INFILL DEVELOPMENT AND THE ENVIRONMENT: INFILL'S IMPACT ON URBAN HEAT AND VEGETATION

by

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A THESIS

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The following thesis studies the impact of infill developments on urban vegetation and land surface temperature in Chicago and Seattle from 2000-2024. Vegetation and temperature impact our daily lives from general aesthetics to quality of life and the comfort of our environments. Surface temperature and vegetation were selected for a focused look at development and each standalone site. Sites were selected if they met the necessary criteria: developed after 2000, completed before 2020, within two miles of a body of water, and significantly changed from pre- to post-development. These criteria allowed the data to fully identify vegetation and surface temperature changes within the study's timeline. Vegetation density through the Normalized Difference Vegetation Index (NDVI) and surface temperature were studied through satellite imagery and ArcGIS analysis.

The thesis followed a case-study approach, exploring 14 sites throughout the cities of Chicago and Seattle. The study revealed an inverse relationship between vegetation and urban heat in half of the studied sites, showing a decrease in vegetation and, therefore, an increase in surface temperature. Predevelopment and changing weather conditions caused the rest of the sites to experience a decrease in vegetation and temperature (Chicago sites) or an increase in vegetation and temperature (Seattle sites). Overall, cities interested in growth and mitigating urban heat should investigate infill developments and vegetation as a potential mechanism.

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Background

As cities grow, the urban form and character of the regions change to accommodate growth. An increasing population can drive the need for housing and services, causing new developments to appear. Historically, cities grew along their outer boundaries and sprawled outwards rather than developing within the city itself (Bragado et al., 2001; Hall, 2006). However, sprawl and suburbanization along the urban fringe reduce available land for agriculture or development by creating low-density urban forms. Low-density patterns, especially in abundance as in suburban communities, emphasize vehicle use for transportation as the distance between commercial and residential uses is unwalkable, raising environmental concerns. Environmental concerns surrounding transportation pollution and disappearing agricultural or habitat lands encourage cities to limit sprawling developments and build within their borders (Firehock, 2015b; US EPA, 2015a). Infill development is one option for cities to grow without expanding outwards. Instead, infill development sites allow cities to grow vertically and increase the density within the region by offering diverse options within a developed neighborhood.

For this project, infill developments are defined as empty or abandoned parcels that are redeveloped (Real Estate Research Corporation, 1982), for example, converting part of a parking lot or a residential backyard into housing. Infill developments can occur in urban, suburban, and rural settings on lots of varying sizes, from ¼ to 20 acres. These developments help cities meet their density and connectivity goals by adding new amenities or housing within existing urban areas. Adding infill developments increases the proximity of housing to commercial destinations, allowing for walkability and attracting potential residents to the region (Leyden et al., 2023; Xiaohe Yue et al., 2022).

As cities continue to grow, infill development can add to a neighborhood's desirability. Infill developments add to the density and desirability of an area by providing new housing, jobs, and amenity options within an existing developed region (Elldér et al., 2022). These developments are opportunities to reinvest in communities without redesigning the entire neighborhood. Instead, infill developments are opportunities to repurpose vacant or abandoned land for the betterment of the community (Reinvestment and Infill, 2017).

Cities can use repurposed infill parcels to meet needs within their community. For example, many cities are beginning to look for diverse housing options to meet growing supply issues. Infill development and rezoning to allow dense development are one way to meet housing needs, especially in desirable neighborhoods. Today, mixed housing is essential as people require different pricing options, locations, and attributes for their personal space. For cities, mixed-use housing is attractive as it's efficient in land use, aesthetic variety, and cost-efficient (Tilt & Cerveny, 2013; Heid, 2004). Prioritizing infill development for housing supply also increases housing choice, adding to the social character of a neighborhood and attracting potential residents (US EPA, 2015a).

Infill developments can increase the housing supply and diversity of a neighborhood, but it also impacts the built environment. All developments play a role in the heat of cities and towns. Specifically, urban heat islands occur when building materials trap and absorb heat rather than filter it (US EPA, 2015). As global temperatures increase, these materials, in turn, amplify rising summer temperatures. However, vegetation and green development tools decrease temperature and its impact on communities, especially when placed in dense built spaces like parking lots or buildings (US EPA, 2015). Infill developments can encourage green development through the introduction of vegetation, green roofs, gardens, and other vegetation that help to cool areas (Russo & Holzer, 2021). Infill developments can help to interrupt artificially hot built environments by introducing these tactics. Overall, placing an emphasis on mitigating heat is helpful for decreasing basic energy usage but also benefits residents' quality of life, human health conditions, and decreases the likelihood of natural disasters like heat waves (US EPA, 2015b).

Literature Review

Infill developments rest within the larger context of urban planning. To understand the impact of infill development on surface temperature and vegetation, it is important to first understand broader planning contexts and implications. Within planning, historical processes such as redlining and sprawl continue to impact current planning decisions and new developments. These historical decisions impact the neighborhoods that are chosen for redevelopments like infill.

Redlining

Redlining, largely created by the Home Owners' Loan Corporation (HOLC) in the 1930s, assessed the risk of issuing mortgage loans based on a neighborhood's status (Egede et al., 2023). Neighborhoods were mapped and sorted into four categories: best (green), still desirable (blue), definitely declining (yellow), and hazardous (red) (Nelson et al., n.d.). Neighborhoods or regions would be outlined in one of these colors to identify the risk of issuing a loan. Regions with a lot of rental properties or high ethnic minority residents were more vulnerable to the 'definitely declining' or 'hazardous' designations (Aalbers, 2011). These designations made obtaining a homeowner's loan for a red or yellow region more challenging.

Redlining contributed to the decline of many neighborhoods as hospitals and other essential services relocated to 'more desirable' locations (Egede et al., 2023). White residents were also incentivized to move into suburban communities where loans were granted more easily, leading to suburban sprawl along the city borders (Aalbers, 2011). Eventually, redlining led to the degradation and disinvestment of neighborhoods deemed undesirable or risky. Gradual disinvestment in redlined neighborhoods continues to impact those communities today, as they suffered from a historical lack of funding and degradation. In particular, redlining has led to higher surface temperatures and lower frequency or amount of vegetation in these neighborhoods (Wilson, 2020). Redlining seeped into every aspect of life, necessitating a multifaceted reinvestment approach in these communities. Specifically, housing programs, educational programs, food stamps like SNAP, and continued investment into the built environment, like sidewalks and open lot developments, are needed for reinvestment (Egede et al., 2023).

