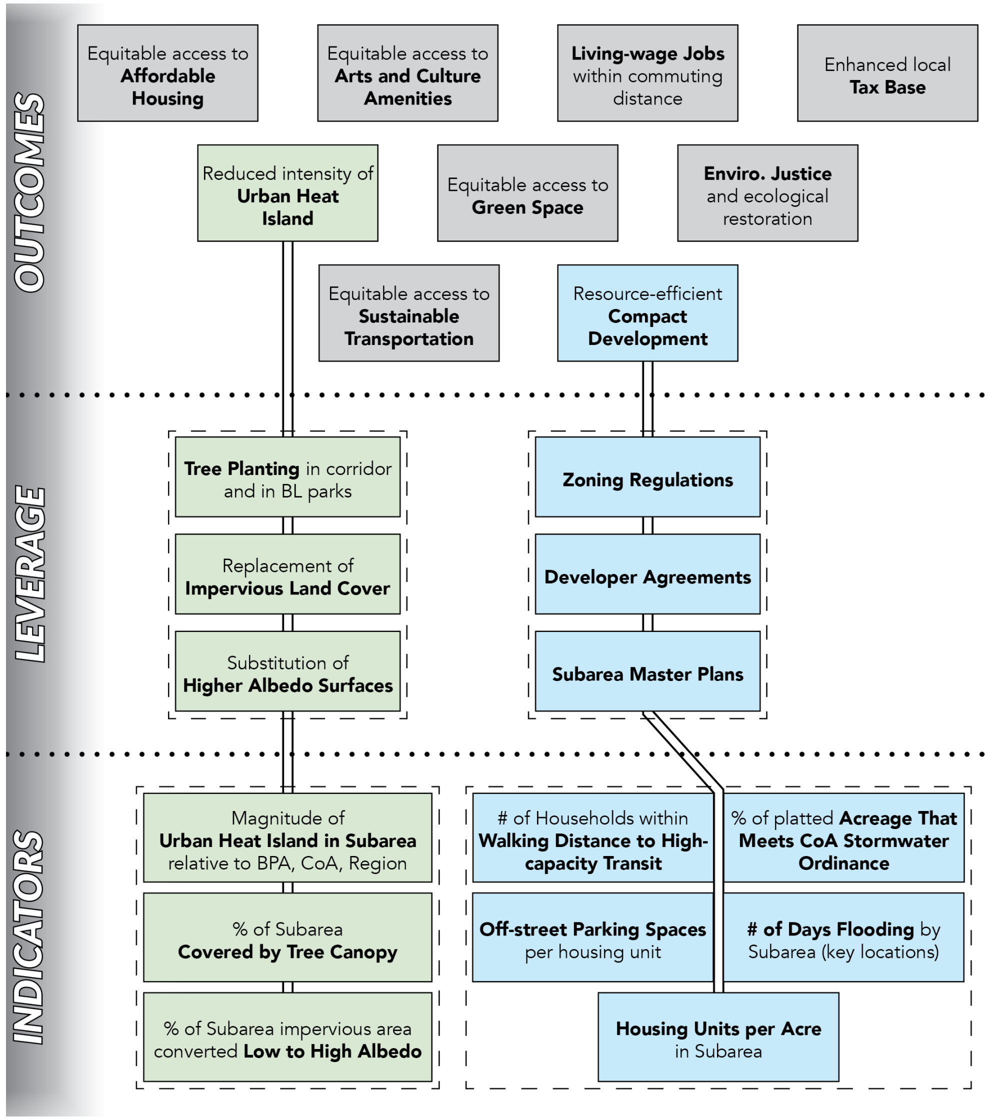


Figure 4: Beltline Resilience Indicators, Leverage Points, and Outcomes

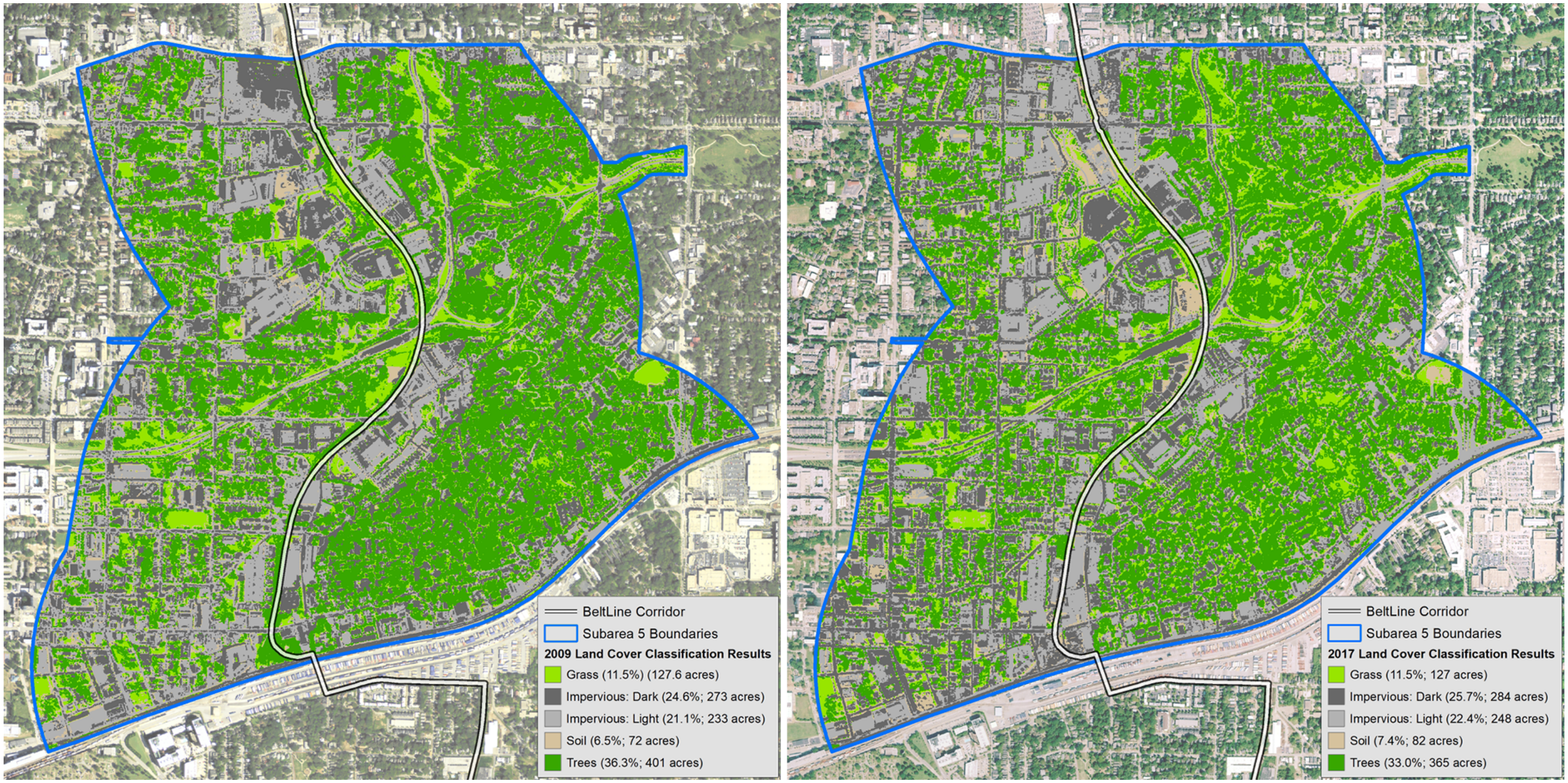


Figure 8: Land Cover Classification, 2009 vs. 2017

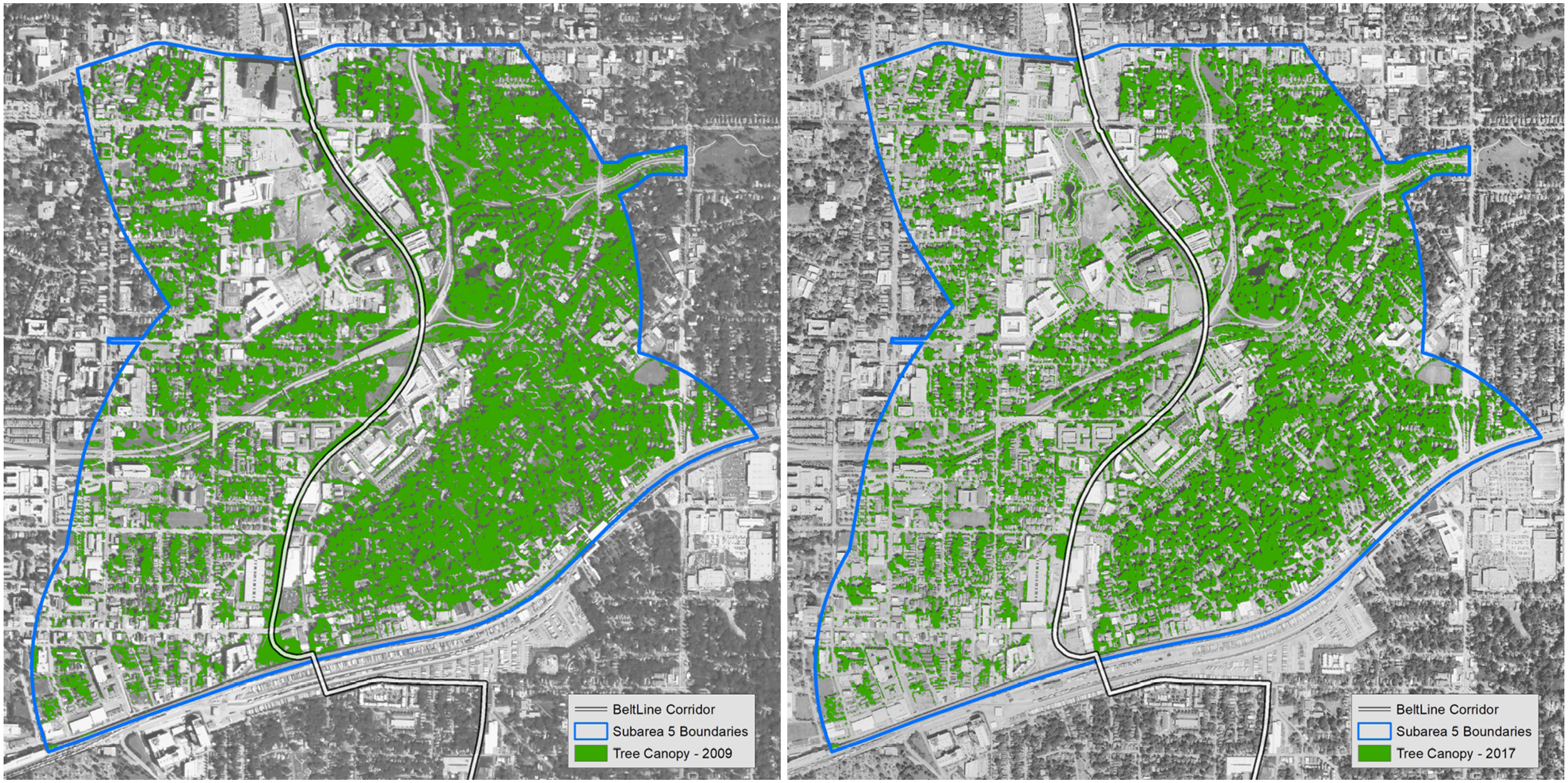


Figure 9: Extracted Tree Canopy Cover, 2009 vs. 2017

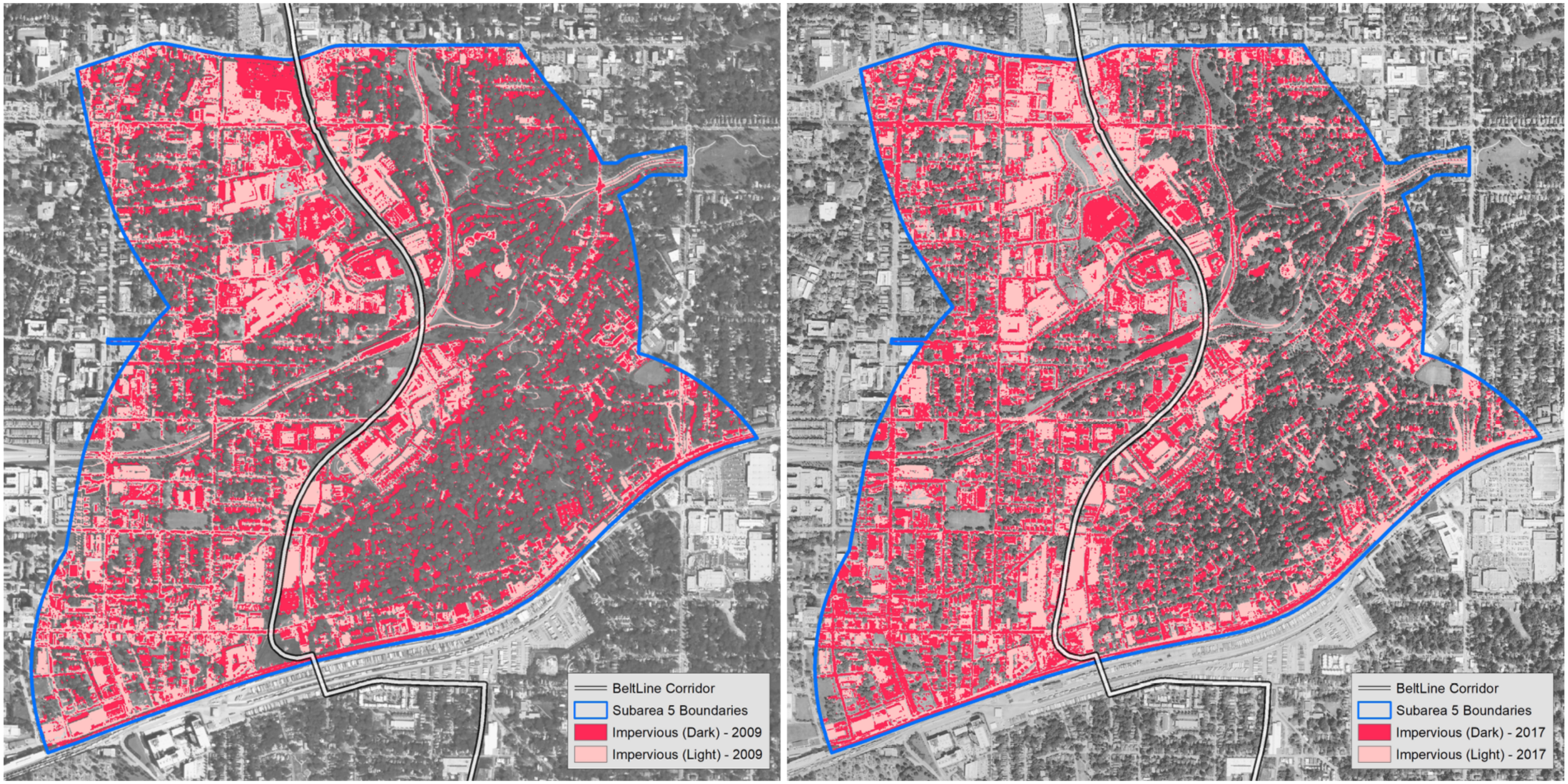


Figure 10: Extracted Impervious Land Cover, 2009 vs. 2017

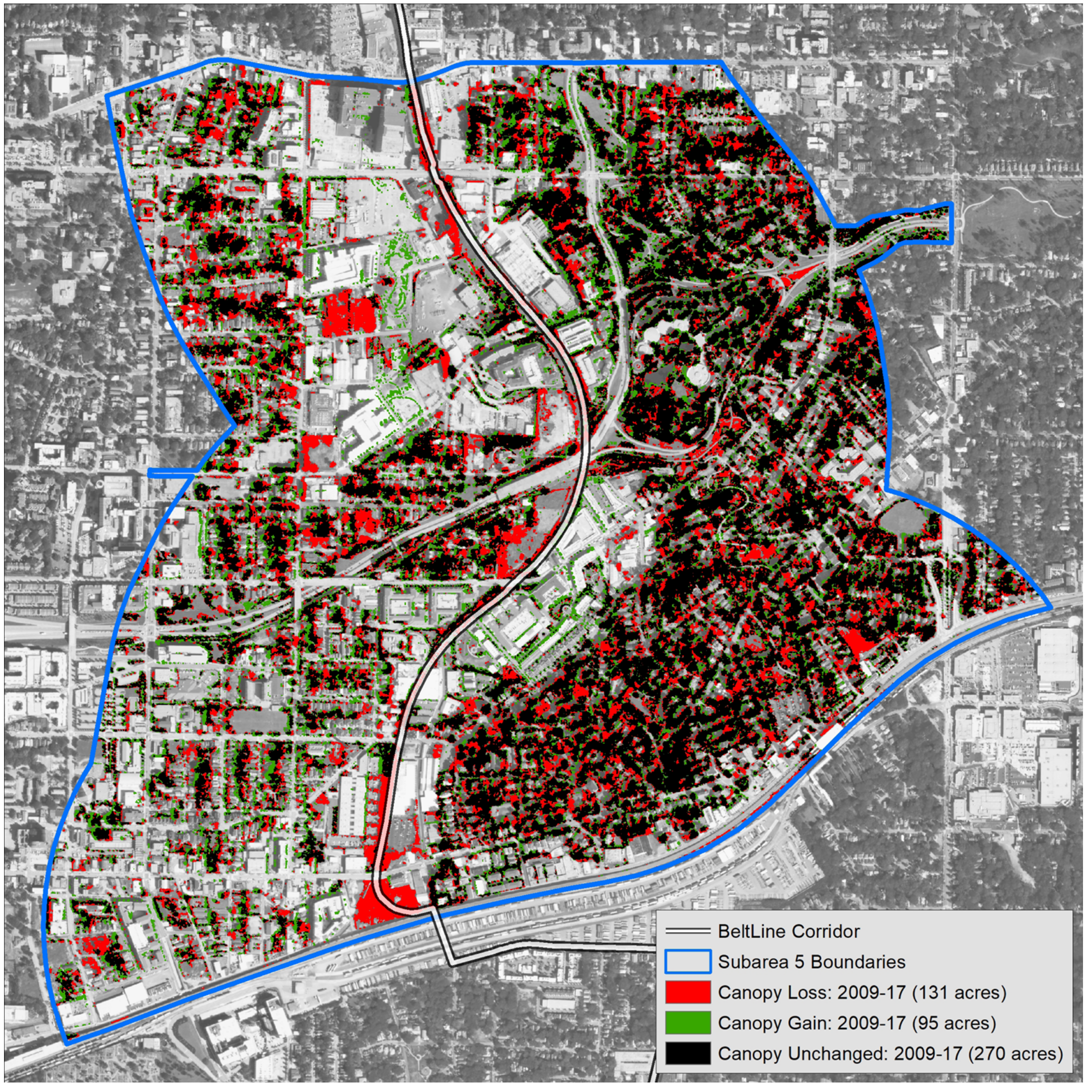


Figure 11: Tree Canopy Cover Change, 2009 to 2017

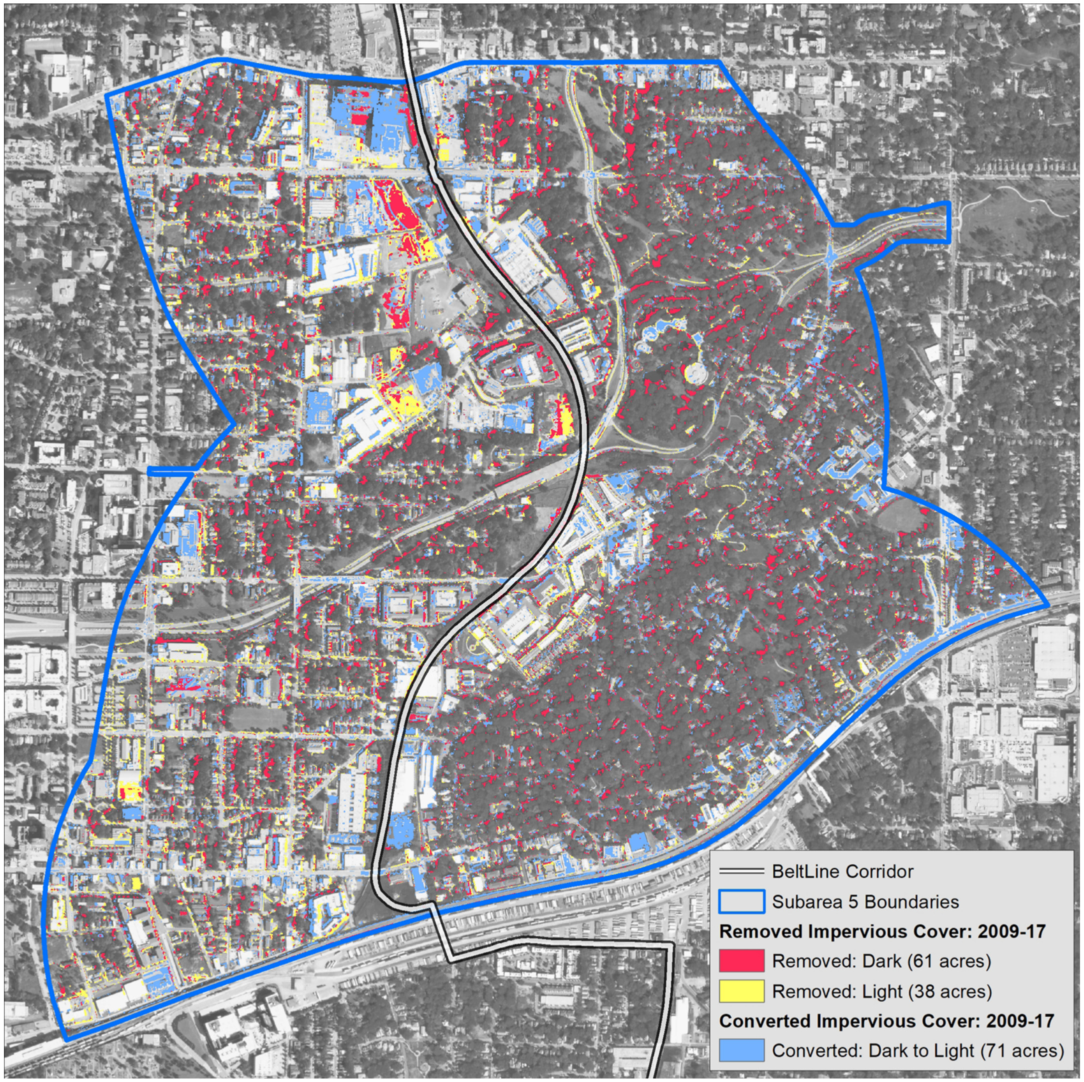


Figure 12: Removed and Converted Impervious Surface, 2009 to 2017

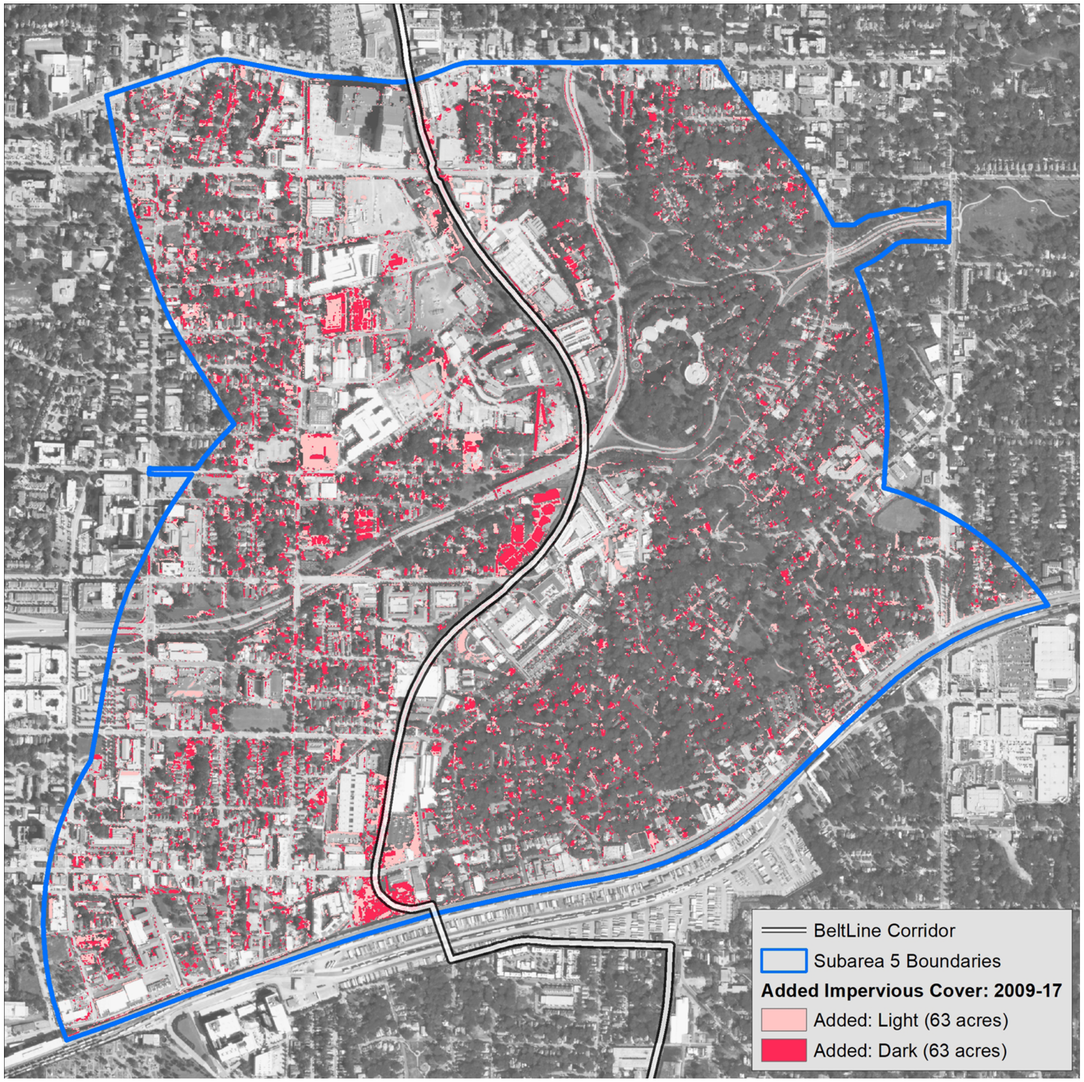


Figure 13: Added Impervious Surface, 2009 to 2017

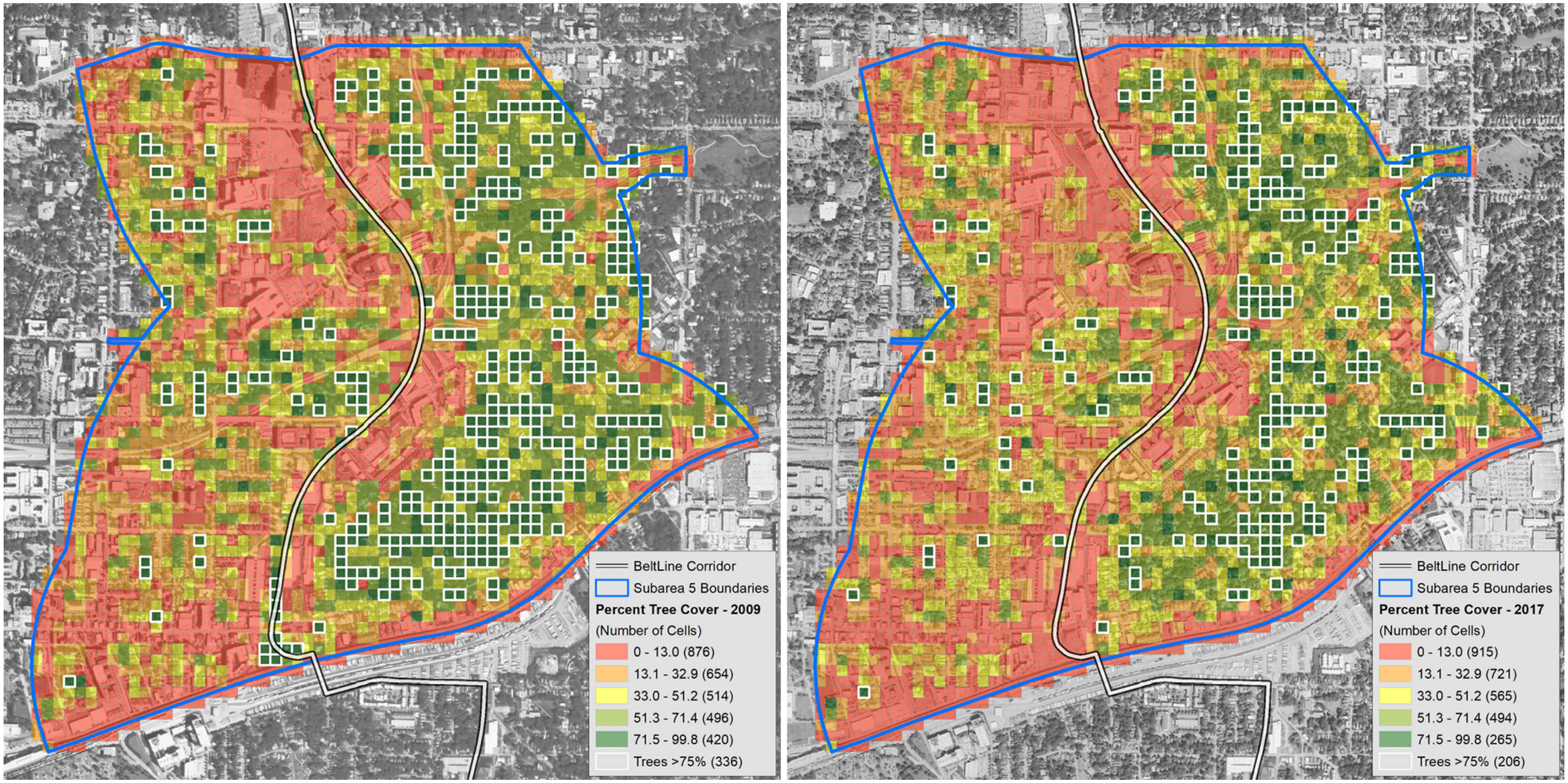


Figure 14: 40-by-40-m Cells by Percent Tree Canopy Coverage, 2009 vs.