Sprawl

Development outside the city border grew from redlining and urban renewal practices as families migrated from cities to suburbs, creating sprawl. Urban sprawl is characterized by the development of rural or underdeveloped land along a city's fringe (Hall, 2006). Often, a city sprawls faster than the population grows, causing underutilized developments within the city (Bragado et al., 2001; Hall, 2006).

Sprawl can also be exacerbated by strict zoning laws pushing developers to areas outside of the city to accommodate lot regulations (Lichtenberg, 2011). Zoning laws designate land use by providing guidelines for commercial, housing, and industrial uses. Zoning code can also regulate the maximum height, density, and unit size of buildings and restrict multi-family homes from entering the market, necessitating development along the urban fringe (Talen, 2013; Mcconnell et al., nd).

Infill development is one mechanism to prevent sprawl along the urban fringe and increase density within the city (Real Estate Research Corporation, 1982). Infill developments occupy and repurpose underutilized plots previously exacerbated by sprawl. Implemented infill plots add to an area's desirability and accessibility through increasing the proximity of housing to jobs and amenities (Elldér et al., 2022). Specifically, placing infill development locations in regions with established green space, walkability, and mixed-use buildings increases the density of these regions (US EPA, 2013).

Infill Development

Infill developments are vacant or abandoned parcels that are redeveloped (Real Estate Research Corporation, 1982). Infills are present in every city and can range from ¼ acre to 20 acres. For cities, these developments are attractive as they use existing infrastructure and require minimal investment in public goods like new roads (Real Estate Research Corporation, 1982).

Infill developments are also attractive for cities as they are a way to increase density, limit abandoned or underutilized parcels and encourage active transportation options. Overall, the existing infrastructure that connects these developments is more cost-effective than developing a greenfield site (US EPA, 2015a). However, cities can run into the same issues that left the parcels vacant. For example, high construction costs, inadequate returns on investment, and other financing issues can increase the risk to a developer and the city when dealing with infill sites (Hamilton & Kellett, 2017).

Impact on the Public

Sprawling low-density neighborhoods place an emphasis on vehicle use as destinations are typically too far for walking or cycling. Spread out or sprawled regions can work for some, but effectively hinder the movement of children, people with disabilities, the elderly, and other groups unable to drive (Bragado et al., 2001). To avoid additional sprawling development patterns or to increase existing density, cities can develop within their borders through unused lots, repurposed buildings, or underdeveloped parcels, such as infill developments.

Infill developments contribute to higher density and mixed land use within a developed region. Infill's presence allows for active transportation as they increase housing choice and the proximity of destinations to one another (US EPA, 2014). Compact regions allow for mobility as services exist within the neighborhood itself (Chapman, 1996). Therefore, infill developments allow for individual autonomy in travel within the neighborhood.

New developments will alter the built environment and can change existing pathways. When considering infill developments, cities must identify how they will impact essential movements for all pedestrians (Chapman, 1996). However, combining infill development and smart growth strategies for walkability and accessibility reduces risk to pedestrian pathways (US EPA, 2013).

Green Infrastructure Impacts

As cities expand and alter the built environment through zoning or development there can be adverse environmental conditions. To counteract these conditions, cities can encourage the implementation of vegetation and green infrastructure through quicker permitting, reduced fees, or form-based code processes (Bragado et al., 2001). Green infrastructure can be defined as nature-based developments or preservation techniques that further human economic, social, or ecological benefits (Dike, 2015). Green infrastructure can take multiple directions. Zoning and maintaining an area for wildlife habitat can be green infrastructure. In an urban setting, green infrastructure is also considered park development, green roofing or walls, gardens, balconies, and greenhouses (Ingaramo & Negrello, 2023).

Green infrastructure is beneficial for biodiversity, human health, and wildlife health. Green areas act as a sort of 'filter area' for people to congregate allowing them to reconnect with nature while they transition from building types (Ingaramo & Negrello, 2023, pp. 145). These spaces contribute to better human health and biodiversity. Residents in neighborhoods with high biodiversity reported better health outcomes than their counterparts (Russo & Holzer, 2021).

Similarly, the presence of green infrastructure helps to mitigate environmental impacts detrimental to human health. Specifically, concrete, pavement, and other impervious built materials absorb radiation and heat, rather than reflect solar radiation like vegetation does, raising surface temperatures and the likelihood for urban heat islands (US EPA, 2015). Green roofing and similar infrastructure features mitigate building and surrounding area temperatures, stormwater management, pollution, and noise (Russo & Holzer, 2021). Planners can utilize satellite imagery to better plan for green infrastructure as they identify protected habitats and desired green space together (Firehock, 2015a). Planners can also target infill development for green infrastructure in increasingly dense urban settings where available green space is declining (Firehock, 2015b).

Methods

The study on infill development was guided by three questions. Each question was crafted to identify a different aspect of the relationship between infill development, vegetation density, and surface temperature. First, it was important to understand if infill development impacted the heat and vegetation within each city. The initial hypothesis was that if the infill developments implemented vegetation, there would be a reduction in surface temperature. This led to the question: has infill development reduced urban heat and increased vegetation density in Seattle and Chicago from 2000-2024? In early research, it appeared that Chicago had a large variety and amount of infill developments throughout the city, whereas sites were difficult to locate in Seattle. As such, the second guiding question asked if Chicago had prioritized infill development compared to Seattle. Combining both questions and focuses, it was important to focus back on vegetation and surface temperature. So, the third question guiding the research asked if vegetation density had been prioritized in infill developments across both cities.

To address each research question, case studies on the City of Chicago and the City of Seattle were performed. Each case study included a focus on comprehensive plans, general theory on infill development, climate change impacts, and historical planning factors. The case studies focused on the long-term impacts of infill development on surface temperature and vegetation. To complete the study, satellite data, comprehensive plans, land use codes, and historical zoning ordinances were studied.

Google Earth, historical maps, Landsat, and Sentinel satellite imagery were employed to select each study site. Each site was selected using the following criteria:

1. The plot is located within the City of Chicago or the City of Seattle's city limits.

2. The plot is located within two miles of a body of water. (This will help control the sites for heat.)
3. The selected plot underwent a change within the 2000-2024 period to constitute an infill development.
4. Satellite imagery can fully capture the selected plot in each study period.
5. The developments were completed during or prior to 2020 to allow for any added vegetation to grow.

A total of 14 sites were selected, with seven in Chicago and seven in Seattle. Once each site was selected, the corresponding satellite images were downloaded from the Earth Explorer Database. For data in 2000, 2010, and 2024, surface reflectance and land surface temperature satellite composites were downloaded from the database. When downloaded, surface reflectance files and heat files were kept separate as they utilize different data and satellite bands. These files were originally TIF storage files before being loaded into the geographic information systems software (GIS). Data from 2017 was accessed through the Copernicus browser for the study. Copernicus operates differently from the Explorer database, as, rather than individual file downloads, the graphs were created in the browser itself. The graphs and any other data were downloaded for analysis as a single file from there.

Earth Explorer satellite images of Chicago were downloaded from July 7, 2000 (Landsat 5), July 3, 2010 (Landsat 5), and July 1, 2024 (Landsat 9). July represents the middle of summer in both cities, therefore representing the extremes of urban heat in an urban setting. Satellite imagery of Seattle was downloaded from July 30, 2000 (Landsat 7), July 27, 2010 (Landsat 5), and July 8, 2024 (Landsat 8). The satellite data was downloaded from the Earth Explorer database and loaded into ArcGIS to study vegetation and urban heat.

Once in ArcGIS, the reflection and temperature satellite bands were kept in separate maps to create separate layers and preserve data quality. After loading the files into GIS, a couple of maintenance steps were required before analysis could begin. Surface reflectance, the vegetation bands, uses multiple bands to provide adequate data. For analysis purposes, the bands were compiled into a single composite band rather than keeping multiple bands for analysis. This band was then scaled. As surface temperature only uses one band, the composite step was omitted from the process. After the composite stage, it was necessary to scale the images to access the data using GIS's analysis features. For surface temperature, the original band was scaled and then multiplied to get the data into Kelvin and eventually Celsius. The scaling and multiplying steps were essential to get the data from basic storage pixels to usable data. For surface reflectance, the composite band was scaled so that the pixels reported usable vegetation data.

A color ramp was applied to the completed thermal layers to better visualize temperatures in each city. The greyscale normalized difference vegetation index (NDVI) was run on the compiled reflectance layer, then converted to a colorized ramp showing the vegetation in each city. Once the 2000 and 2024 layers were complete, a third layer was created using ArcGIS's band arithmetic. This layer was used to show the specific change in heat and vegetation for both cities over time. Tables for every map were also created using ArcGIS's zonal statistics tool. These tables detail the maximum, minimum, median, standard deviation, and average of each site's data.

All the scaled vegetation and heat layers were then put together into a map within ArcGIS. The years and cities were kept in separate maps, so each city had three final maps, one for 2000, 2010, and 2024. Each map held the vegetation data, surface temperature data, city border, neighborhood borders, and redline designations. The final deliverables include satellite images highlighting urban heat and vegetation with the selected infill developments highlighted. It also includes a written analysis of the case study and an overview of the connections between urbanization and climate change.

Case Studies

Chicago

Overview

In the 1960s, the city of Chicago began to systematically reinvest in the Loop and other neighborhoods following previous periods of civil unrest. Historically, some Chicago neighborhoods were strictly zoned for industrial or commercial uses and bordered by neighborhoods defined as ‘hazardous’ and ‘definitely declining’ by the HOLC and Federal Housing Administration (FHA) (Nelson et al., n.d.). Often, neighborhoods within these categories were communities of color or low-income families. Now, the city has rezoned these neighborhoods so residential uses can coexist with commercial uses. The Loop and many other neighborhoods continue to be a focus of reinvestment for the city as the region sees new housing developments and industrial building conversions (Conzen et al., 2006; Garcia, 2023). As such, several infill sites within the Loop were selected for this study in addition to sites throughout the city of Chicago.

For this study, seven infill sites were chosen throughout the city. Several of the seven Chicago case studies overlap in infill development type and neighborhood formats. Table 1 below summarizes each site’s defining characteristics. Figure 1 visualizes where the infill sites are located to help orient each development within the city. The redlined neighborhood designation is also portrayed.

ID	Infill Site	Type (Predominant)	Parcel Size (Acres)	Distance to Water (Miles)	Additional Characteristics
1	South Loop	Commercial	54	1	Commercial and green space
2	Stadium Near S Side	Mixed: Housing & Commercial	24	0.5	Borders redlined neighborhood
3	Housing	Housing	9	1.3	Redlined
4	Apt/Business	Mixed: Housing & Commercial	7	1.3	Borders redlined neighborhoods
5	SFH/Commercial	Mixed: Housing & Commercial	4	0.6	Redlined
6	Kenwood Infill	Mixed: Housing & Commercial	1.83	0.38	Redlined
7	Row Homes	Housing	0.83	1.2	Redlined