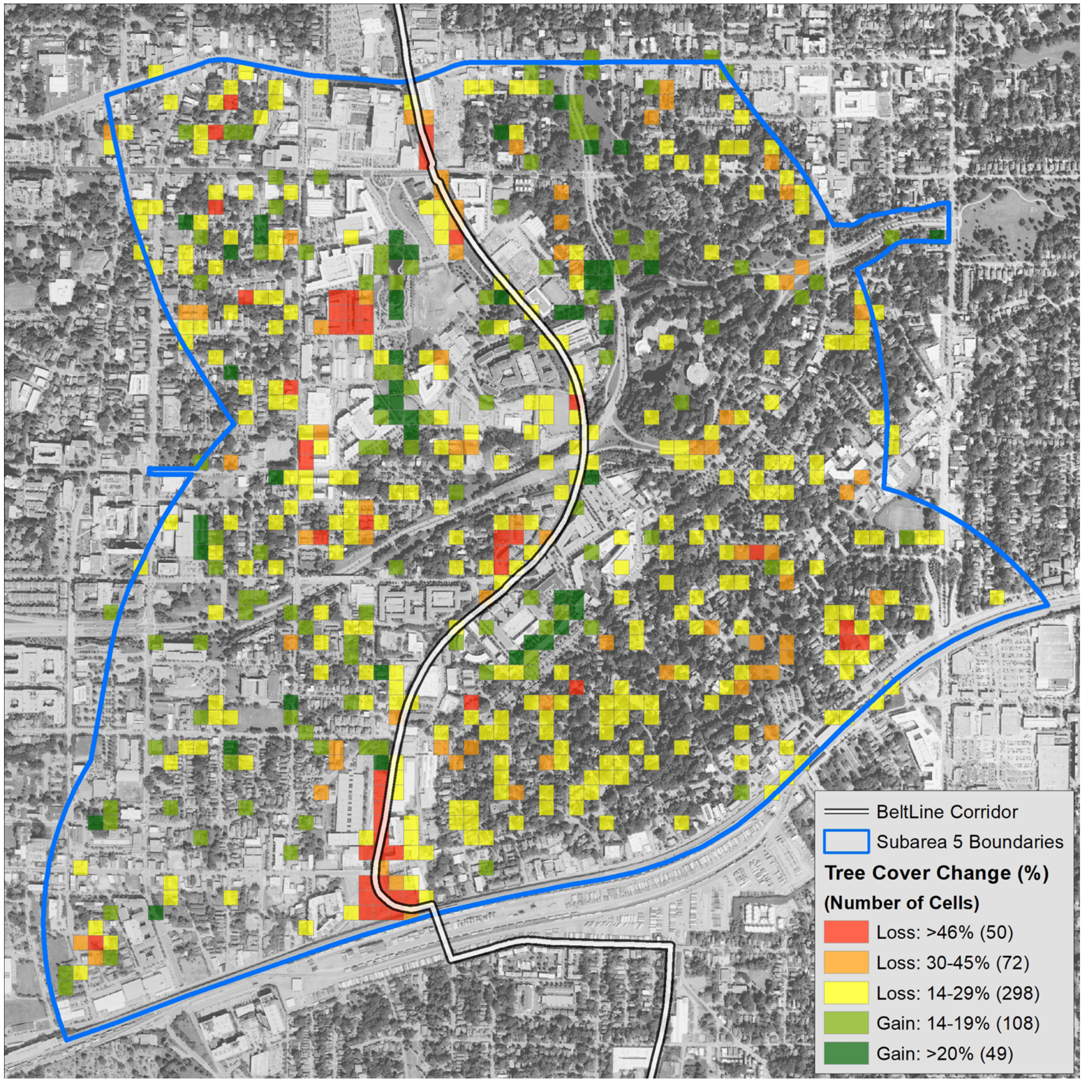


Figure 15: 40-by-40m Cells by Percent Change Tree Canopy, 2009 to

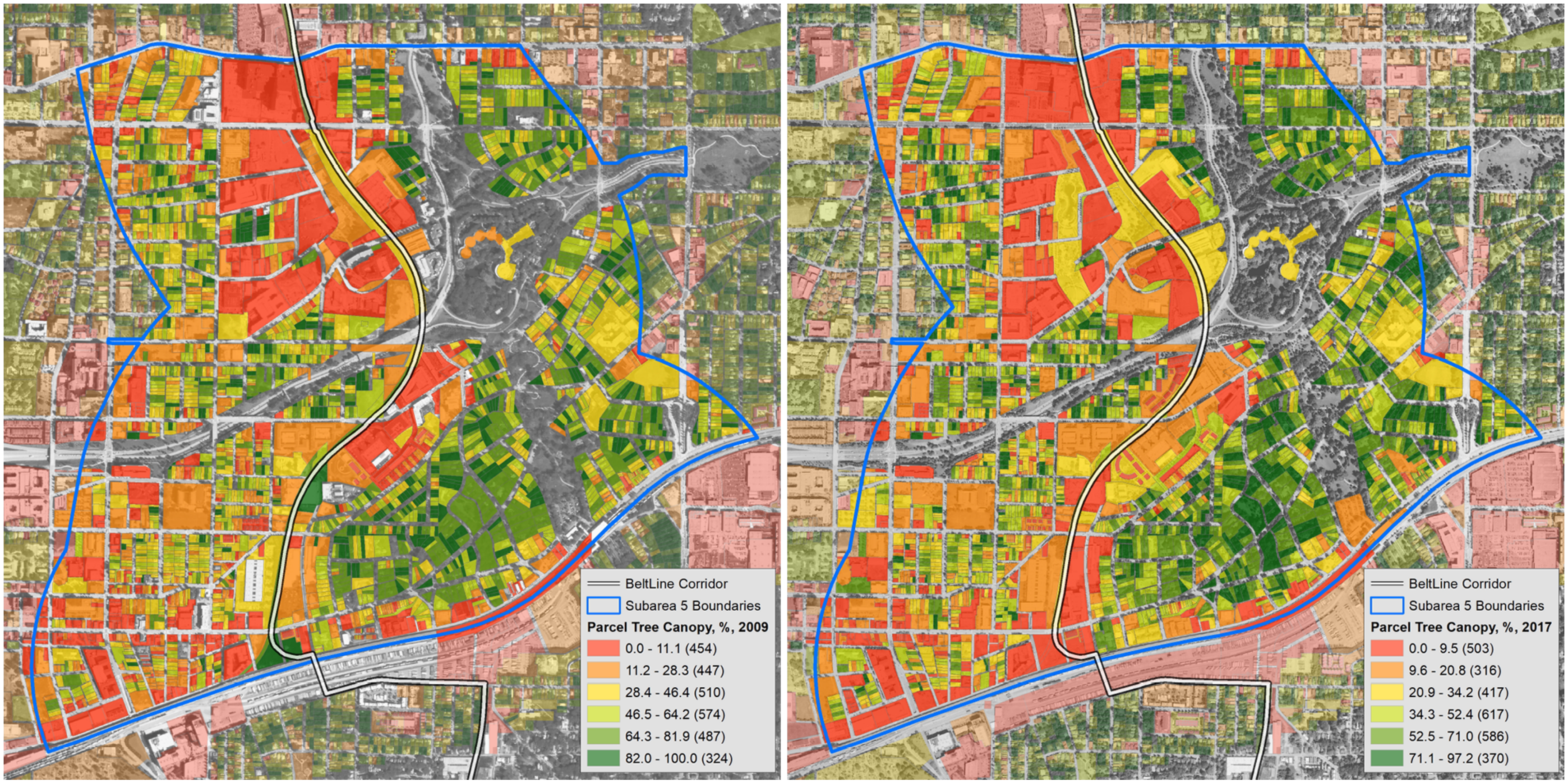


Figure 16: Parcels by Percent Tree Canopy Coverage, 2009 vs. 2017

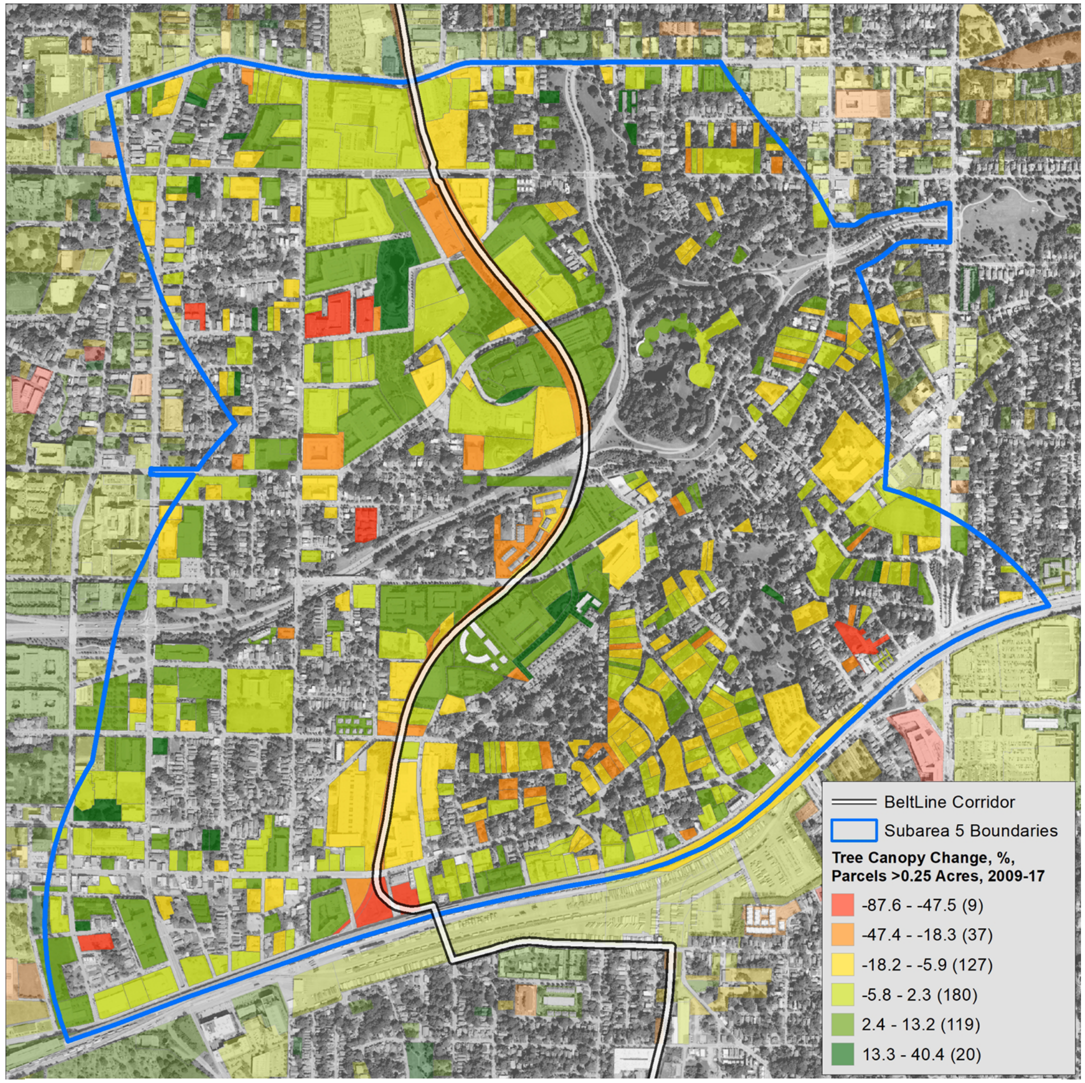


Figure 17: Parcels ≥ 0.25 Acres by Percent Change Tree Canopy, 2009 to

Table 4: Composition of Key Land Cover Types by Zoning Category, 2017

Highlight Table

Zoning Classifications	Acres	Tree Canopy 2017	Impervious (Light) 2017	Impervious (Dark) 2017
Two-Family Residential	309.6	48.8%	12.7%	21.2%
Multifamily Residential	186.8	37.5%	19.4%	20.5%
Quality of Life / Mixed-Use	128.7	11.2%	39.7%	33.9%
Commercial	117.2	15.7%	35.1%	35.5%
Industrial	87.2	13.0%	32.0%	33.6%
Historic & Cultural	77.9	21.4%	19.4%	40.2%
Planned Development	62.9	23.5%	34.0%	26.0%
Special Public Interest	62.4	54.1%	6.4%	7.4%
Single-Family Residential	53.2	54.1%	10.2%	18.3%
Residential (Limited Commercial)	10.5	37.0%	26.1%	21.9%
Neighborhood Commercial	9.2	19.9%	34.0%	12.1%
Live-Work	1.1	17.0%	31.2%	25.1%

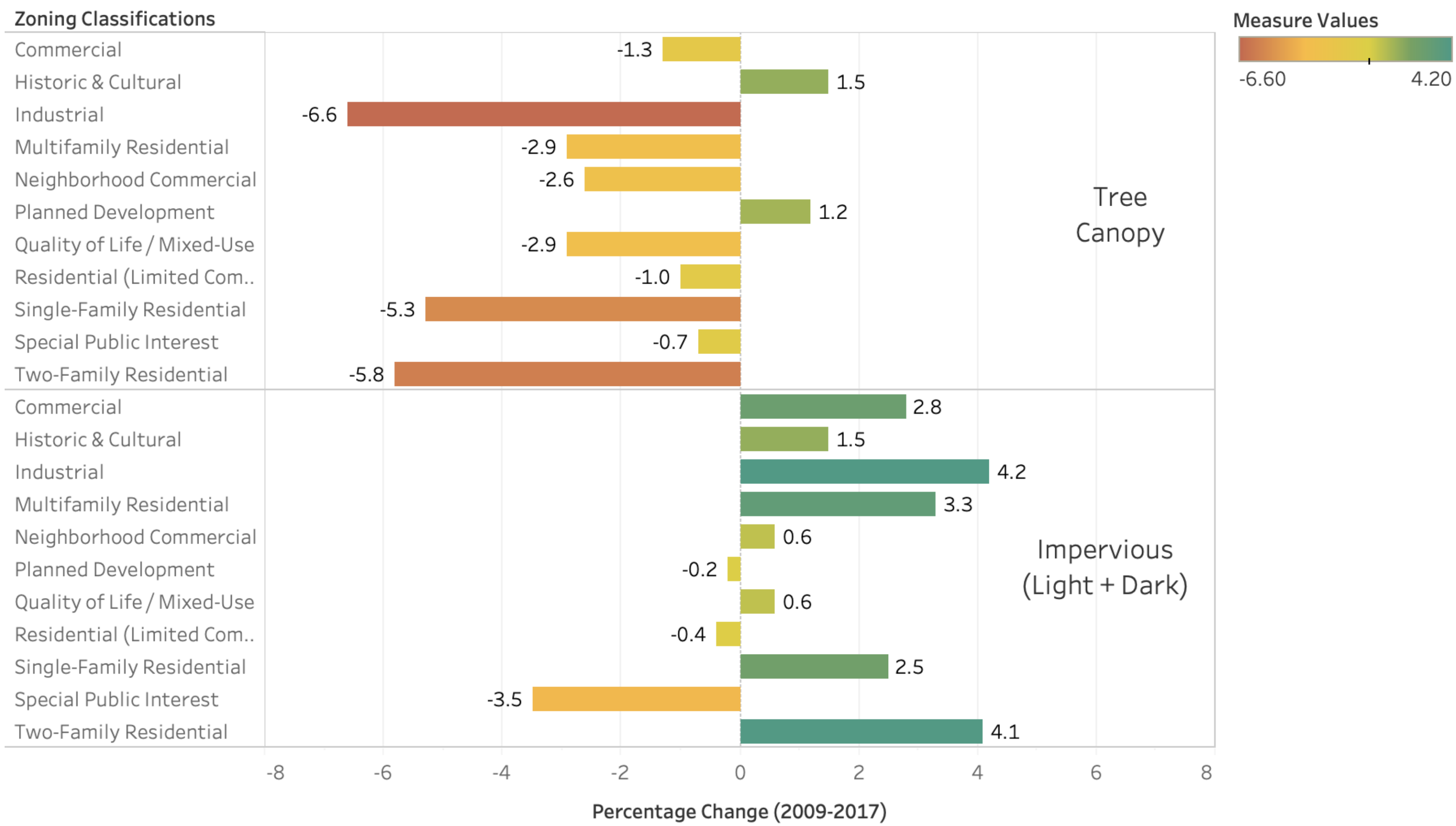
Tree Canopy 17
11.2% 54.1%

Impervious (Light) 17
6.4% 39.7%

Impervious (Dark) 17
7.4% 40.2%

Acres
1.1 309.6

Selected land cover percentages for 2017 for Tree Canopy, Impervious (Light), Impervious (Dark) broken down by Zoning Classifications (accompanied and sorted by class acreage).



Tree Canopy and SUM([Impervious (Dark)]+[Impervious (Light)]) for each Zoning Classifications. Color shows Tree Canopy and SUM([Impervious (Dark)]+[Impervious (Light)]). The view is filtered on Zoning Classifications, which has multiple members selected.

Figure 18: Land Cover Percent Change by Zoning Category, 2009-17

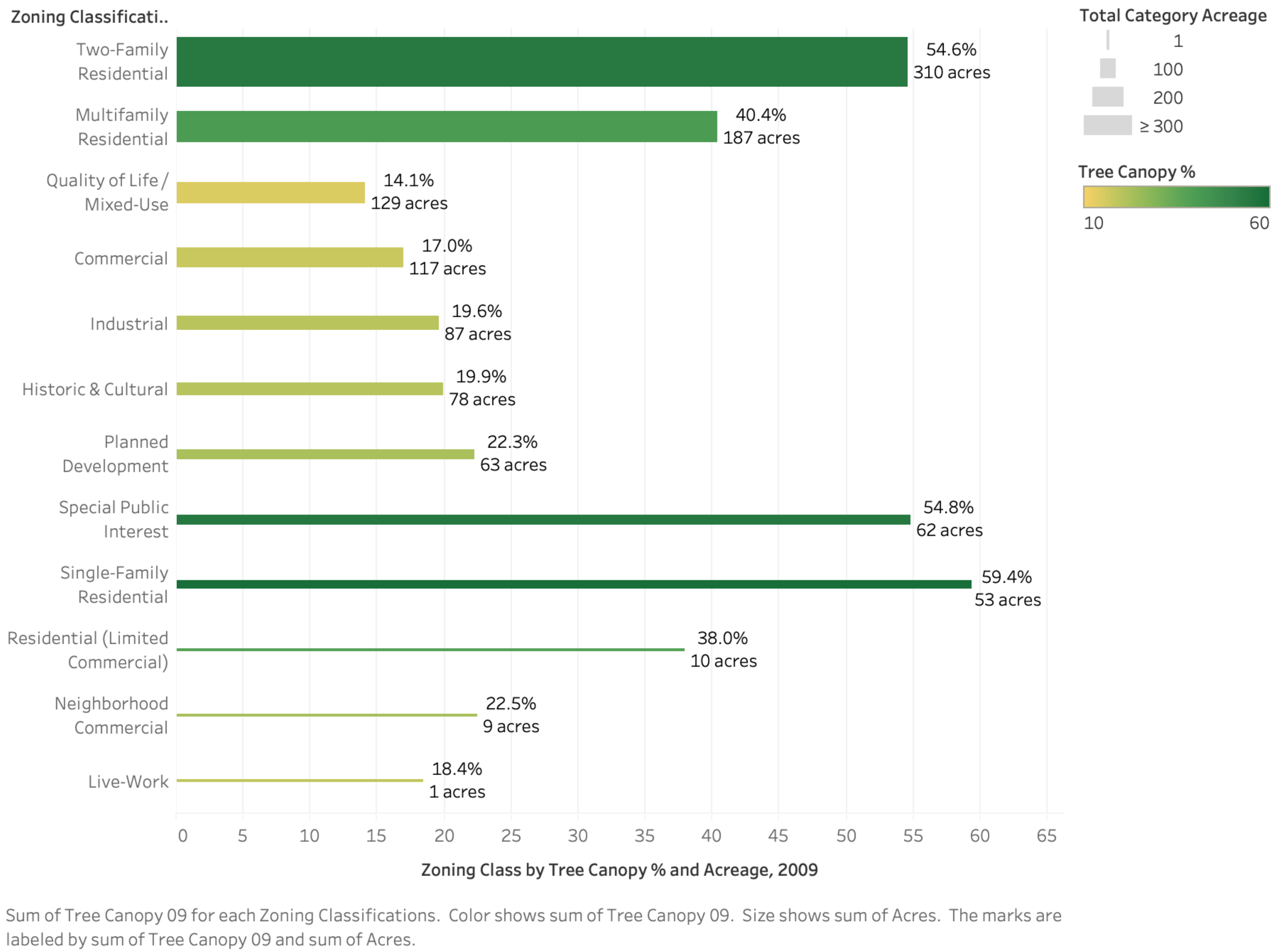


Figure 19: Zoning Category by Tree Canopy and Acreage, 2009 vs. 2017

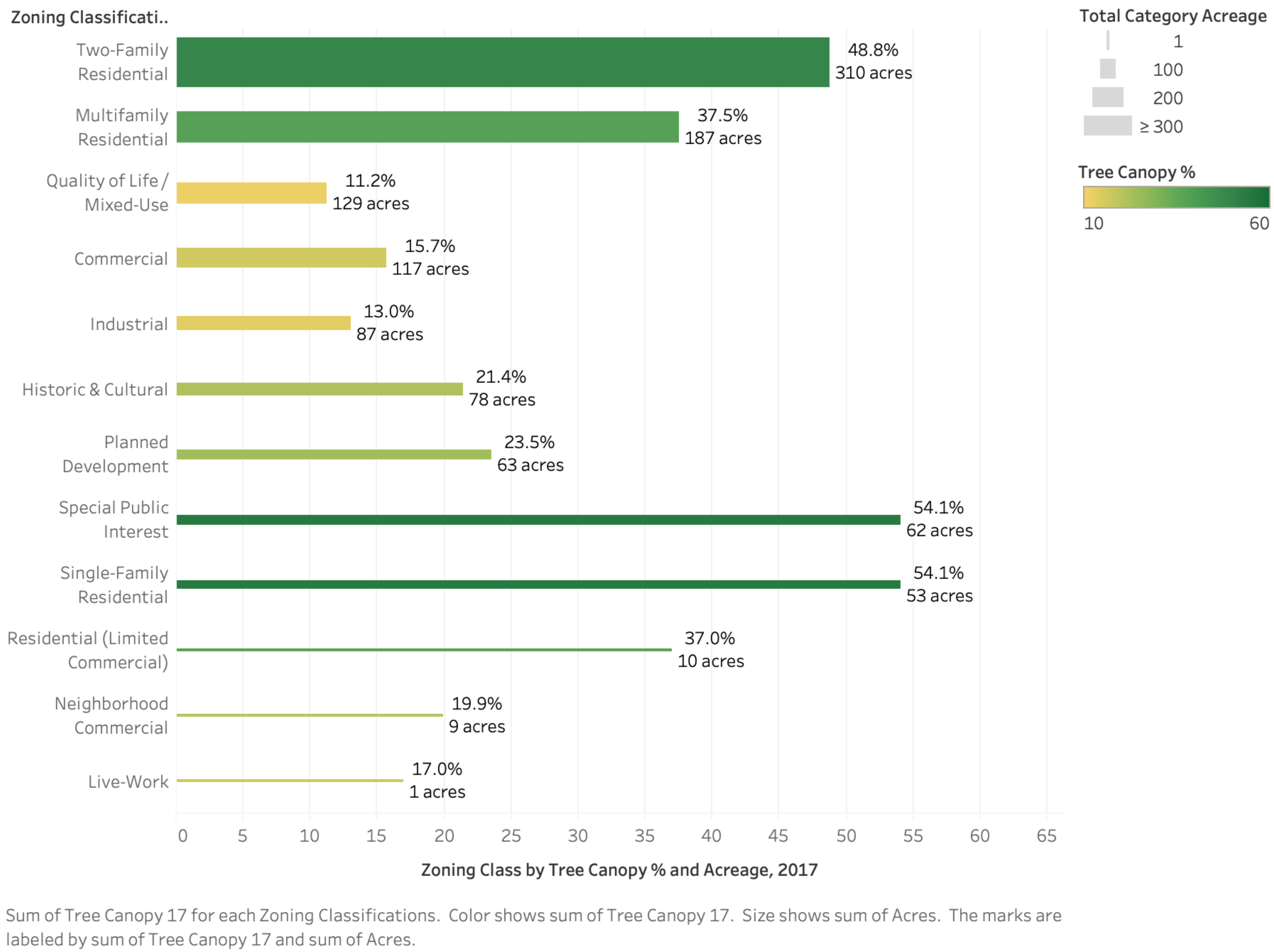


Figure 19: Zoning Category by Tree Canopy and Acreage, 2009 vs. 2017 (continued)

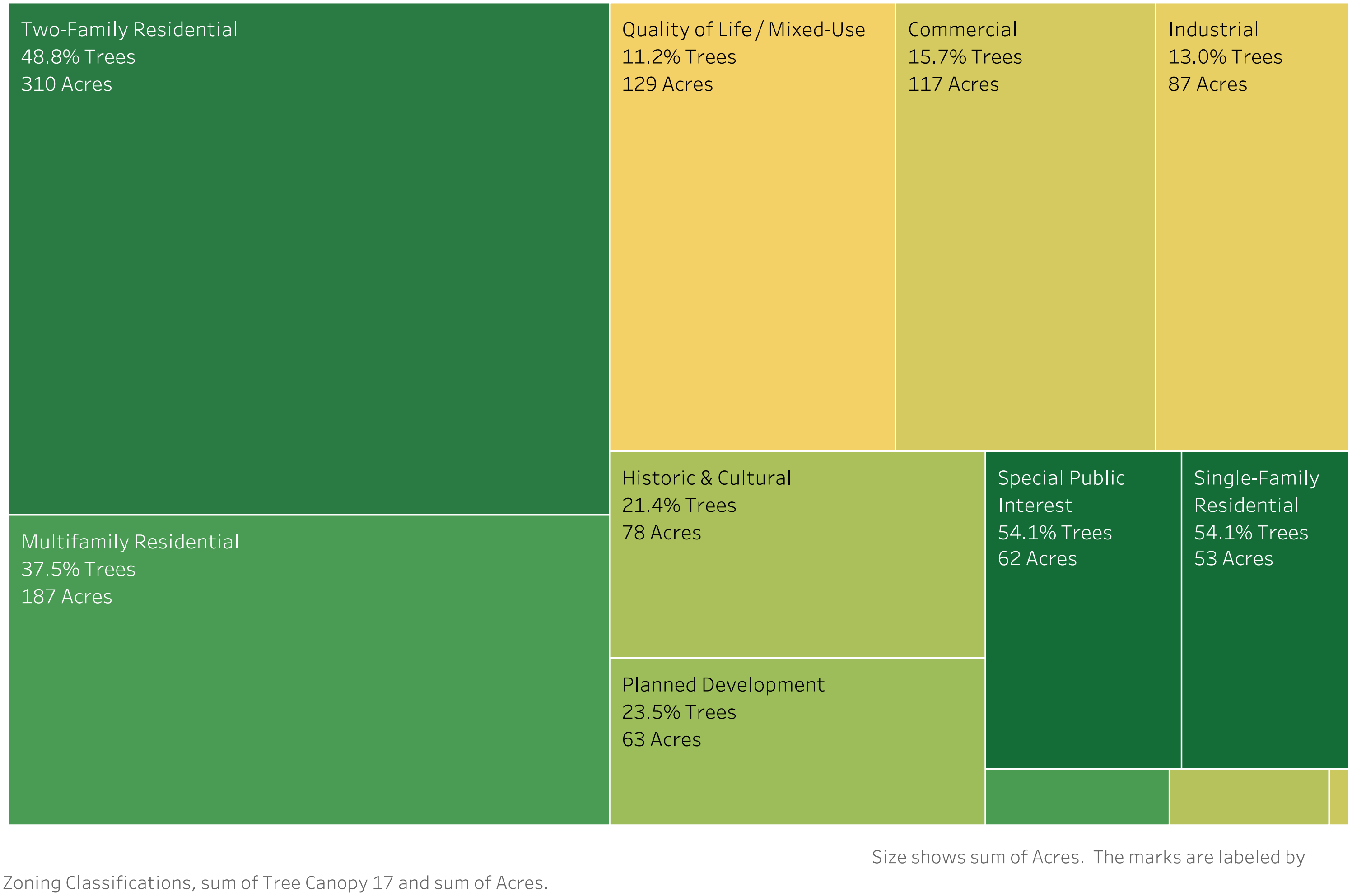


Figure 20: Zoning Categories by Percent Tree Canopy (Top), Combined Impervious Cover (Bottom), and Acreage, 2017