Table 1: *Chicago Sites Summary Table*

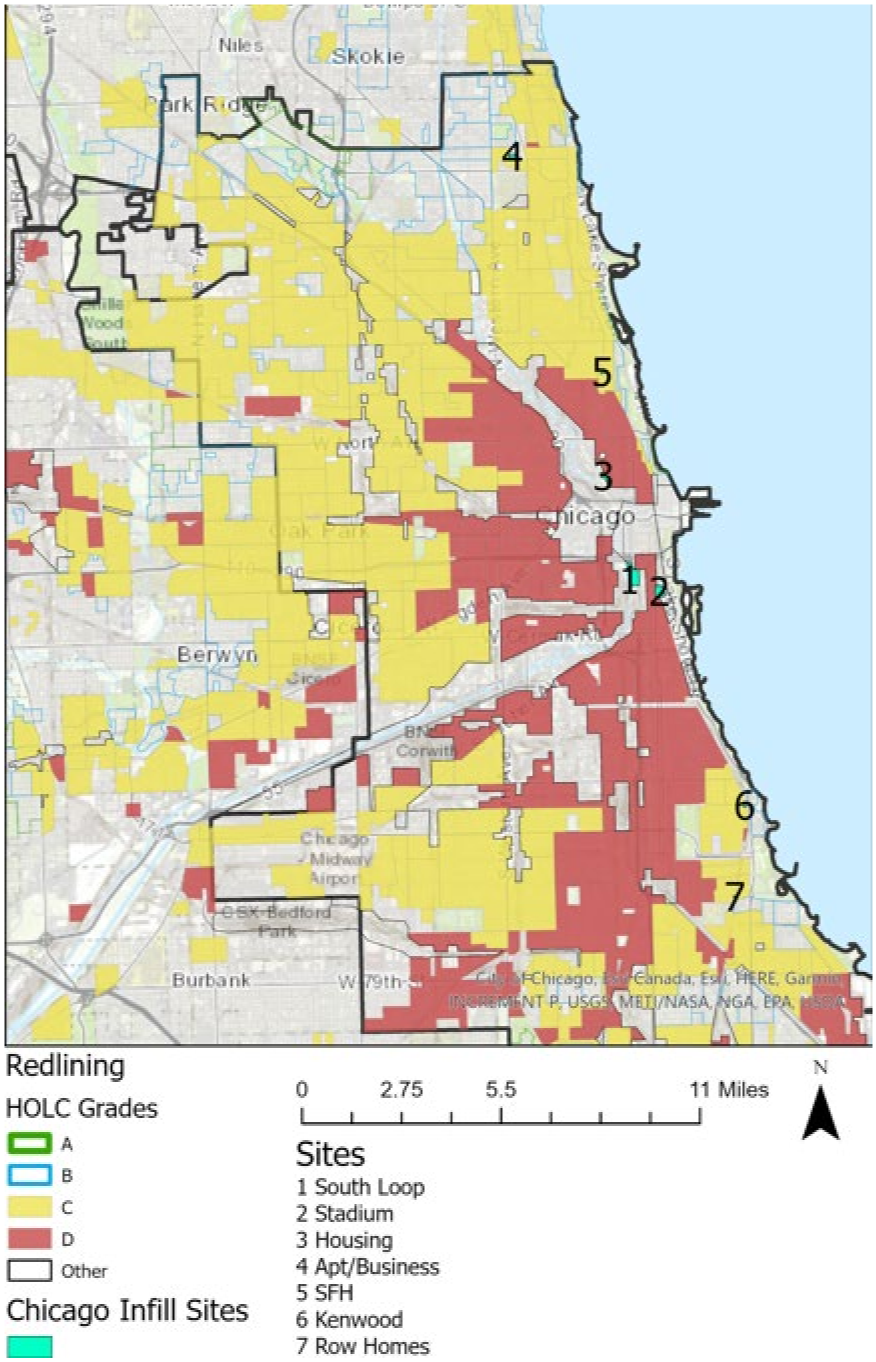

Figure 1: *Chicago Outline and Sites*

Chicago Site 1: The South Loop Site

The South Loop Site is close to the center of Chicago in the Loop neighborhood (Jessemaps, 2020). It's roughly a mile away from Lake Michigan and the largest chosen site at 54 acres. Most of the area underwent infill development, causing it to be a good case study. The commuter rail line runs through the site, which probably contributed to the infill development's location.

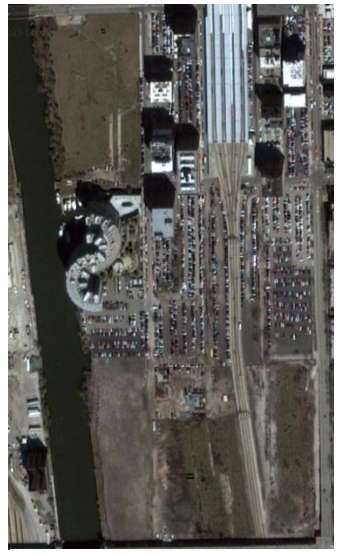

Figure 2: *Chicago Predevelopment – South Loop, April 2000*

Figure 3: *Chicago Post Development - South Loop, July 2024*

Predevelopment, the area contained parking lots with some commercial opportunities. Post development, the area now holds mainly commercial developments. Select parking lots remain, but for the most part, the area developed or preserved green space.

Chicago Site 2: Stadium Near South Side

The Stadium Near South Side location is a half mile from Lake Michigan in the Near South Side neighborhood (Jessemaps, 2020). The site makes up roughly 24 acres. The location borders a previously redlined district and Soldier Stadium, where

Figure 4: *Chicago Predevelopment - Stadium in South Loop Neighborhood, April 2000*

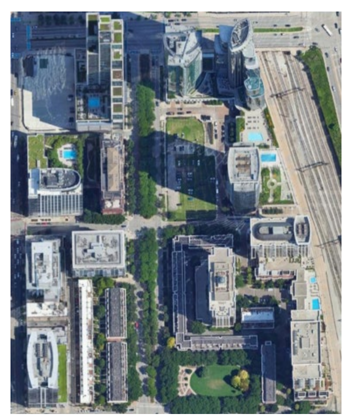

Figure 5: *Chicago Post Development - Stadium in South Loop Neighborhood, July 2023*

the Chicago Bears currently play (University of Richmond, 2023). Predevelopment, like many of the sites in this study, the land was undeveloped with a few low-density buildings. Post-development, the site became a high-density area with a mixture of high and low-rise buildings. The area now offers commercial uses, housing, and a park for recreation.

Chicago Site 3: Housing

The Housing site is located 1.3 miles from Lake Michigan in the River North neighborhood (Jessemaps, 2020). The site measures about nine acres. The Housing site's eastern edge borders a redlined neighborhood, but it was not redlined itself (University of Richmond, 2023). Predevelopment, the site held a couple of buildings with generally low density. Post development, the site became a mixture of housing types with landscape features incorporated into the courtyards.

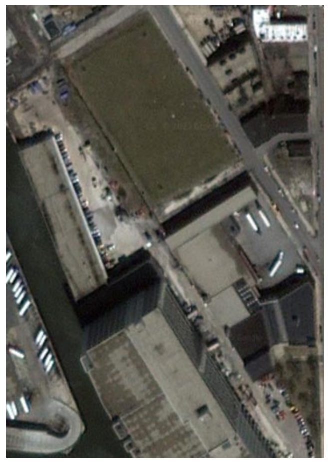

Figure 4: *Chicago Predevelopment – Housing Site, April 2000*

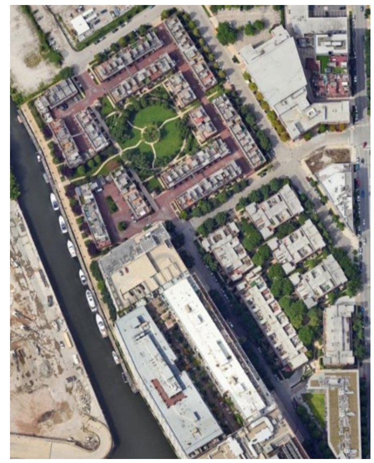

Figure 5: *Chicago Post Development – Housing Site, July 2023*

Chicago Site 4: Apartment and Business

Site 4 in the West Ridge neighborhood is the northernmost site selected for study (Jessemaps, 2020). Comprised of seven acres, it is also 1.3 miles away from Lake Michigan. Predevelopment, the site held farmland with one house. Post development, the area is now comprised of low-density apartments and businesses. The complex is also completely gated off. Like the Housing site, this site is not located in a

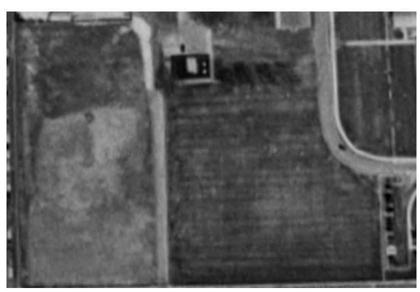

Figure 6: *Chicago Predevelopment - Apt/Business Site, March 1999*

Figure 7: *Chicago Post Development - Apt/Business Site, July 2022*

neighborhood that was redlined. However, it borders neighborhoods labeled as 'definitely declining'(University of Richmond, 2023).

Chicago Site 5: Single Family Homes and Commercial

Site 5 is located in the Lincoln Park neighborhood, previously labeled as 'definitely declining' (Jessemaps, 2020; University of Richmond, 2023). The site is four acres large and .6 miles away from Lake Michigan. Good satellite images of this site were difficult to find due to the frequency of satellite capture. In 1999, Google images show the site as an open field with a couple of trees. By the next clear capture in 2000, the site had already begun development and appeared to be empty fields with several cars. The area concluded development between 2013-2015 and now offers single-family homes, apartments, and commercial opportunities.

Figure 8*: Chicago Predevelopment - SFH/Commercial Site, April 2000*

Figure 9: *Chicago Post Development - SFH/Commercial Site, May 2019*

Chicago Site 6: Kenwood Infill

The Kenwood Infill Site is in the Hyde Park neighborhood in an area previously labeled as 'definitely declining' (Jessemaps, 2020; University of Richmond,

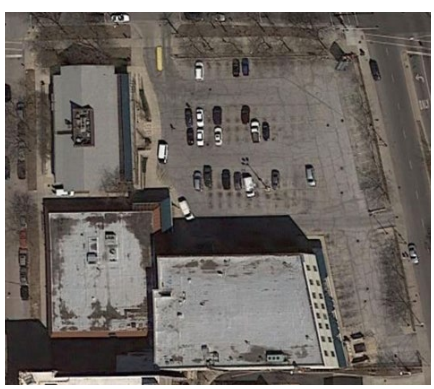

Figure 12: *Chicago Predevelopment - Kenwood Site, April 2013*

Figure 13: *Chicago Post Development - Kenwood Site, May 2021*

2023). The site rests on the Southern border of the Kenwood neighborhood. Comprised of 1.83 acres, it is also one of the smallest Chicago sites in this study. The site is located about .38 miles away from Lake Michigan. Site 6 is also one of the only Chicago sites where the main development commenced after 2000. In 2013, Site 6 comprised three commercial buildings and a parking lot.

Figure 10: *Chicago Post Development - Kenwood Site Street View, May 2021*

After significant development changes, the site now has one building. The ground floors of the building are reserved for commercial uses, and the upper floors are apartment spaces with a green roof.

Chicago Site 7: Row Homes

Sie 7 is located in the Woodlawn neighborhood, which was previously designated as 'definitely declining' (Jessemaps, 2020; University of Richmond, 2023). The site is about 1.2 miles away from Lake Michigan. Site 7 is only .83 acres, making it the smallest Chicago site. Like Site 6, the site was developed after 2010 and was mainly comprised of undeveloped land and trees. Post development, the site now comprises eight row homes with solar panels and detached garages.

Figure 15*: Chicago Predevelopment - 8 Row Homes, July 2010*

Figure 16*: Chicago Post Development - 8 Row Homes, April 2024*

Seattle

Overview

The City of Seattle is a growing metropolitan region targeting specific neighborhoods for urban growth under the new Seattle comprehensive plan. Many of the selected infill sites for this study fall into neighborhoods targeted for rezoning and urban growth. The rezoning proposal aims to increase housing diversity and supply throughout the city (*One Seattle Plan - OPCD | Seattle.Gov*, n.d.). The rezone proposal was adopted in June 2025 and is reflected in the sites studied here. The categories were Neighborhood Residential (low density housing), Lowrise 1 (low density housing allowing for townhomes up to three-stories), Lowrise 2 (multifamily housing up to four stories), Lowrise 3 (multifamily housing up to 5 stories), Midrise (multifamily housing from six-eight stories), Neighborhood Commercial (mixed use areas combining housing and commercial uses), and Commercial (retail, office, or other spaces) (*Zoning Map*, n.d.).

For this study, seven infill sites were also chosen throughout the city of Seattle. All seven Seattle sites were predominantly comprised of housing infill developments. Each site varied in size, distance to water, and additional characteristics. Table 2 below summarizes each of the major components of each infill development site. Similarly, Figure 17 visualizes where each infill is located to help orient the developments through the city. The redline designations are also listed for each neighborhood.

ID	Infill Site	Type (Mainly)	Parcel Size (Acres)	Distance to Water (Miles)	Additional Characteristics
1	Bitter Lake Townhomes	Housing	0.24	1.2	Not redlined or rezoned.
2	Apt Complex	Housing	0.8	1	Rezoned for mix of neighborhood and commercial
3	Mann Apt Complex	Housing	1.24	0.95	Redlined
4	Mann Housing	Housing	0.79	0.83	Rezoned for residential/low-rise density. Redlined
5	Minor High Rises	Housing	1.39	1.39	Rezoned for higher density. Redlined
6	Broadway Infill	Housing	0.96	1.5	Redlined
7	Seaview Complex	Housing	0.58	0.5	Only southwest Seattle site.