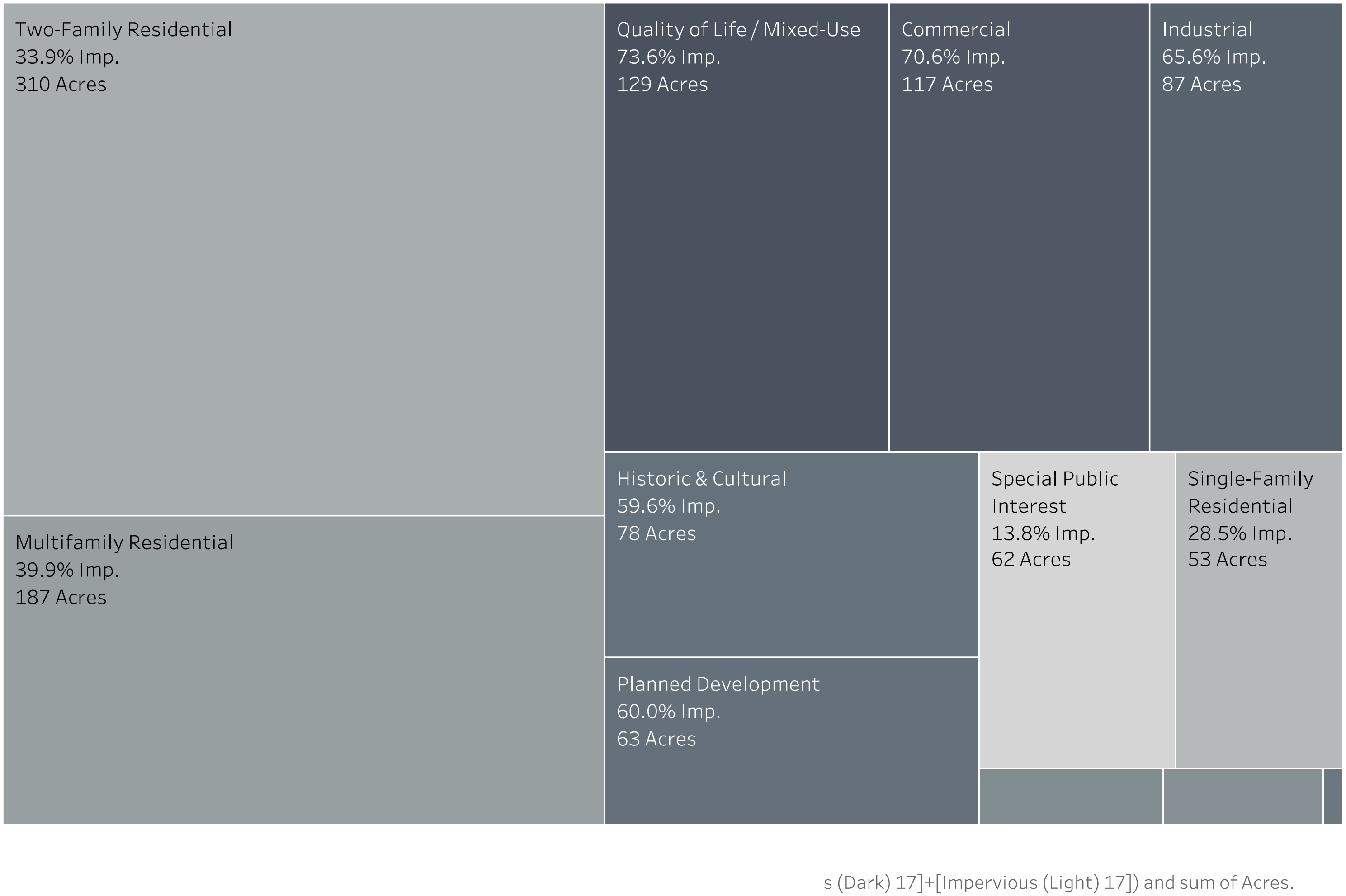


Figure 20: Zoning Categories by Percent Tree Canopy (Top),

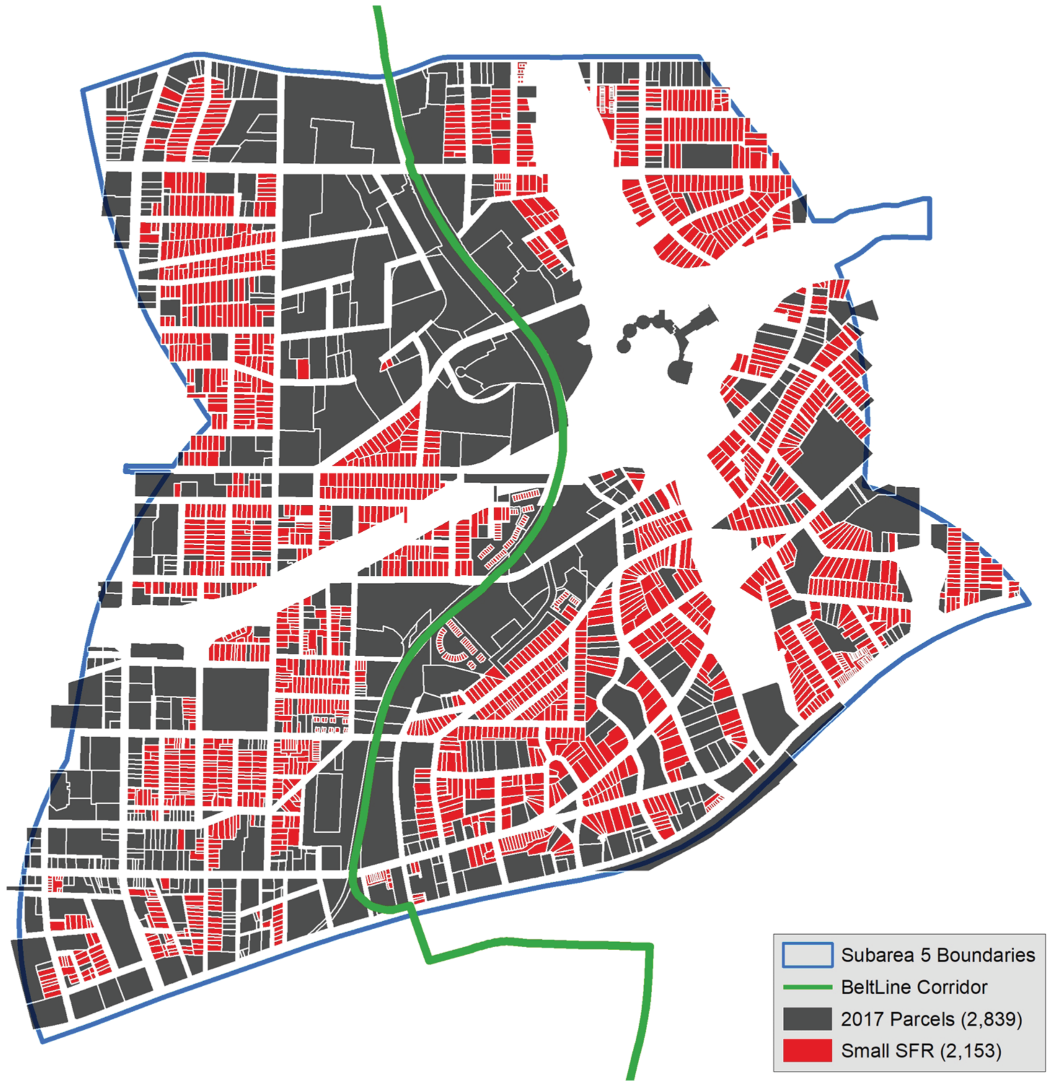


Figure 21: Excluded Parcels in Subarea 5, 2017, by Exclusion Criteria

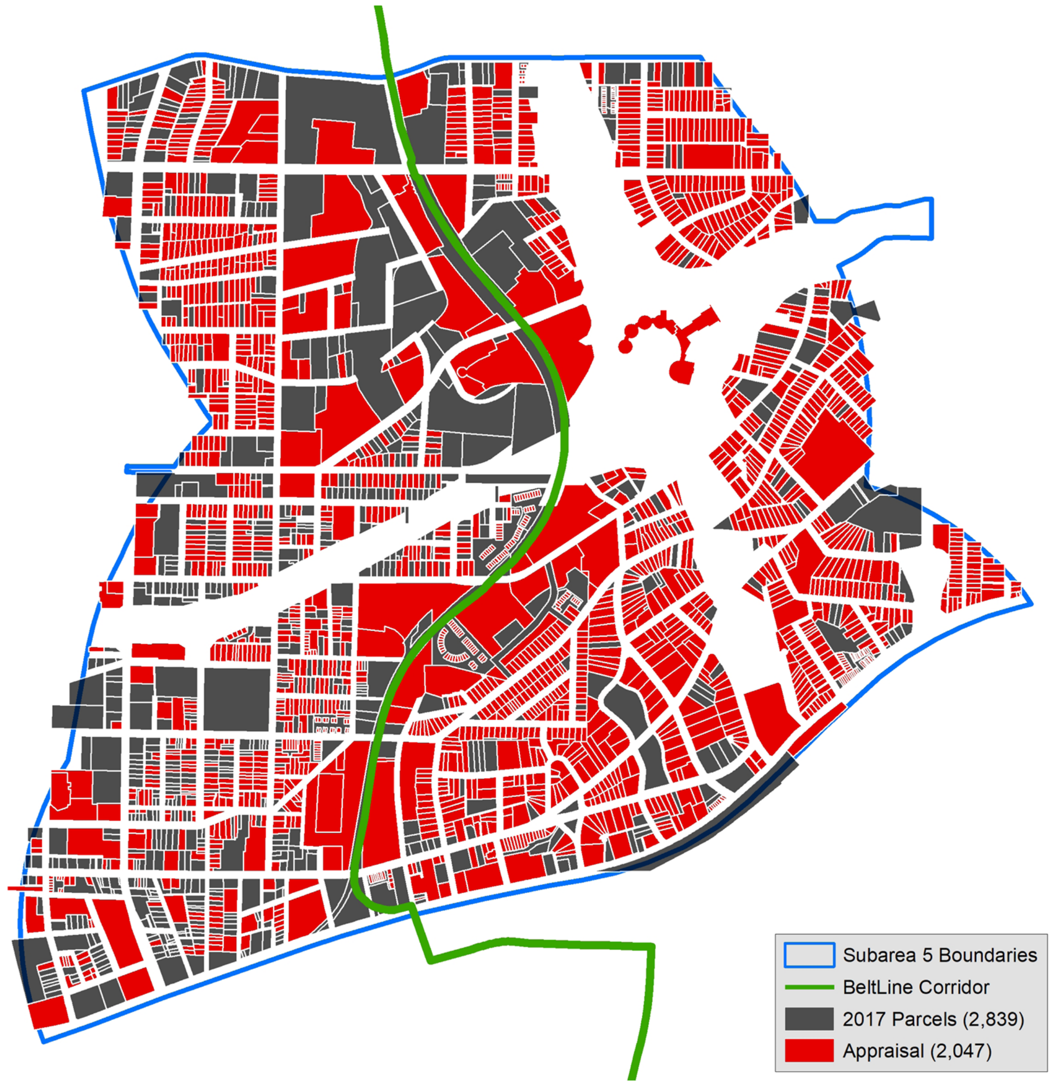


Figure 21: Excluded Parcels in Subarea 5, 2017, by Exclusion Criteria

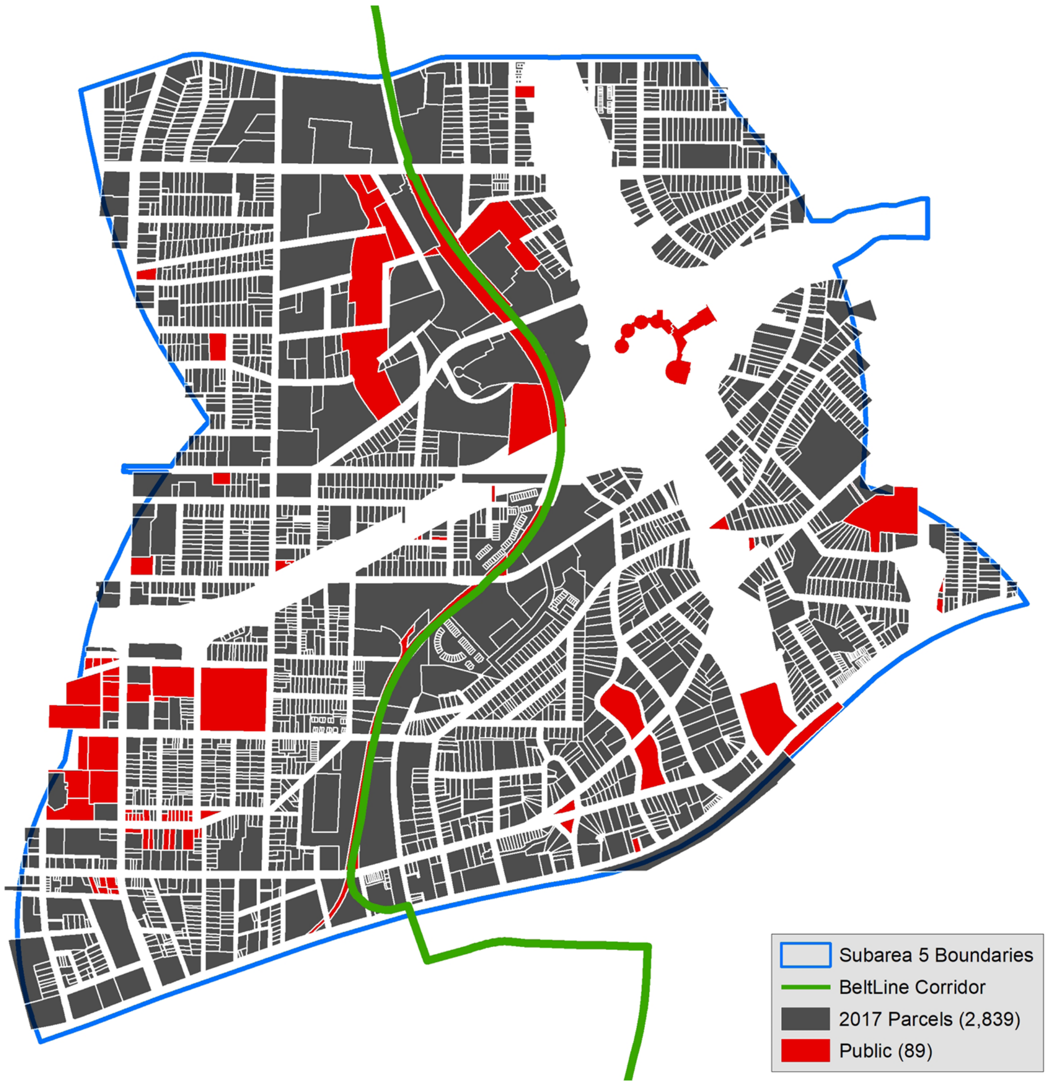


Figure 21: Excluded Parcels in Subarea 5, 2017, by Exclusion Criteria

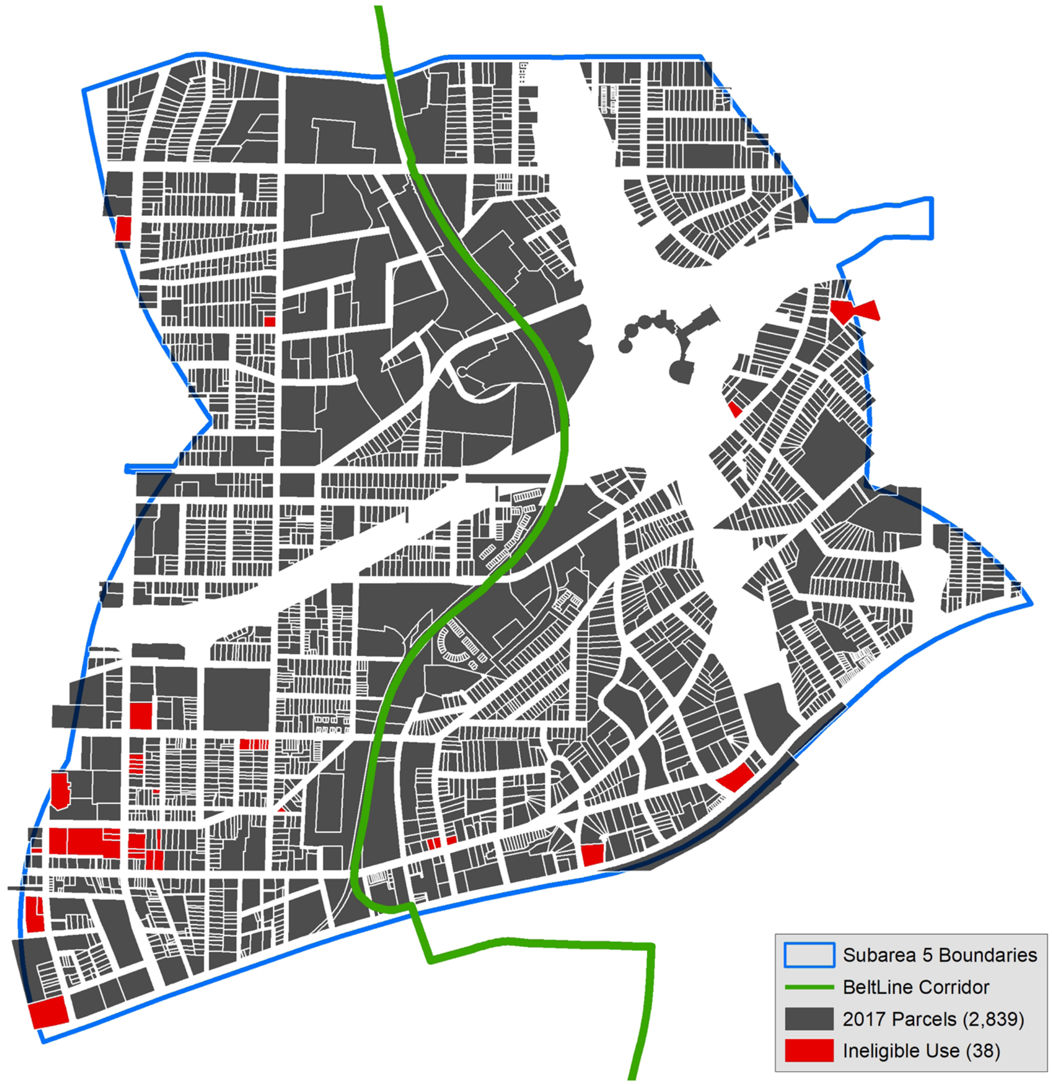


Figure 21: Excluded Parcels in Subarea 5, 2017, by Exclusion Criteria

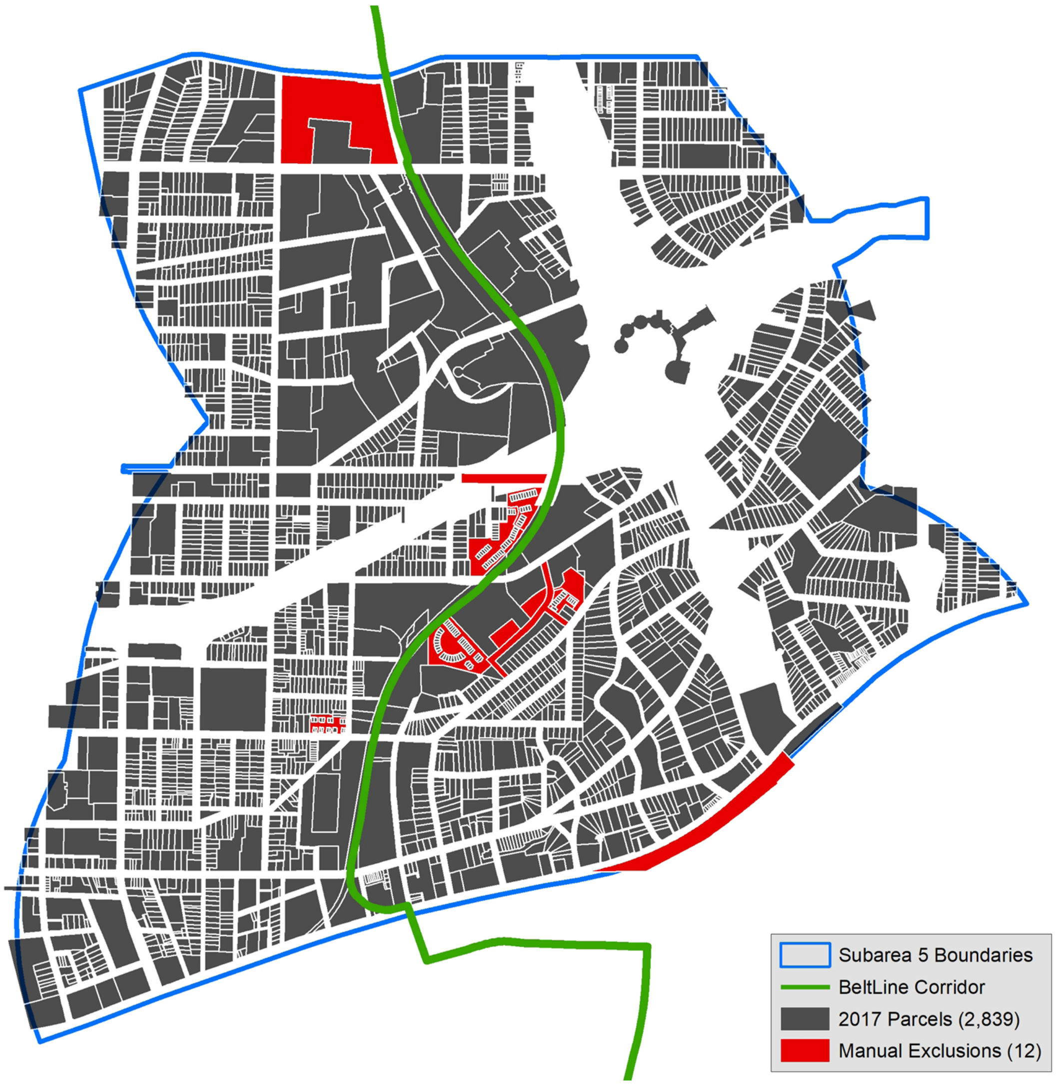


Figure 21: Excluded Parcels in Subarea 5, 2017, by Exclusion Criteria

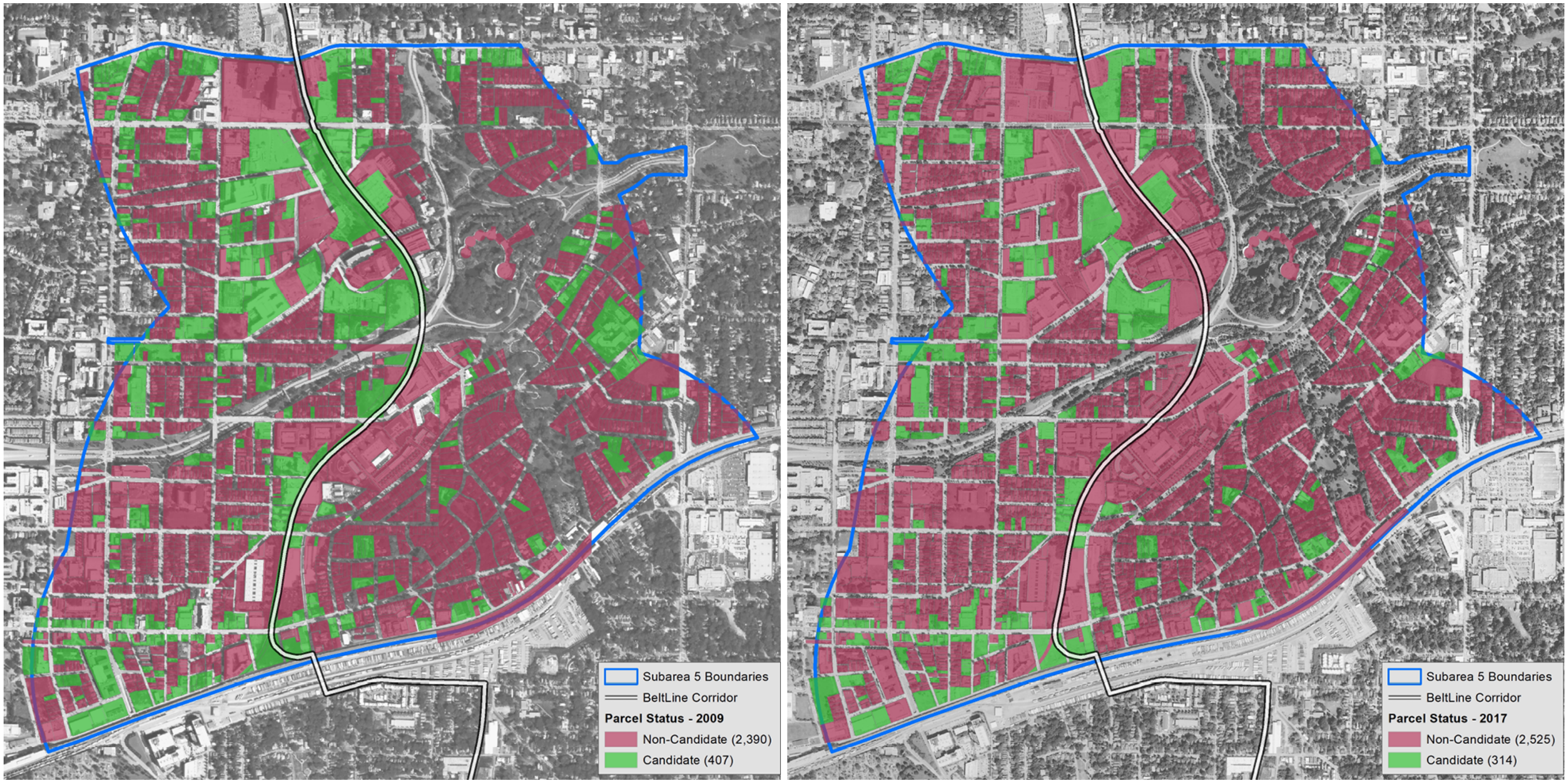


Figure 22: Subarea 5 Parcels by Candidate Status, 2009 vs. 2017

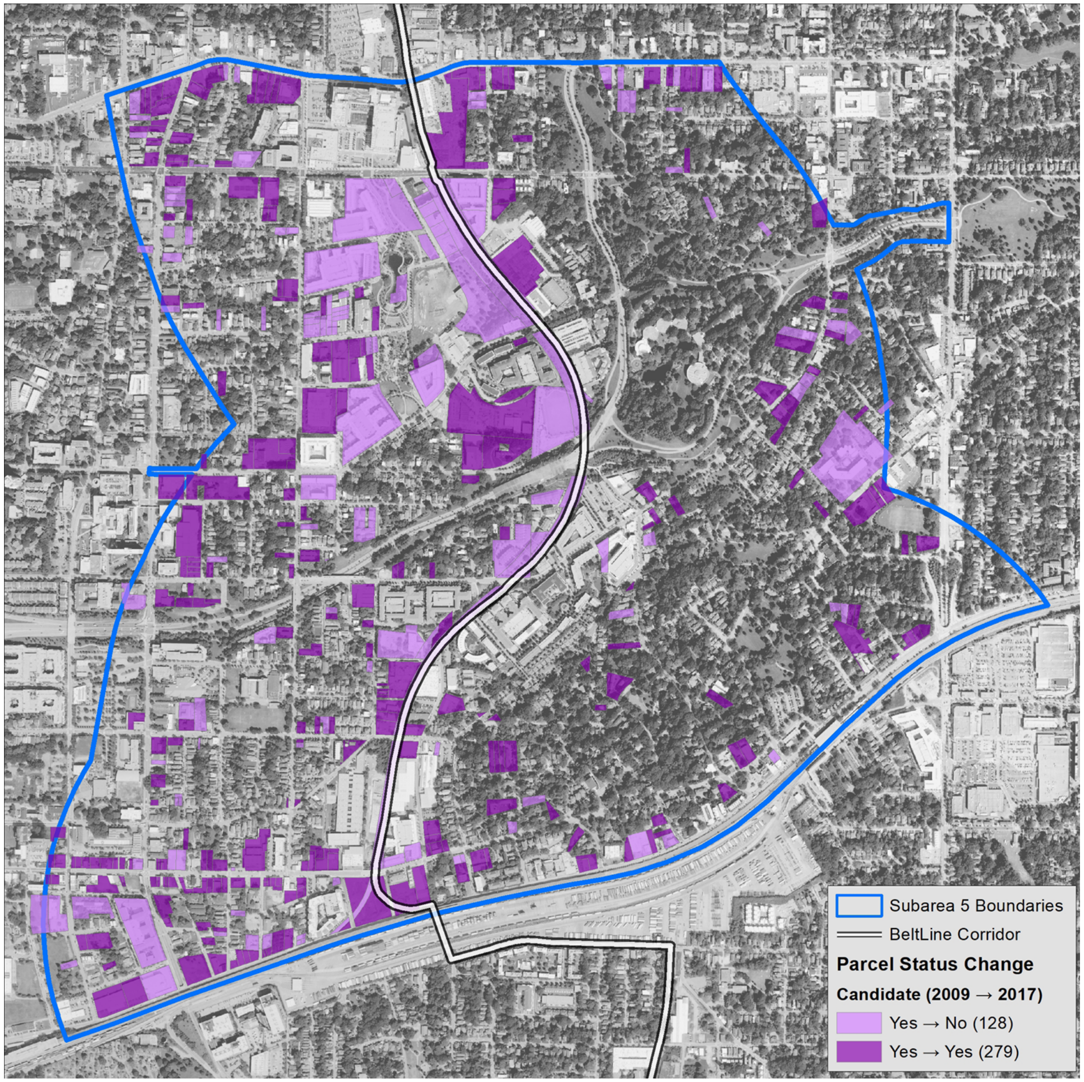


Figure 23: Status of 2009 Candidate Parcels in 2017

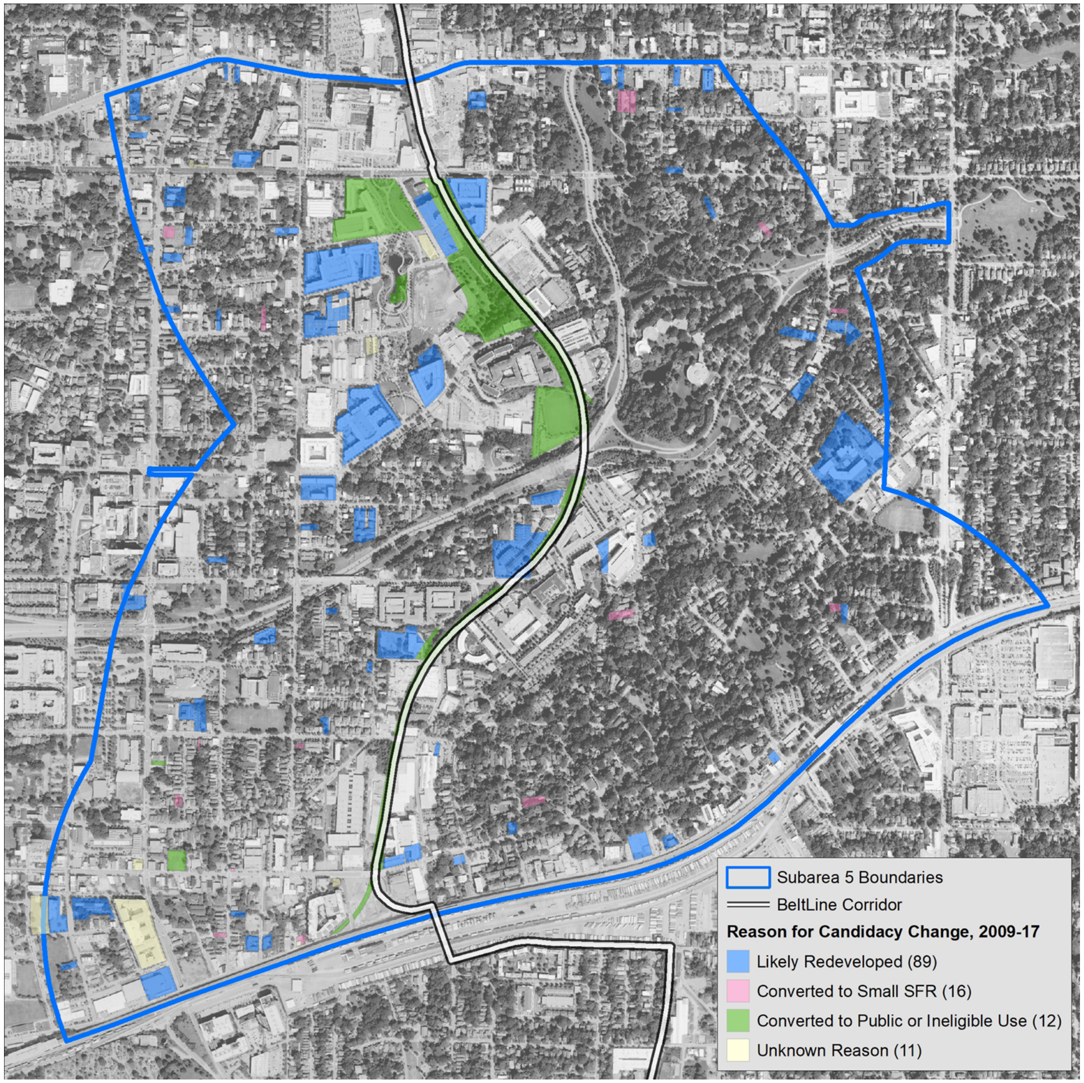
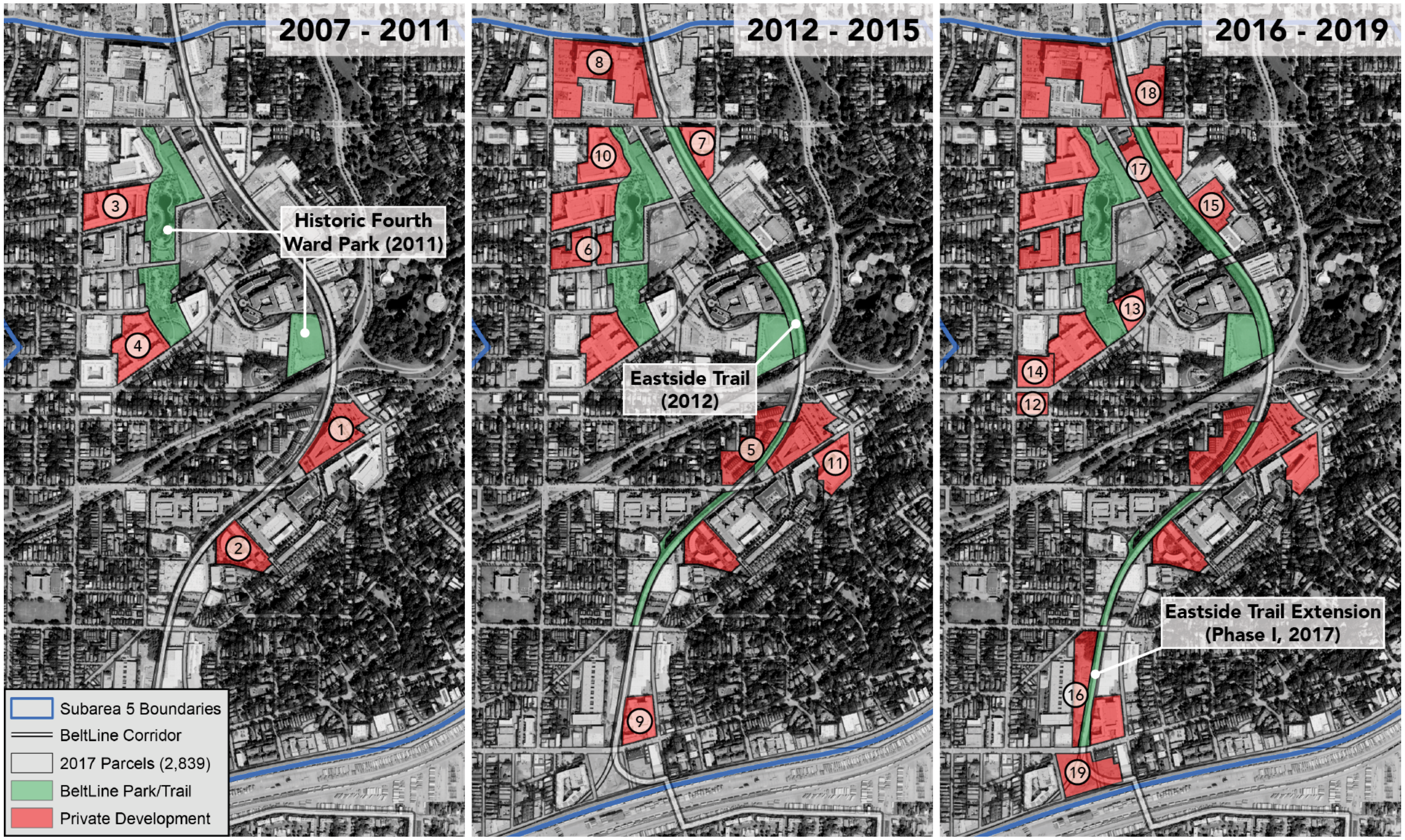