Table 2: *Seattle Sites Summary Table*

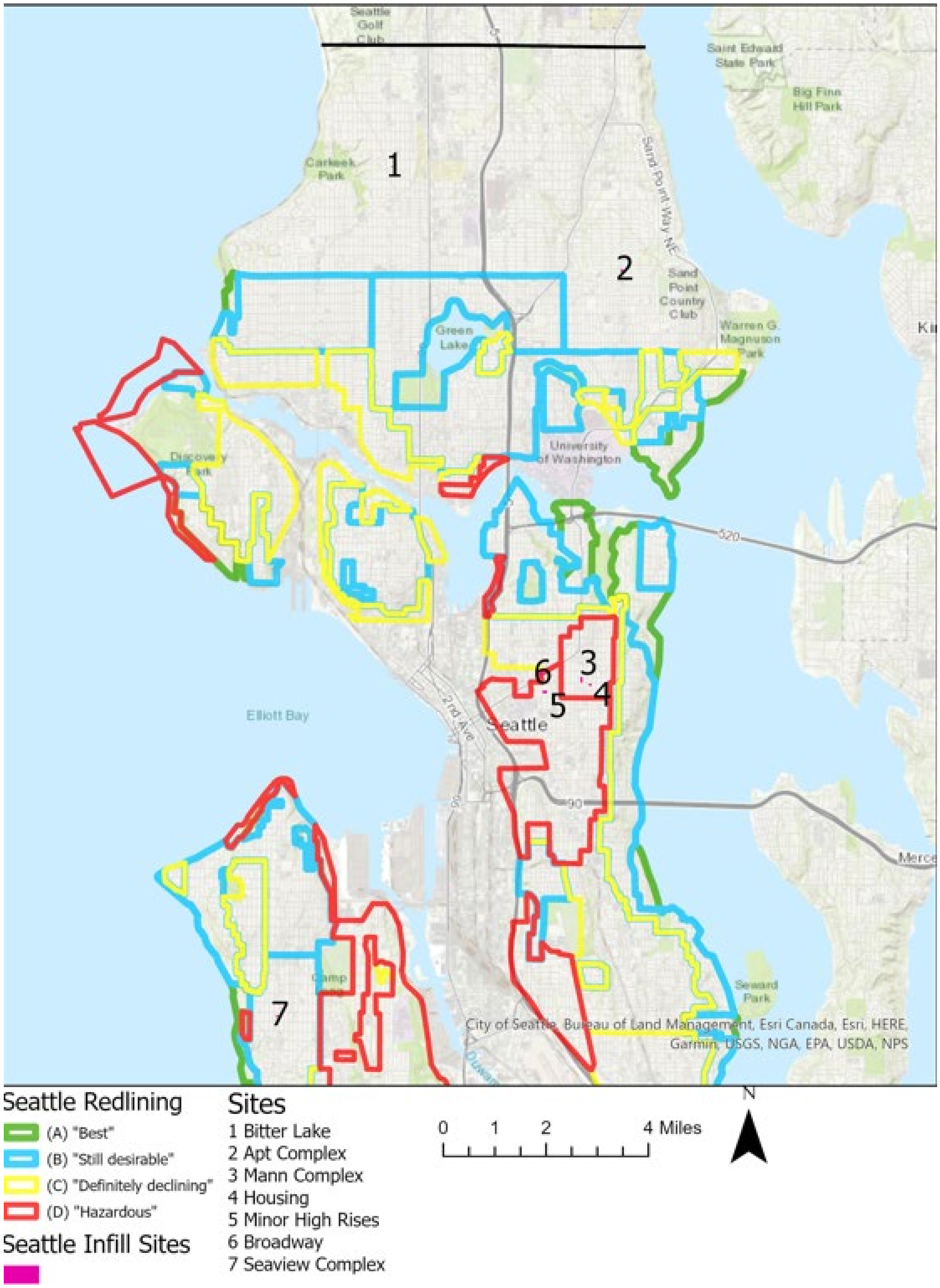

Figure 11: *Seattle Outline and Sites*

Seattle Site 1: Bitter Lake Townhomes

Site 1 is located in the Bitter Lake neighborhood of Seattle (City of Seattle Planning, 2020). Unlike the other Seattle sites, it is not located within any rezoning or redlining maps. The site is 1.2 miles away from the Puget Sound and the smallest of all the sites in this study at .24 acres. While satellite imagery is available from 2000, a clear image is not. As such, the clearest image from the early 2000s shows the predevelopment stage. Predevelopment, the site held one low-density building. Following construction completion in 2007, the site now offers eight townhomes.

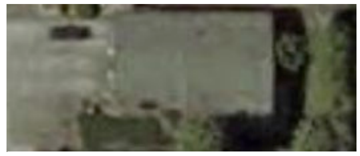

Figure 12: *Seattle Predevelopment - Bitter Lake Townhomes, June 2002*

Figure 13: *Seattle Post Development - Bitter Lake Townhomes, April 2024*

Seattle Site 2: Apartment Complex

Site 2 is located in the Wedgwood neighborhood and is currently rezoned for a mix of neighborhood and commercial (City of Seattle, 2024; City of Seattle Planning, 2020). The area was not previously listed on redline maps. The site is about .8 acres and a mile away from Lake Washington. Predevelopment, the site was an abandoned one-story commercial development. Post development, the site now operates as an apartment complex.

Figure 14: *Seattle Predevelopment - Apartment Complex, June 2002*

Figure 15*: Seattle Post Development - Apartment Complex, April 2024*

Seattle Site 3: Mann Apartment Complex

Site 3 is in the Mann neighborhood and is 1.24 acres in size. The site measures about .95 miles away from Lake Washington (City of Seattle Planning, 2020). The complex was originally labeled as 'hazardous' under the redlining map (City of Seattle, n.d.). It was not proposed for rezoning. Predevelopment, the site held one low-density commercial building and several single-family homes. Post development, three of the original homes remain, and several high-density housing complexes have been added. The new complexes also implemented a small green roof and landscaping features.

Figure 22: *Seattle Predevelopment - Mann Apt Complex, June 2002*

Figure 23: *Seattle Post Development - Mann Apt Complex, July 2024*

Seattle Site 4: Mann Housing

Site 4 is also in the Mann neighborhood of Seattle and is about .83 miles from Lake Washington (City of Seattle Planning, 2020). The site is only .79 acres but is in two zones of the rezoning map (City of Seattle, 2024). This area of Mann is now zoned for neighborhood residential and low-rise density. The site was originally labeled as 'hazardous' under the redlining map. Predevelopment, the site only offered single-family housing (City of Seattle, n.d.). Post development, several apartment complexes and townhomes have been added, raising the area's density.

Figure 16: *Seattle Predevelopment - Mann Housing, June 2002*

Figure 17: *Seattle Post Development - Mann Housing, July 2024*

Seattle Site 5: Minor High Rises

Site 5 is in the Minor neighborhood of Seattle and is about 1.39 miles from Lake Washington (City of Seattle Planning, 2020). The site is about 1.39 acres in size. Previously, the site was zoned as Low-rise 1 density and is now zoned for Low-rise 3 density (City of Seattle, 2024). Historically, the site and the entire Minor neighborhood were redlined as 'hazardous' (City of Seattle, n.d.). Predevelopment, some dense apartment complexes existed, but it mainly held single-family homes. Now, the area features several townhomes and apartment complexes, raising the site's density.