Figure 24: Reason for Parcel Status Change, 2009 to 2017



(1) North Highland Steel Apartments (2007)
(2) Inman Village Townhomes (2007-12)
(3) AMLI Old 4th Ward (2008)
(4) AMLI Parkside (2009)
(5) Highland Park Townhomes (2012-16)
(6) Camden Fourth Ward (2013)
(7) 755 North (2014)
(8) Flats at Ponce City Market (2014)
(9) Alexan on Krog (2015)
(10) AMLI 641 North (2015)
(11) Inman Quarter (2015)
(12) Glen Iris Townhomes (2016)
(13) Anthem on Ashley (2017)
(14) Windsor Old Fourth Ward (2017)
(15) Common Ground (2018)
(16) Studioplex Expansion (2018)
(17) North and Line (2018)
(18) 725 Ponce (2019)
(19) The Edge (2019)

Figure 25: Selected Developments and BeltLine Infrastructure, 2007-2019

APPENDIX B. METHODOLOGY: TREE CANOPY STUDY

ASSEMBLE NAIP DATASET

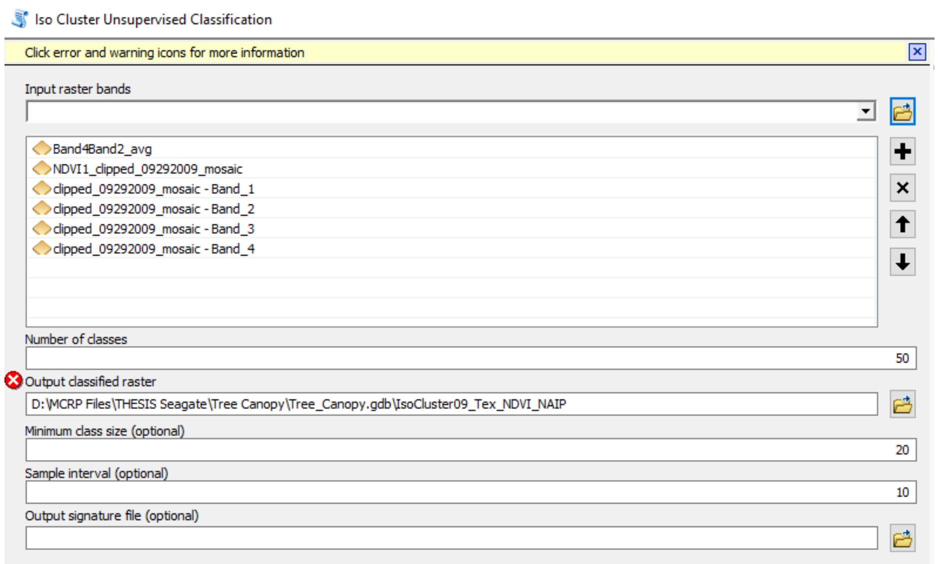
- Perform Mosaic to New Raster tool to combine all imagery into a single raster file (StatePlane Georgia West projection; 8 bit unsigned pixel type; 1m cell size; 4 bands; LAST mosaic operator (Default); FIRST colorband operator (Default))
- Then, clip resulting raster to the boundaries of the Atlanta City Limits vector
- Use the NAD_1983_2011_StatePlane_Georgia_West_FIPS_1002 (Meters) coordinate system

LAND COVER CLASSIFICATION

- Fortunately, all of Subarea 5 fits within a single NAIP image, so this analysis can use only one and obviate the risk of distorting spectral properties by blending mosaics.
- Project m_3308414_sw_16_1_20090929 to SA5_2009_8414_sw_16_1_20090929 and do the same for its 2017 counterpart.
- Clip each layer to the SA5_buffer_qtrmi feature class
- Starting with 2017, perform the following steps:
- To perform land cover classification, we employ the NAIP Color-IR Imagery methodology explained by Behee and simplified by Ziegler
    - Generate NDVI layer using Image Analysis window (with Band 1 as visible red and Band 4 as NIR; and with Scientific Output box not checked) and symbolize appropriately as a classified vegetation layer (with one class, HSV of 80-39-89)
        - Set threshold at 125 (excluding 0-124); this is more generous than Behee's analysis but appears to be the threshold at which grass is no longer identified as trees without compromising tree edges (similar dynamic range to Behee: stretched on an 8-bit 0-255 scale, the Atlanta results ranged from 12 to 199 with a mean of 117 and standard deviation of 25; Behee's ranged from 8 to 200 with a mean of 127 and S.D. of 50). Behee contends that 139 is the proper threshold for distinguishing between vegetation (values 140-255) and non-vegetation (0-139).
    - Perform texture analysis using Focal Statistics tool with 23ft-by-23ft (7m-by-7m) rectangular neighborhoods (RANGE statistics type; ignore NoData)

- Create Focal Range images for Band 4 (near-IR) and Band 2 (visual green); then, use Raster Calculator to average the two

- Iso Cluster Unsupervised Classification using the four bands provided for by NAIP (RGB and near-IR), the averaged raster from the texture analysis, and the NDVI layer using the default parameters (except for number of classes – 50, in keeping with Behee).



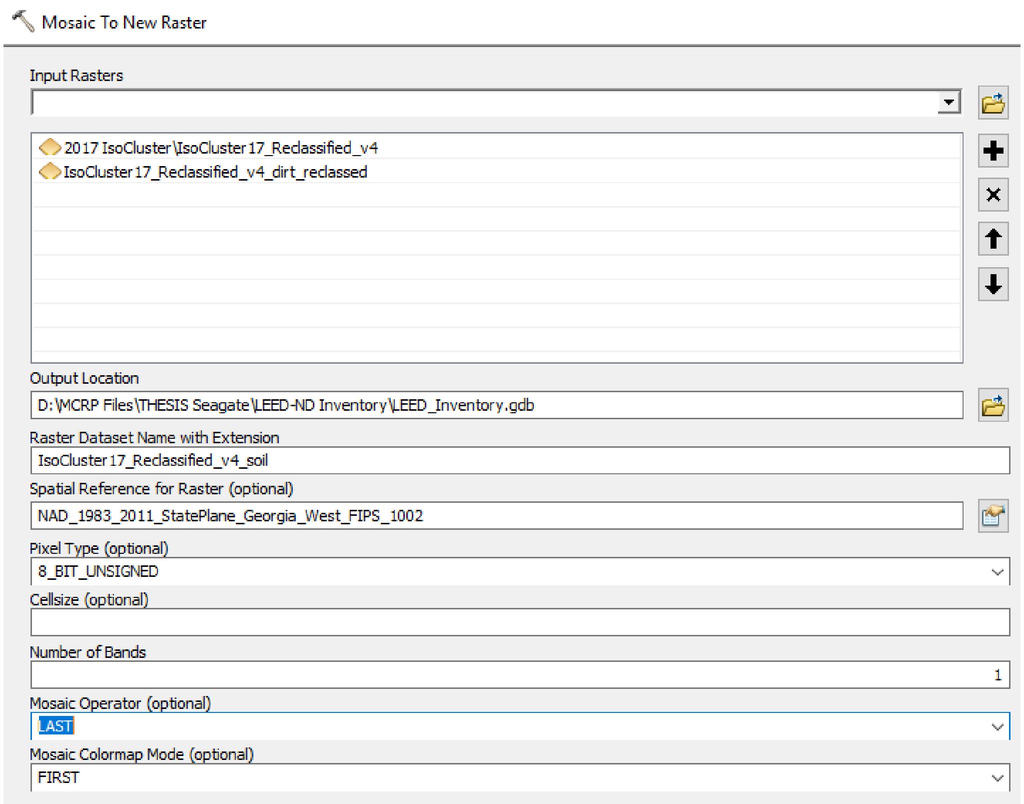
- Sort 50 classes into meaningful groups using visual inspection and recording in a table to be used for reclassification:
  - 1: Soil
  - 2: Trees
  - 3: Grass
  - 4: Water/Shadow
  - 5: Impervious_Dark
  - 6: Impervious_Light
- Reclassify using a table and check final results for accuracy
- Perform Reclass by Table
- Symbolize appropriately

- The analyst made three more attempts at reclassifying the least definitive classes produced by the unsupervised IsoCluster until achieving satisfactory accuracy in the area surrounding the BeltLine corridor in Subarea 5. The unsupervised classification struggled with distinguishing between soil light-colored impervious surfaces due to the low contrast in the NAIP image from 2017, so the Soil estimate was notably deflated as a result (0.5%). Other classes were estimated as follows:
  - Trees: 34.4%

- Impervious (Light): 21.9%
- Impervious (Dark): 20.7%
- Grass: 11.3%
- Water/Shadows: 11.2%

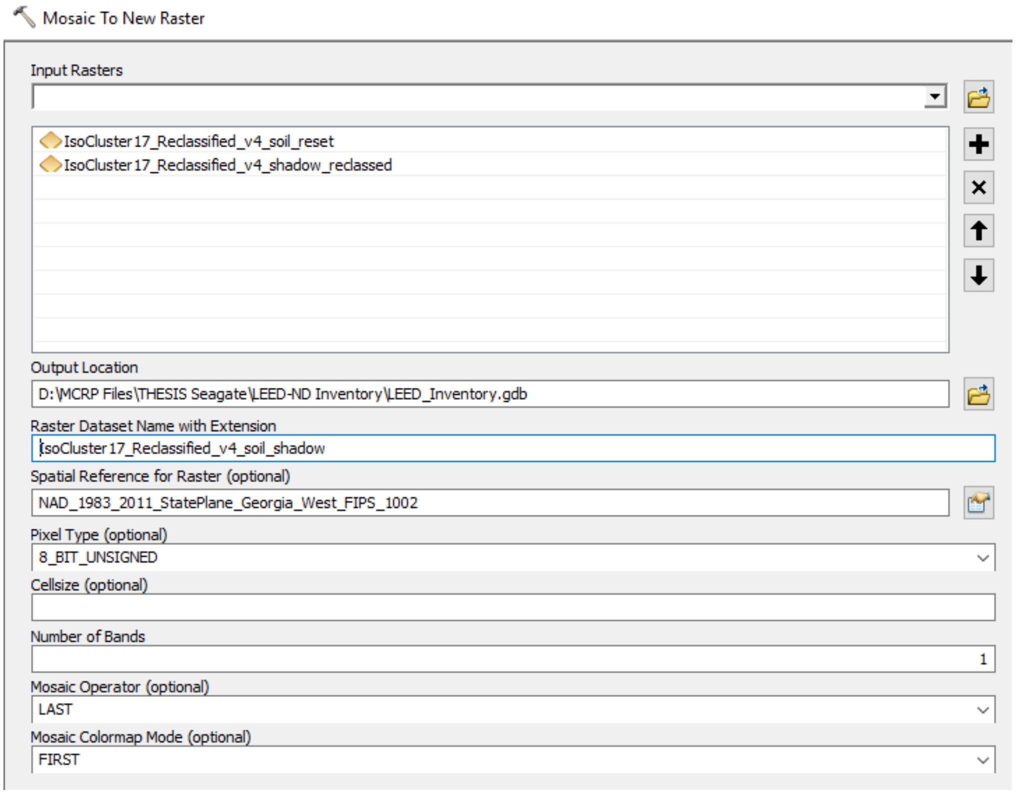
SPECTRAL CORRECTIONS

- Correct for the soil issue Correct for shadows using Stevenson's methodology as seen here: http://contours-coregis.blogspot.com/2016/06/reducing-shadows-in-landcover.html



  - The final raster is named "IsoCluster17_Reclassified_v4_soil_reset" and should be merged with the shadow classification in the next steps to produce the final image
- Correct for shadows using Stevenson's methodology as seen here: http://contours-coregis.blogspot.com/2016/06/reducing-shadows-in-landcover.html
  - The analyst performed "Extract by Attributes" on "IsoCluster17_Reclassified_v4" ("Value = 5")
  - "Extract by Mask" the original NDVI to the shadow layer in order to clip it

- Perform Unsupervised Iso Cluster on NDVI_2009_Shadows (10 classes, default settings otherwise)
- Reclassify to the extent possible (six of 10 were successfully reclassified to trees, grass, or dark impervious)
- Use Mosaic to New Raster tool to combine with “IsoCluster17_Reclassified_v4_soil_reset” to merge both sets of extracted edits with the original master raster



- Raster statistics are misreported at this point because they copied directly from the first input raster; so reclass to four classes to force ArcGIS to reset.
- Cell counts for “IsoCluster17_Reclassified_v4_soil_shadow_reset” now more closely resemble Giarrusso’s findings. They are:
    - Trees: 38.5%
    - Impervious (Dark): 24.8%
    - Impervious (Light): 16.2%
    - Water/Shadows: 7.3%
    - Grass: 6.8%
    - Soil: 6.4%

- After performing these steps for both NAIP images, distributions for 2009 and 2017 are very similar prior to performing postprocessing (and shadow reclassification for 2009…):

IsoCluster09_Reclassified

OBJECTID *	Value	Count	Percentage	Type
2	2	4552243	38.62173	Trees
5	5	2508560	21.2829	Impervious_Dark
6	6	1891333	16.04628	Impervious_Light
4	4	1347431	11.43175	Water_Shadow
3	3	1033613	8.769286	Grass
1	1	453560	3.848053	Soil

IsoCluster17_Reclassified_v4_soil_shadow_reset

OBJECTID *	Value *	Count	Percentage	Type
2	2	4533421	38.50787	Trees
5	5	2916141	24.77034	Impervious_Dark
6	6	1910588	16.22895	Impervious_Light
4	4	861284	7.315934	Water_Shadow
3	3	798487	6.782523	Grass
1	1	752793	6.394388	Soil

- One type of saturated grass color was persistently misclassified as tree canopy in the 2017 IsoCluster – particularly along the BeltLine corridor and near the intersection of Freedom Parkway and Ponce de Leon – so the author ran another series of reclassifications (first extracting everything with value 2 (trees) and performing the IsoCluster tool with 10 classes; then isolating one class within that which posed the greatest issue and extracting it separately to another five classes. The author then merged these layers stepwise back up to the master layer, exported as "IsoCluster17_Reclassified_merged_trees_final_v2" and then reclassified to IsoCluster17_Reclassified_FINAL and saved down in the main LEED_Inventory.gdb
    - After performing this step, the portion of tree canopy has diminished several percentage points while grass and soil have increased to account for about 17% of land cover

IsoCluster09_Reclassified_FINAL

OBJECTID *	Value	Count	Percentage	Type
2	2	4552243	38.62173	Trees
5	5	2640140	22.39924	Impervious_Dark
6	6	1891333	16.04628	Impervious_Light
4	4	1215851	10.31541	Water_Shadow
3	3	1033613	8.769286	Grass
1	1	453560	3.848053	Soil

IsoCluster17_Reclassified_FINAL

OBJECTID *	Value *	Count	Percentage	Type
2	2	4074934	34.61338	Trees
5	5	2916141	24.77034	Impervious_Dark
6	6	1910588	16.22895	Impervious_Light
3	3	1256974	10.67701	Grass
4	4	861284	7.315934	Water_Shadow
1	1	752793	6.394388	Soil

POSTPROCESSING

- Perform Majority Filter once using default values (4x4 grid, Majority)
- Then run the Boundary Clean tool using Ascend as the sorting technique and deselecting the default "Run expansion and shrinking twice" in order to only run using one sorting method (according to Keranen and Kolvoord 2017)
  - o Cell counts for "IsoCluster17_Reclassified_FINAL_fbc" and "IsoCluster09_Reclassified_FINAL_fbc" shuffle slightly in favor of the smaller classes due to the application of the Ascend sorting technique:

IsoCluster17_Reclassified_FINAL_fbc

OBJECTID *	Value	Count	Percentage	Type
2	2	3850091	32.70331	Trees
5	5	2576199	21.88266	Impervious_Dark
6	6	1994577	16.94227	Impervious_Light
3	3	1237756	10.5137	Grass
4	4	1143228	9.710768	Water_Shadow
1	1	970936	8.247291	Soil

IsoCluster09_Reclassified_FINAL_fbc

OBJECTID *	Value	Count	Percentage	Type
2	2	4353786	36.93777	Trees
5	5	2242486	19.02538	Impervious_Dark
6	6	2013649	17.08392	Impervious_Light
4	4	1432979	12.15748	Water_Shadow
3	3	1116293	9.470695	Grass
1	1	627619	5.324756	Soil

- "Often with very high resolution data, land cover class results can be mixed, where small pixel clusters of one class are embedded in another class (i.e., mistakenly classified), causing a grainy or "salt and pepper" classification effect. To remove the granularity and smooth out the classes, a series of 7 pixel x 7 pixel neighborhood filters were run on the composite image. This helped reallocate stray pixels or small clusters of pixels into their appropriate classes" (Giarrusso 2018, 17)
- "In the classified output, some isolated pixels or small regions may be misclassified. This gives the output a salt-and-pepper or speckled appearance. Postclassification processing removes the noise generated by these errors and improves the quality of the classified output. The Spatial Analyst toolbox provides a set of generalization tools for the postclassification processing task" (Keranen and Kolvoord 2017, *Making Spatial Decisions Using ArcGIS Pro*).
- Majority Filter and Boundary Clean tools are particularly useful for this (Ibid, 109).
  - o These tools (and the use of the "ascend" method for the Boundary Clean tool) are appropriate for this application because the analysis is concerned with parcel-level land cover. The kind of coarse-grain smoothing that might be appropriate for the study of large spatial scales – e.g., in landscape ecology – has the effect of diminishing the resolution of the

land cover raster and thus its sensitivity to subtle changes over the study period. On the other hand, the analyst must remain mindful that the use of Boundary Clean's ascend method *after* the Majority Filter may counteract the smoothing interpolation it had performed and runs the risk of exaggerating extraneous artifacts.

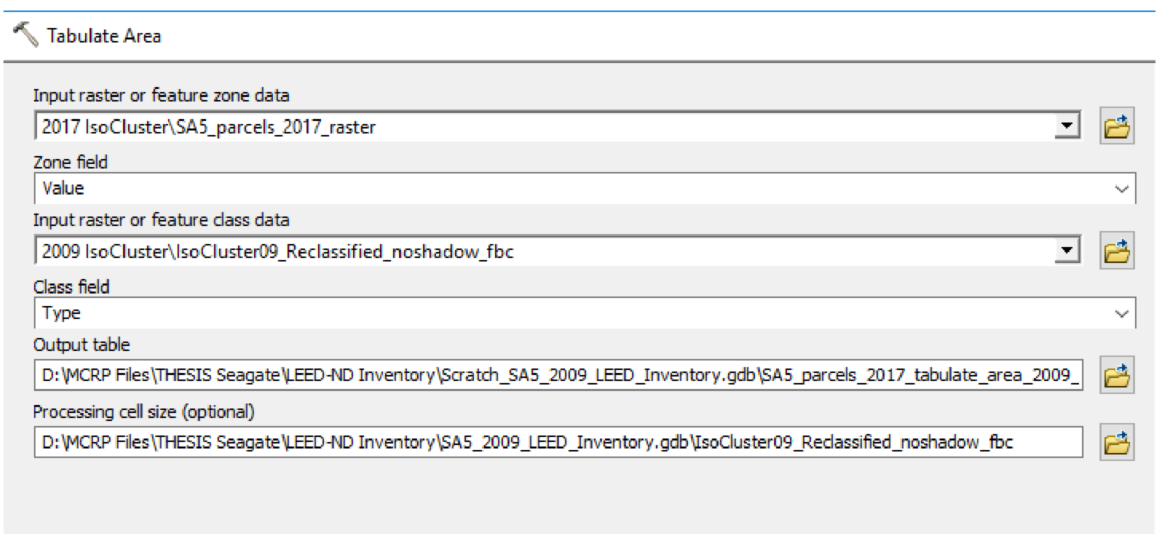
- Finally, clip both rasters to the SA5 boundaries (rather than the rectangular bounding box) and recalculate percentages
    - 2009 pixel sum: 4478330
    - 2017 pixel sum: 4478329

RESULTS

- To generate summary tables for zoning classifications, do the following:
    - Clip the Zoning District feature class to the SA5 boundaries
    - Create a new field, ZONECLASS_GENERAL, and merge any conditional zoning categories to their basic categories (e.g., C-2-C becomes C-2)
        - Select by Attribute with query ZONECLASS LIKE '%-C'
        - Use Field Calculator and the Python command !ZONECLASS!.replace("-C","")
        - Also remove the Subarea suffixes from any SPIs
    - Dissolve by the ZONECLASS_GENERAL field to create multipart features, summing count and area, and then create a new Acres field and calculate geometry for each feature
    - Perform Polygons to Raster on the Zoning District feature class, then Tabulate Area to overlay it with the final clipped land cover classification.
    - Create a new class, Count, and sum the cell counts for each class
    - Lastly, join these values to the Zoning District feature class attribute table and create and calculate fields to find percentages and acreage of each land cover in the various zoning categories.
        - E.g., Perc.Soil = ([Soil] / [Count]) * 100
        - Create a temporary field, Check_Total, and sum the five columns to ensure 100% and validate field calculations
        - For area, e.g., [Acres]*([Perc_Soil]/100)
        - Validate with the Check_Total field once again, comparing with each district's acreage, then delete the field
    - Export to new feature class, Zoning_District_clipped_FINAL, for integration with 2009 land cover classification:

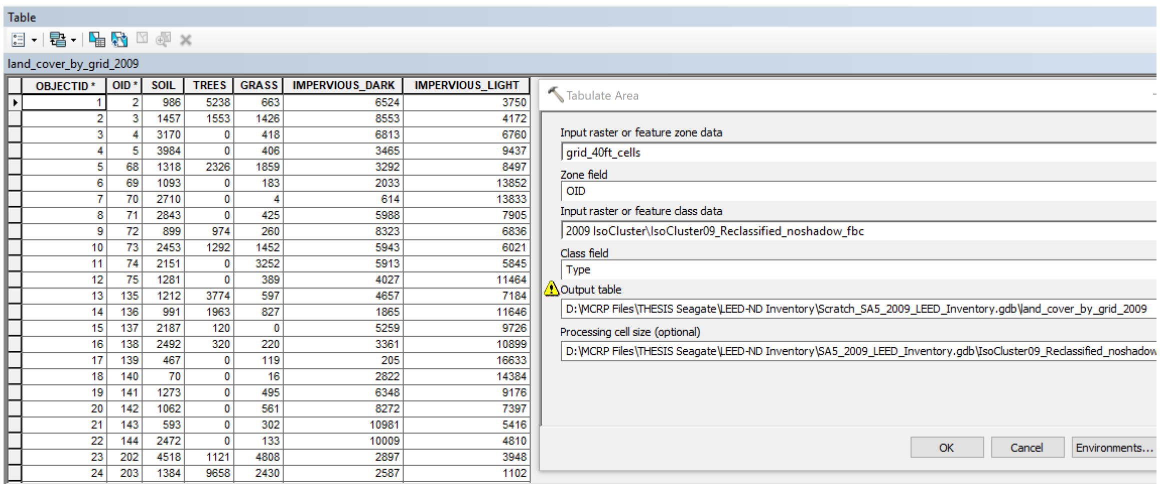
        - Append “_17” suffix to newly created fields
    - Create accompanying new fields with “_07” suffix
    - Repeat the Tabulate Area step with the final clipped land cover layer for 2009, join to the “_FINAL” table, and calculate fields to finish populating the attribute table
    - Export to Excel to calculate acreage and percentage changes by zoning category and collapse zoning categories into broader groups

- To visualize parcel-level changes in tree canopy coverage, it is important to work from a single set of parcel boundaries to control for confounding effects that might result from changes in parcel geometry. In this case, the 2017 parcel boundaries provide the physical framework for measuring changes between 2009 and 2019.
    - Batch perform Alter Field tool on SA5_parcels_2017_merge_FINAL_ALL in order to append “_2017” to original field names for land cover percentages.
    - Refer to the steps performed in Appendix B, 0, “OVERLAY LAND COVER CLASSIFICATION AND PARCEL BOUNDARIES,” for calculating land cover percentages for individual parcels, which apples the 2009 land classification to 2009 parcel boundaries and 2017 classification to 2017 parcel boundaries.
    - In this case, the 2009 land classification should be compared against the *2017 parcel boundaries* in the feature class SA5_parcels_2017_merge_FINAL_ALL in order to calculate a new set of attributes based on 2009 land cover types
    - Perform the Tabulate Area tool using the following parameters, and making sure to set the Extent and Snap Raster to “SA5_Parcels_2017_raster” within the Environment settings:



- After joining the 2009 land cover percentages to the table SA5_parcels_2017_merge_FINAL_ALL table and calculating permanent fields, create fields for “Perc_Chg_Trees”, “Perc_Chg_Dark”, and “Perc_Chg_Light”
- Use the field calculator to subtract Trees_2009 from Trees_2017 and so forth.
- Symbolize appropriately to denote whether parcels gained or lost each of these land cover types over the study period.

- To visualize tree canopy change more generally, use the Create Fishnet tool to overlay a network of 40-by-40-meter squares clipped and snapped to the extent of the clipped 2017 land classification. Deleting grid cells outside the boundaries of SA5 will result in a final tally of 2,960 cells.
  - Then, perform Tabulate Area on the 2009 data, using the fishnet as the feature zone data and the 2009 land classification as the class raster, to determine the tree canopy coverage for each grid cell. This tool will produce a table, “land_cover_by_grid_2009,” which can then be joined to the fishnet layer using the original Object ID field as the join key.

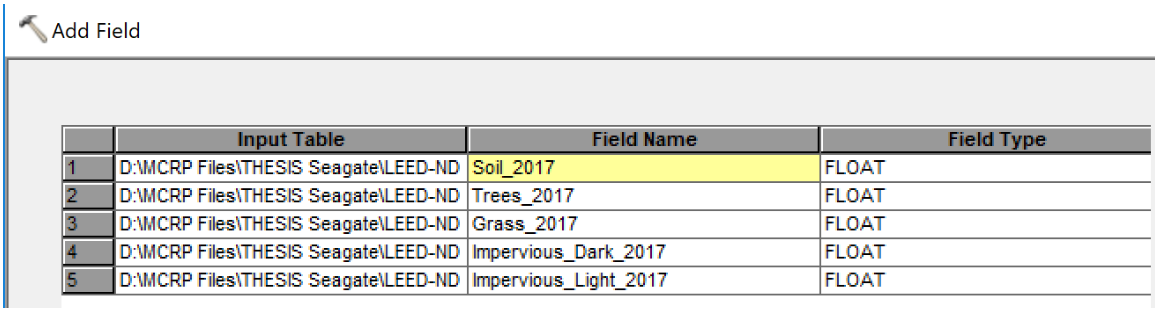


Table

land_cover_by_grid_2009

OBJECTID *	OID *	SOIL	TREES	GRASS	IMPERVIOUS_DARK	IMPERVIOUS_LIGHT
1	2	986	5238	663	6524	3750
2	3	1457	1553	1426	8553	4172
3	4	3170	0	418	6813	6760
4	5	3984	0	406	3465	9437
5	68	1318	2326	1859	3292	8497
6	69	1093	0	183	2033	13852
7	70	2710	0	4	614	13833
8	71	2843	0	425	5988	7905
9	72	899	974	260	8323	6836
10	73	2453	1292	1452	5943	6021
11	74	2151	0	3252	5913	5845
12	75	1281	0	389	4027	11464
13	135	1212	3774	597	4657	7184
14	136	991	1963	827	1865	11646
15	137	2187	120	0	5259	9726
16	138	2492	320	220	3361	10899
17	139	467	0	119	205	16633
18	140	70	0	16	2822	14384
19	141	1273	0	495	6348	9176
20	142	1062	0	561	8272	7397
21	143	593	0	302	10981	5416
22	144	2472	0	133	10009	4810
23	202	4518	1121	4808	2897	3948
24	203	1384	9658	2430	2587	1102

  - Repeat the Tabulate Area process for the 2017 land classification layer, IsoCluster17_Reclassified_FINAL_v2_fbc, adjusting parameters as necessary.
  - Create new float fields for each pair of land cover type and year (e.g., Soil_2017”) and then calculate each using the joined fields from land_cover_by_grid_2009.” Calculate the percentage change for each square cell in tree canopy (“Perc_Chg_Trees”), dark impervious cover (“Perc_Chg_Dark”), and light impervious (“Perc_Chg_Light”) by subtracting respective 2009 values from 2017.xs


Add Field

	Input Table	Field Name	Field Type
1	D:\MCRP Files\THESIS Seagate\LEED-ND	Soil_2017	FLOAT
2	D:\MCRP Files\THESIS Seagate\LEED-ND	Trees_2017	FLOAT
3	D:\MCRP Files\THESIS Seagate\LEED-ND	Grass_2017	FLOAT
4	D:\MCRP Files\THESIS Seagate\LEED-ND	Impervious_Dark_2017	FLOAT
5	D:\MCRP Files\THESIS Seagate\LEED-ND	Impervious_Light_2017	FLOAT

   - Symbolize appropriately. Select all cells that have tree canopy coverage greater than 75% and export to a separate layer which should be symbolized with a thick, white border for emphasis.

- The Raster Calculator tool offers a third way to visualize land cover change – in addition to the 40-by-40-meter grid and parcels.
   - Use the Extract by Attribute tool to isolate the tree canopy areas from the 2009 Iso Cluster layer (e.g., Value = 2). Use this as the base layer upon which to overlay the canopy gain/loss layer
   - Reclassify the final 2009 and 2017 land cover rasters such that the Trees class receives a value of 1 and all other classes receive value of 0
   - Using the Raster Calculator, subtract the 2009 layer from the 2017 layer; this will result in three classes: -1 (tree canopy loss), 1 (tree canopy gain), and 0 (all else, which should be excluded from map)
   - Add a float field “Acres” and use field calculator to calculate with the expression = [COUNT] / 4046.86 (e.g., square meters to acres)
   - Symbolize appropriately and denote the acreage for each class in the legend (in the case of Canopy Unchanged, subtract the Canopy Loss acreage from its raw figure to avoid double-counting this acreage)
   - Repeat the steps above for Dark and Light Impervious cover classes
   - To avoid data entry errors, create a new text field named “Label” and use the Field Calculator with the following Python expression, then use this field in the legend:
      - !Type! + “ (" + str(round(!Acres!,1)) + " acres)"

ISSUES

- Assembling a mosaic from such a large number of separate raster images presents challenges for data quality. Although the images were all captured on the same flight for 2009 (and over two days in 2017), there remains a risk that spectral variation may degrade the quality of the resulting mosaic image.

APPENDIX C. METHODOLOGY: LEED-ND INVENTORY

PREPARE 2017 PARCELS:

- Batch project each of the shapefiles to feature classes in the geodatabase "SA5_Parcels"
- Use the contemporaneous data sets from Fulton County for 2009 and 2017 tax parcels
- For 2009, Select all Tax Parcels with 0.25 miles of the SA5 boundaries (8,718) and refine from there:
    - 4,671 intersecting the boundaries of SA5
    - 4,595 that have their centroids within SA5 boundaries
    - 4,534 that are completely within SA5 boundaries
- Now, for 2017, Select all Tax Parcels within 0.25 miles of the SA5 boundaries (9,650 parcels) and refine from there:
    - 4,726 intersecting the boundaries of SA5
    - 4,641 that have their centroids within SA5 boundaries
    - 4,570 that are completely within SA5 boundaries
- NOTE: Dekalb county does not make historical parcel data available, so present-day parcel data is substituted instead. These additional 932 parcels are appended to the SA5_parcels_2017_qtr_mi layer. This is critical for determining eligibility of approximately 340 parcels within the SA based on the diverse use criterion.
- Produce a summary table of the Property Class codes represented in SA5 (intersecting) and find a description of each from the Fulton County GIS web app
    - Summarize ClassCode
    - Summary statistics: LandAssess (Min, Max, Average, Standard Deviation); and ImprAssess (Min, Max, Average, Standard Deviation)
- There are 20 ClassCodes in 2017, the most common of which are:
    - R3 (3,916)
    - C3 (431)
    - E1 (91)
    - I3 (62)
- Together, these account for 4,500 parcels (95.2%) of parcels in SA5. For the top two (and for 12 of 20 ClassCodes overall) average improvement assessment is greater than average land assessment, while the E1 and I3 codes have average

land values that surpass improvement values, suggesting they will be better suited to redevelopment and thus to LEED-ND eligibility

- There are 112 parcel records in the SA for which no information is available. These records were exported to a separate shapefile, deleted from SA5_parcels_2017_qtr_mi, and then overlaid with the original layer to identify duplicate records that do have more information attached to them.
- MERGE PARCELS WITHIN PARCELS ("SUB-PARCELS")
    - Select by Location all parcels within SA5_parcels_2017_qtr_mi that are "completely within" other parcels from the same layer.
    - There are 2,841 such parcels, which together represent 3,567 units of condos, townhomes, etc. (Inside SA5 boundaries, there are 1,718 such parcels and 2,500 units)
    - Use the field calculator to code all of the selected records with the "within" exclusion
    - Modify the query to select those records that completely contain other parcels (e.g., the enveloping parcels, of which there are 116). Export these to a new feature class, "SA5_parcels_2017_qtr_mile_dissolved"
- Perform a Spatial Join on this new feature class
    - Target features = SA5_parcels_2017_qtr_mile_dissolved
    - Join features = SA5_parcels_2017_qtr_mile
    - Output = "...\SA5_parcels_2017_qtr_mile_dissolved_joined"
    - Field Map: Remove all additional fields except for ParcelD_1 (merge rule = joined, with 5,000-character max length), Address_1 (last, with 100 character max length), LivUnits_1 (summed), and any associated with appraisal and assessment values (summed)
    - Match Option = Completed Contains
- The spatial join is successful for 109 of the 116 records in the larger study area (0.25-mi buffer around SA5), accounting for 3,598 units.
- Four of these missing parcels are within SA5 itself; they must be investigated further.
    - Select each individually, then Select by Location the features in SA5_parcels_2017_qtr_mile that are completely within and inspect the attribute table, copying and pasting values where appropriate
- In almost every case, there are no subparcels, and thus the records should be deleted from the dissolved_join layer. In two cases, the parcels did envelop sub-parcels that had to be merged within the SA5_parcels_2017_qtr_mi layer after summing and editing relevant fields.
- Add a text field named ParcelID_all with max length of 5,000 characters to both SA5_parcels_2017_qtr_mile and SA5_parcels_2017_qtr_mile_dissolved_joined

- Examine the attribute table for the dissolved_joined layer and use the field calculator to migrate values to the original fields. It is important that the field map match that of the original feature class before attempting to merge data.
- Merge the two feature classes, eliminating the extraneous fields ending in "_1", into one feature class named SA5_parcels_2017_merge
- Select by location all records in the new SA5_parcels_2017_merge layer that are completely contained by records in the SA5_parcels_2017_qtr_mile_dissolved_joined layer, of which there should be 2,840
    - Delete these 2,840 records
    - There should now be 6,890 remaining parcels in the SA5_parcels_2017_merge layer
- Select by location all records in the new SA5_parcels_2017_merge layer that are identical to records in the SA5_parcels_2017_qtr_mile_dissolved_joined layer, of which there should be 217.
    - From this selection, select by attribute those records in SA5_parcels_2017_merge that have TotAppr = 0, of which there are 104
    - Delete these 104, leaving 6,785 unique parcels
- Visually examine the _2017_merge layer and select all remaining parcels that contain smaller sub-parcels but were not selected in the previous exercise (typically, due to discontinuous topology, they do not "completely contain" the sub-parcels).
    - 45 parcels were determined to meet this criteria
    - Flag exclusions for all of these in the Exclude field based on "common" exclusion.
- Visually examine the _2017_merge layer for instances where one parcel is entirely within another -- for example, public housing developments where all land value is attributed to a larger parcel and all improvement value to a parcel within that.
    - 16 parcels were identified that met this criterion.
    - Export these 16 parcels to a new layer named SA5_parcels_2017_merge_bigparcels
- Edit vertices for each of the larger parcels and remove any sub-parcel geography (There are 31 such sub-parcels)
- Then, select the larger parcels and perform a spatial join using same parameters as in earlier step of summing sub-parcel appraisal values. E.g.,
    - Target features = SA5_parcels_2017_merge_bigparcels
    - Join features = SA5_parcels_2017_merge