Figure 26: *Seattle Predevelopment - Minor High Rises, June 2002*

Figure 27: *Seattle Post Development - Minor High Rises, July 2024*

Seattle Site 6: Broadway Infill

Site 6 is in the Broadway neighborhood of Seattle and about 1.5 miles from Lake Washington (City of Seattle Planning, 2020). The site is .96 acres in size. While the site is not especially large, it does fall between two redlined districts. It was labeled both 'definitely declining' and 'hazardous' on redline maps (City of Seattle, n.d.). The site was not proposed for any rezoning. Predevelopment, the site had an apartment complex and two low-density commercial buildings. Post development, the apartment complex remains, and two more housing complexes were added in addition to new vegetation.

Figure 28*: Seattle Predevelopment - Broadway Infill, June 2002*

Figure 29*: Seattle Post Development - Broadway Infill, July 2024*

Seattle Site 7: Seaview Complex

Site 7 is in the Seaview neighborhood and only .5 mile from the Puget Sound (City of Seattle Planning, 2020). It is .58 acres large, and the only site selected from Southwest Seattle. It is not on the rezoning or red-lined maps. The site was originally made up of several single-family homes. Post development, the site now offers several multiplexes with a shared driveway.

Figure 19: *Seattle Predevelopment - Seaview Complex, June 2002*

Figure 18*: Seattle Post Development - Seaview Complex, July 2024*

Results

Chicago

Statistical results of Chicago's seven selected infill sites revealed temperature changes from 2000-2024. Five of the seven sites experienced an average temperature cooling, while two sites warmed. Looking at historical air temperature data, July 7, 2000, had a low air temperature of 66 degrees Fahrenheit (18º Celsius) and a high of 76 degrees Fahrenheit (24º Celsius) (*Chicago Weather in 2000*, n.d.). July 1, 2024, showed a low air temperature of 60 degrees Fahrenheit (15º Celsius) and a high of 74 degrees Fahrenheit (23º Celsius) (*Chicago Weather in 2024*, n.d.). While the air temperatures remained relatively the same, the sites each experienced a change in land surface temperature. Across all the sites, the temperature changed by up to three degrees Celsius as shown in Table 3.

ID	Infill Site	Min. Temp.	Max. Temp.	Mean
1	South Loop	-4.09	6.15	1.04
2	Stadium Near S Side	-4.78	0.21	-2.26
3	Housing	-3.02	2.39	-0.26
4	Apt/Business	0.68	5.2	3.16
5	SFH/Commercial	-7.64	-0.07	-3.53
6	Kenwood Infill	-4.99	-1.89	-3.24
7	Row Homes	-1.11	-0.85	-0.98

Table 3: *Chicago Heat Compute Change 2000-2024*

Figure 32 visualizes temperature change across the city of Chicago from 2000-2024. The map's red coloring indicates areas that experienced warming, while the blue indicates a decrease in temperature. Comparing Figure 32 and Table 3, each site is consistent with the heat map representation of temperatures throughout the city of Chicago. See Appendix B for the full map data.

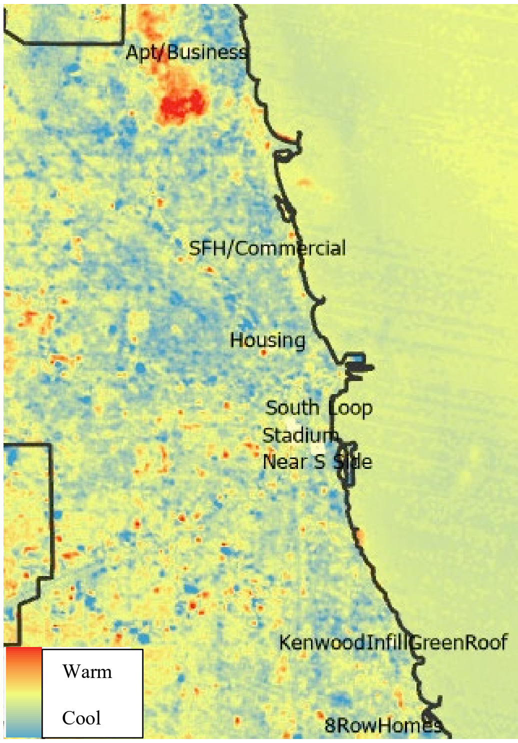

Figure 20: *City of Chicago Compute Change Heat, 2000-2024*

Normalized Difference Vegetation Index (NDVI) measures the vegetation reflected in the satellite capture. Dense and healthy vegetation receives a higher NDVI score, while barren or unhealthy vegetation will receive a score closer to -1. The NDVI scale is reported along a scale of 1 to -1. One represents the healthiest and most dense vegetation, while -1 represents unhealthy or poor vegetation. Chicago's sites all had a similar relationship to vegetation change. Six of the seven infill sites experienced a decrease in NDVI. The decreasing NDVI ranged from .02-.17. Excluding the Kenwood site, all the sites were developed on greenfield land. It's expected that they would have experienced a decrease in NDVI as vegetation was interrupted for the development.

ID	Infill Site	Mean Vegetation Density Change
1	South Loop	-0.08
2	Stadium Near S Side	-0.07
3	Housing	-0.02
4	Apt/Business	-0.12
5	SFH/Commercial	-0.04
6	Kenwood Infill	0.02
7	RowHomes	-0.17

Table 4: *Chicago NDVI Compute Change 2000-2024*

South Loop and Stadium Near South Side

The South Loop and Stadium Near South Side sites are in adjacent neighborhoods, allowing their results to be reported together. Data showed consistent temperatures between 2000 and 2024 with slight changes. As shown in Table 5, the South Loop's average temperature warmed by about one degree Celsius, and the Stadium site's average temperature cooled by about two degrees Celsius.

ID	Infill Site	Min. Temp.	Max. Temp.	Mean
1	2000 - South Loop	28.6	38.32	33.53
1	2024 - South Loop	29.85	38.74	34.58
1	South Loop Change			1.04
2	2000 - Stadium Near S Side	32.39	38.71	35.05
2	2024 - Stadium Near S Side	30.45	35.35	32.78
2	Stadium Near S Side Change			-2.26

Table 5: *Chicago Heat - Loop Sites*

As shown in Table 6, the average NDVI for both sites decreased from 2000-2024. However, data from 2010 indicates an increase in average NDVI from 2000-2010. Figure 33, representing NDVI graph data from 2015-2017, shows similar data. The summers of 2015 and 2016 reported NDVI of .2-.3, but those numbers began to dip by July of 2017. Comparing Figure 33 and Table 6 indicates the decrease in NDVI occurred sometime between 2017-2024.