- Output = "...\SA5_parcels_2017_merge_bigparcels_joined"
- Field Map: Remove all additional fields except for ParcellD_1 (merge rule = joined, with 5000 character max length), Address_1 (last, with 100 character max length), LivUnits_1 (summed), and any associated with appraisal and assessment values (summed)
- Match Option = Contains

* The spatial join is successful for 109 of the 116 records in the larger study area (0.25-mi buffer around SA5), accounting for 3,598 units.
* Examine the attribute table for the the "…dissolved_joined" layer and use the field calculator to migrate values to the original fields. It is important that the field map match that of the the original feature class before attempting to merge data.
* Delete duplicate identical (14) and contained (30) records from the original feature class and then merge the two feature classes, eliminating the extraneous fields ending in "_1", into one feature class named SA5_parcels_2017_merge_FINAL
    - Also delete extraneous join fields and FID fields from this final layer
    - This final layer SA5_parcels_2017_merge_FINAL should be used for all candidacy and eligibility analysis henceforth
* (Extra step: add Dekalb 2017 parcels, join on the Parcel ID, copy relevant attributes over and concatenate addresses, and export to a final Feature Class called "SA5_parcels_2017_merge_FINAL_ALL")

PREPARE 2009 PARCELS:

* Repeat process for the 2009 parcels layer:
* Select by Location all parcels within SA5_Tax_Parcels_2009_qtr_mile that are "completely within" other parcels from the same layer.
    - There are 1,419 such parcels, which together represent 1,961 units of condos, townhomes, etc.
    - (Inside SA5 boundaries, there are 943 such parcels and 1,508 units)
    - Use the field calculator to code all the selected records with the "within" exclusion
    - Modify the query to select those records that completely contain other parcels (e.g., the enveloping parcels, of which there are 561). Export these to a new feature class, "SA5_parcels_2009_qtr_mile_dissolved"
* Perform a Spatial Join on this new feature class
    - Target features = SA5_parcels_2009_qtr_mile_dissolved
    - Join features = SA5_Tax_Parcels_2009_qtr_mile

- Output = "...\SA5_parcels_2009_qtr_mile_dissolved_joined"
    - Field Map: Remove all additional fields except for PARlD_1 (merge rule = joined, with 5000 character max length), ADD2_1 (last, with 100 character max length), LivUnits_1 (summed), PROP_CLASS_1 (joined, 80 characters) and any associated with appraisal and assessment values (summed)
    - Match Option = Completed Contains
- The spatial join is successful for all 561 records in the larger study area (0.25-mi buffer around SA5). There are still quite a few duplicates with identical geometry (thus circumventing the location queries used in the 2017 dataset) and therefore which must be identified and removed through a different method...
- Perform Find Identical on the SA5_Tax_Parcels_2009_qtr_mile layer (see Find_Duplicates_2009_Parcels for Python snippet) based on shape, exporting only duplicates, and then join this table (using key IN_FID) to SA5_Tax_Parcels_2009_qtr_mile on the join key OBJECTID_1.
    - There are 4,037 duplicates in 124 groups
    - The FEAT_SEQ field groups these identical features together
    - This is helpful in cases where the duplicates are not sub-parcels completely contained within larger polygons -- but rather identical polygons with identical geometry overlaid atop one another (e.g., 400 Village Parkway condos)
    - Make the join permanent by exporting to a new feature class called "SA5_Tax_Parcels_2009_qtr_mile_identicals"
- Summarize the FEAT_SEQ field for the 561 records in SA5_parcels_2009_qtr_mile_dissolved_joined, revealing that just nine parcels account for 486 duplicate records.
    - Purge these duplicates manually in the attribute table, leaving any with NULL values in the FEAT_SEQ field.
    - Select and delete the overlapping records in the original merge table, and for now, wait to merge the resulting 83 records back into it
- Return to the "SA5_Tax_Parcels_2009_qtr_mile_identicals" layer to prepare it for merging with the spatially joined encompassing parcels.
    - Select by Attribute any parcels for which FEAT_SEQ is not null (e.g., there are identically shaped duplicates; 4,037 records) and then Select by Location from within that selection parcels that are "identical to" records in SA5_parcels_2009_qtr_mile_dissolved_joined (486 records)
    - Delete these duplicate records with FEAT_SEQ equal to 122, 105, 91, 87, 73, 50, 10, and 8 to ensure there is only one remaining records for each once the polygons from "...dissolved_joined" have been re-integrated

    - Next, perform a new Select by Location of features that are "completely within" the dissolved_joined layer (there should be 1,419, all contained within the 83 parcels in that layer. Delete these records.
    - Also select and delete the 77 features that are "within" the dissolved_joined layer. These are the last duplicates dealt with in the earlier spatial join. There are now 7,020 parcels (before adding Dekalb parcels).
    - Next, examine the remaining records for which FEAT_SEQ is not null; these are additional duplicates that weren't caught by the earlier process. There are 2,194 such records contained within 69 groups in the SA5_Tax_Parcels_2009_qtr_mile_identicals layer. Copy these 2,194 records to a new layer called SA5_Tax_Parcels_2009_qtr_mile_identicals_only.
- Perform the Delete Identical tool on SA5_Tax_Parcels_2009_qtr_mile_identicals_only.
    - This removes 2,125 duplicates.
    - Copy the remaining 69 to a new layer called SA5_Tax_Parcels_2009_qtr_mile_identicals_nodupes and then restore the SA5_Tax_Parcels_2009_qtr_mile_identicals_only to its full 2,194 records to prepare for the Dissolve.
- Dissolve SA5_Tax_Parcels_2009_qtr_mile_identicals_only on the FEAT_SEQ field, summing appraisal values and living units (see "Dissolve_Values_Duplicates_2009_Parcels.txt" for Python snippet; it is important to allow multipart features), and output to a new layer called SA5_Tax_Parcels_2009_qtr_mile_iden_only_dissolve
- Then, return to the SA5_Tax_Parcels_2009_qtr_mile_identicals_nodupes layer and perform a join on the FEAT_SEQ field. These summed values should then be transferred over using the field calculator.
- Remove the 2,194 records with FEAT_SEQ values from the SA5_Tax_Parcels_2009_qtr_mile_identicals layer, leaving 4,826.
- Finally, append the 69 cleaned parcels from the layer SA5_Tax_Parcels_2009_qtr_mile_iden_only_dissolve to the 83 cleaned parcels from the layer SA5_parcels_2009_qtr_mile_dissolved_joined after modifying the field map where necessary to ensure consistency.
- Then, append the 152 records in the newly expanded SA5_parcels_2009_qtr_mile_dissolved_joined layer to the SA5_Tax_Parcels_2009_qtr_mile_merge_FINAL, resulting in a total of 4,978 parcels (2,841 of which intersect SA5 boundaries; by comparison, there are 6,755 parcels in the 2017 dataset, which includes Dekalb county, and 2,931 parcels intersecting SA5 boundaries)

- Add the present-day Dekalb parcel geography to the 2009 parcels by selecting all parcels from SA5_parcels_2017_merged_FINAL_ALL with ParcelID that begins with '15%' -- 925 records -- and copying them to the SA5_Tax_Parcels_2009_qtr_mile_merge_FINAL layer.
- The 2009 Parcels layer is now prepared to be coded with exclusions.

REMOVE REMAINING 2017 DUPLICATE PARCELS:

- Return to the SA5_parcels_2017_merge_FINAL_ALL and perform the same steps with the Find Identical tool in order to ensure there aren't overlapping parcel records.
- Perform Find Identical on the SA5_parcels_2017_merge_FINAL_ALL layer (see Find_Duplicates_2009_Parcels for Python snippet) based on shape, exporting only duplicates, and then join this table (using key IN_FID) to SA5_parcels_2017_merge_FINAL_ALL on the join key OBJECTID_1.
    - o There are 875 duplicates in 80 groups
    - o Make the join permanent by exporting to a new feature class called "SA5_parcels_2017_merge_FINAL_ALL_w_identicals"
- Dissolve SA5_parcels_2017_merge_FINAL_ALL_w_identicals on the FEAT_SEQ field, summing appraisal values and living units (see "Dissolve_Values_Duplicates_2009_Parcels.txt" for Python snippet; it is important to allow multipart features), and output to a new layer called SA5_parcels_2017_merge_FINAL_ALL_w_identicals_dissolve
- Transfer values with the field calculator, export the 875 duplicate records then perform the Delete Identical tool on them. This removes 995 duplicates and leaves 80. Delete the 875 from the master layer and then paste the 80 summed records back into it.
- There are now 5,960 records in the SA5_parcels_2017_merge_FINAL_ALL layer, including 2,926 intersecting the SA5 boundaries (vs. 5,903 and 2,897 respectively in the 2009 parcels)
- While the LEED-ND eligibility tests also require consideration of parcels within a quarter-mile buffer – in order to evaluate whether a candidate parcel meet criteria for being an “infill” site, for example – these parcels are not necessary for constructing the candidate parcel set. The most relevant parcels are those whose centroid lies within the boundaries of Subarea 5.
- So, the next step is to Select by Location those parcels in both 2009 and 2017 datasets and export to new feature classes named “SA5_parcels_2009_centroid” and “SA5_parcels_2017_centroid”, respectively.

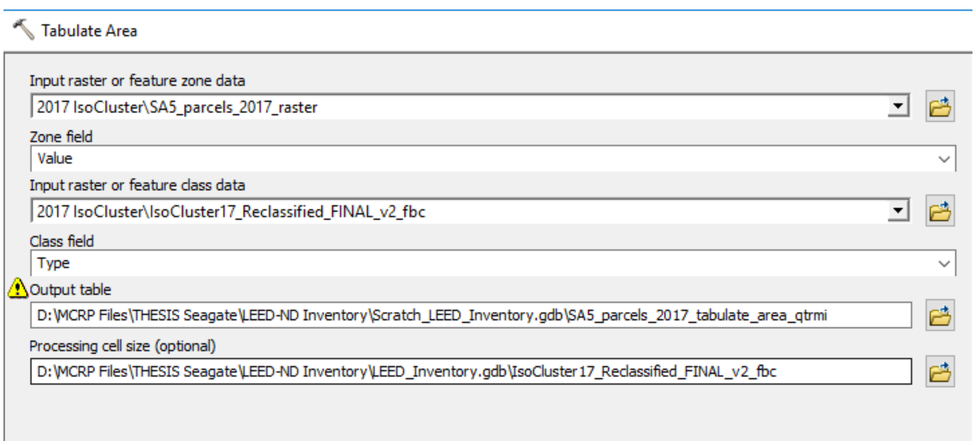
IDENTIFY CANDIDATE PARCELS:

- From Talen et al. 2013: "Parcels with percent impervious values greater than 50 were deemed “previously developed” per the LEED-ND definition. To also be consistent with USGBC policy, airports, railyards, cemeteries, golf courses, school campuses, and parks were classified as 100% previously developed regardless of their imperviousness."
- Create new fields in the SA5_Tax_Parcels_2009_qtr_mile_merge_FINAL and SA5_parcels_2017_merge_FINAL_ALL attribute tables:
    - Include (text): yes, no
    - Include_Check (text): yes, no
    - Candidate_Type (text): vacant, redevelopable
    - Dev_Status (text): vacant, developed, water
    - Unique (long): OBJECTID_1 + 1
    - Exclusion (short): 0 - 4
    - Small_SFR (short): 1, 0
    - Public (short): 1, 0
    - Appraisal (short): 1, 0
    - Ineligible_Use (short): 1, 0
    - Ineligible_Use_Type (text):
    - Perc_Developed (float): 0-100
- Identify and exclude the following by coding “1” in the appropriate field
    - Records with ClassCode = R3 and LandAcres <= 0.5 (small_SFR)
    - Records with ClassCode = E1, e.g., undevelopable public property (public)
    - Records with ClassCode = E2, e.g., place of workship (ineligible_use)
    - Records with ClassCode = E4, e.g., cemetery (ineligible_use)
    - Records with ClassCode = E5, e.g., hospitals (ineligible_use)
    - Records with ClassCode = E6, e.g., school (ineligible_use)
    - Records with ClassCode = U2, e.g., operating utility (ineligible_use)
- Identify (using Select by Attributes) and exclude any parcels for which improvement appraisal exceeds land appraisal by coding a 1 the “appraisal” exclusion. (Use the field calculator to also manually code this exclusion for all 47 parcels in Dekalb County, as their available appraisal figures do not disaggregate land and improvement value.)

- At each step, be sure to Switch Selection and code all records that do not meet a particular exclusion with a score of 0 to allow for summing in the following step.
- To code the “Exclusion” field, use the Field Calculator to sum the small_SFR, public, appraisal, and ineligible_use fields (resulting in a score between 0 and 4)
- Coding for impervious land cover is the last remaining step to finalize the candidate parcels.

OVERLAY LAND COVER CLASSIFICATION AND PARCEL BOUNDARIES

- To prepare for overlaying the land cover classification over the parcels, first perform Polygon to Raster tool on the SA5_parcels_2017_merge_FINAL_ALL layer, using a 2ft cell size, Maximum_Combined_Area cell assignment type, and assigning “Unique” as the Value field. Save to “SA5_parcels_2017_raster”
- Perform Tabulate Area tool using the following settings, and being careful to set the Extent and Snap Raster to SA5_Parcels_2017_raster in the Processing Extent section of the Environment Settings:



- Create a new field, Unique, and copy over the value from VALUE using the field calculator (to avoid using a reserved keyword in subsequent join)
- Create a Count field (long integer) and then percentage fields (float) for each of the five classes and use the field calculator to generate these values
  - E.g., Count = [SOIL] + [TREES] … etc.
  - E.g., Perc_Soil = [SOIL]/[Count]*100
  - The Count field represents square feet. The largest site in the dataset, 197,400 sqft, is 4.52 acres.
- Join the resulting table to the master feature class, SA5_parcels_2017_merge_FINAL_ALL, based on the Unique field in the latter and the Value field in the former
- Create two new float fields, Impervious_Dark and Impervious_Light, and use the field calculator to copy percentages from the joined table.

- Use the field calculator to code the Perc_Developed attribute with the sum of Impervious_Dark and Impervious_Light.
- For any parcel with Perc_Developed over 50%, code the "Dev_Status" attribute "developed" (1,167 parcels)
    - Additionally, any other parcel under 1 acre should be coded "small_developed" if it has *any* previous development. However, the author set a threshold of 10% to allow for random error in the classification (In general, 10% is considerably lower than allowable lot coverage.) (2,391 parcels)
    - All other parcels with Perc_Developed below 50% (e.g., with Dev_Status still NULL) should be coded "vacant"
- To complete the candidate inventory, code for the "Include" field:
    - Yes: parcels with Candidate_Type = Vacant and Exclusions = '0'
    - Yes: parcels with Candidate_Type = Redevelopable and Exclusions = '0'
    - No: all others
- Finally, code the candidate parcels (Include = "Yes") for the "Candidate_Type" field using the following criteria:
    - Vacant: records with IMPR_APPR = 0
    - Redevelopable: records with LAND_APPR > IMPR_APPR
- The LEED-ND v4 Reference Guide defines "developed" in very idiosyncratic ways. In general, a parcel should be classified as developed if impervious surface occupies at least 50% of its total area. However, any parcels under 1 acre may be coded "developed" and excluded from the candidate pool if they have any previous development on the lot, even demolished structures or concrete pads, regardless of the portion of land cover disturbed. (This is fortuitous in the case of this analysis because the 1-meter NAIP imagery does not produce sufficient resolution to reliably distinguish land cover on most small lots in the study area.)
- Repeat the land cover overlay process for the 2009 parcel layer, beginning with Polygon to Raster, then Tabulate Area, then the series of joins and field calculations, and eventually coding the 2009 parcels for inclusion in the candidate set.
- To compare 2009 and 2017 candidate status, add two additional fields to the SA5_parcles_2009_centroid feature class:
    - Include_2017
    - Developed_09_17
- Join the 2017 layer (ParcelID field) to the 2009 layer (PARID field) with the Parcel ID as the join key, bearing in mind that there will be discrepancies in the tax digest that still must be reconciled. Using the join key successfully matches 91.6% of parcels and 356 of the 419 candidate parcels.

    - Select the 266 parcels that have “Yes” Include values in both years and code the Include_2017 field “Yes”, as well.
    - Select the 90 parcels that have “Yes” Include values in 2009 but not 2017 and code the Include_2017 field “No”.
- The status of the remaining 63 parcels must be manually validated to determine whether they remained candidates in 2017. In most cases, these are parcels that underwent either subdivision or assemblage during the intervening years and had new parcel IDs assigned in the process. In some instances, parcels maintained the same perimeter boundaries but had new townhome parcels carved out of their interior. It is also likely that in certain cases where overlapping parcels were merged and their appraisal values summed – e.g., condos, townhomes, or detached single-family planned unit development – parcel IDs were not maintained in ways that ensured consistency between 2009 and 2017.
    - Of these 63, 40 were coded “No”, 21 were coded “Yes”, and 2 were left “Null” because they were extraneous slivers of parcels
- Review the candidate pools for extraneous parcels that should not be included under the Criterion Planners’ methodology, namely:
    - Public rights of way
    - Private rights of way (e.g., circulation within subdivision/mixed-use site)
    - Common areas or dedicated open space within subdivision/mixed-use site
- For any of the above, code the Include_Check field “No”; otherwise, code “Yes”
    - Select any records that have Include_2017 <> “Yes” and Include_Check = “No” – there are 12 in this case – and re-code the former field to Null
    - This final sum of “Yes” parcels represents the “Candidate Parcels after Manual Exclusions”, which can then be disaggregated by category and used for further analysis.
- To evaluate whether change in candidacy typically indicated that a parcel redeveloped between 2009 and 2017, export these 128 records to a new feature class, “Parcels_Cand_to_NonCand_09_17”, join the 2017 parcel status layer based on parcel ID, and check which exclusions were present in 2017 (or, compare improvement values in 2009 and 2017).
    - For the 38 parcels that do not join successfully, inspect visually using the 2009 and 2017 imagery and code each by hand
- Create two new text fields, “Status_Chg_Reason” and “Reason_Label” and populate them both for each of the 128 “converted” candidate parcels using the follow criteria:

Reason_Label	Status_Chg_Reason	Criterion
Likely Redeveloped	Appraisal	Impr > Land Appraisal
	Redev	Redevelopment visually confirmed
Converted to Small SFR	Small_SFR	R3 ≤ 0.5 acres
Converted to Public or Ineligible Use	Public	New property class code
	Ineligible_Use	
	Park	
Unknown Reason	NoChng or (blank)	None of the above

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