ID	Infill Site	Min. Veg. Density	Max. Veg. Density	Mean
1	2000 - South Loop	0.06	0.4	0.2
1	2010 - South Loop	0.03	0.81	**0.21**
1	2024 - South Loop	0.0032	0.36	0.12
1	2000-2024 South Loop Change			-0.08
2	2000 - Stadium Near S Side	0.04	0.36	0.22
2	2010 - Stadium Near S Side	0.029	0.76	**0.23**
2	2024 - Stadium Near S Side	0.001	0.43	0.14
2	2000-2024 Stadium Near S Side Change			-0.07

Table 6: *Chicago NDVI Density Change, 2000-2024*

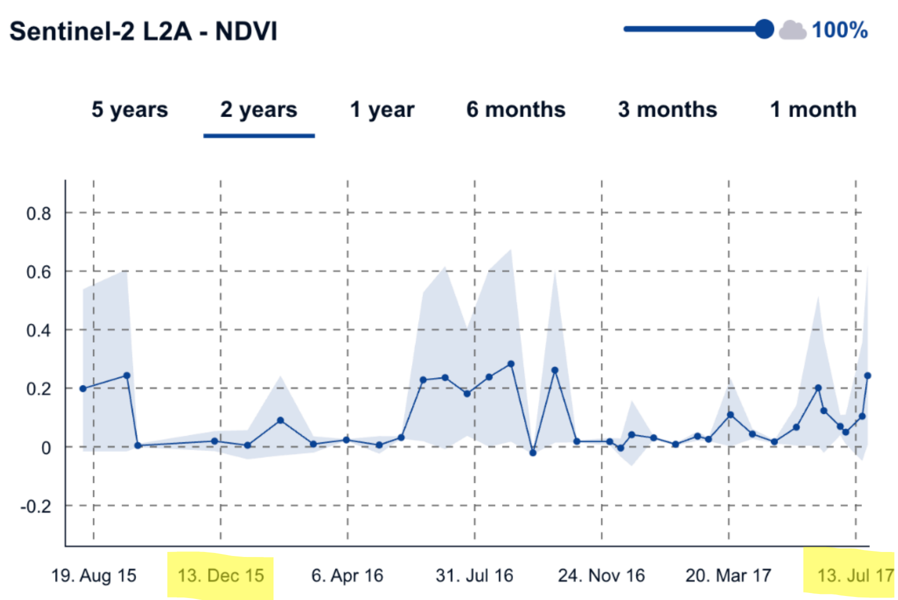

Figure 21*: Chicago Stadium Site - Sentinel NDVI Data, August 2015-July 2017*

Housing Site

Data from the Housing site showed a decrease in maximum and minimum temperatures from 2000 to 2024, but a stable average temperature. Overall, the Housing site did not experience a major change in temperature over time. The Housing site's average temperature dipped by .26 degrees for an average of 35.66 degrees Celsius in 2024.

ID	Infill Site	Min. Temp.	Max. Temp.	Mean
3	2000 - Housing	34.13	38.75	35.93
3	2024 - Housing	33.45	37.43	35.66
3	Housing Change			-0.26

Table 7*: Chicago Housing Site, Heat*

Like the previous sites, the Housing site experienced a general decrease in NDVI from 2000-2024. However, average NDVI increased by about .045 from 2000-2010 before decreasing in 2024. As shown in Table 8, the average NDVI decreased from .23 to .17 from 2010 to 2024.

ID	Infill Site	Min. Veg. Density	Max. Veg. Density	Mean
3	2000 - Housing	0.04	0.38	0.19
3	2010 - Housing	0.1	0.63	**0.23**
3	2024 - Housing	0.05	0.41	0.17
3	2000-2024 Housing Change			-0.019

Table 8: *Chicago Housing Site, NDVI*

Apartments and Businesses Site

The Apartment and Businesses site saw the largest surface temperature increase of the Chicago infill sites. As shown in Table 9, the site experienced a 3.16 degrees Celsius increase in surface temperature from 2000-2024. The average surface temperature increased to 36.65 degrees Celsius in 2024.

ID	Infill Site	Min. Temp.	Max. Temp.	Mean
4	2000 - Apt/Business	32.38	35.87	33.49
4	2024 - Apt/Business	34.13	38.22	36.65
4	Apt/Business Change			3.16

Table 9: *Chicago Apt/Business Site, Heat*

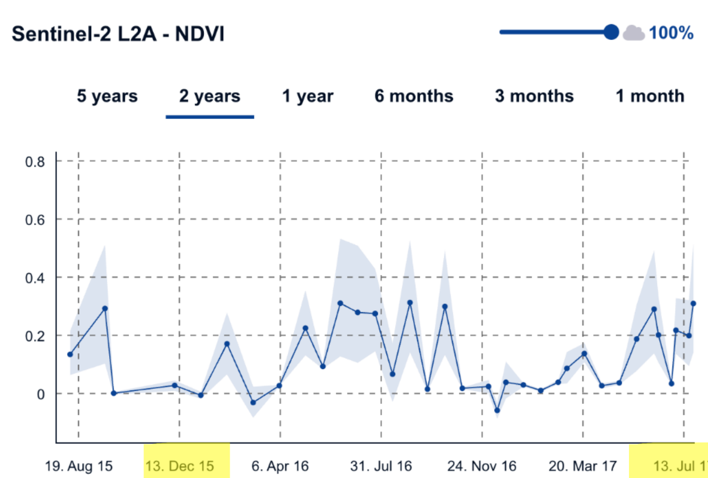

Figure 22: *Chicago Apt/Business Site - Sentinel NDVI Data 2015-2017*

The Apartment infill development, finished in 2016, greatly cut down on the existing green space on the site post development. In turn, the site added several roads, buildings, and sidewalks to the plot. Figure 34 represents the NDVI changes from the summer of 2015 to the summer of 2017. The site's NDVI dips repeatedly from December 2015 to July 2017. The data from 2016 represents the lowest NDVI reported. From 2000-2024, the NDVI experienced an average decrease of .12.

ID	Infill Site	Min. Veg. Density	Max. Veg. Density	Mean
4	2000 – Apt/Business	0.13	0.43	0.33
4	2024 – Apt/Business	0.09	0.36	0.21
4	Apt/Business Change			-0.12

Table 10: *Chicago Apt/Business Site, NDVI*

Single Family Homes and Commercial Site

The Single Family Homes and Commercial site saw the largest temperature decrease of all sites at 3.53 degrees Celsius from 2000-2024. Satellite captures before 2000 were infrequent, and the quality is not very reliable. Parts of this site began development between 1999 and 2000, so it's difficult to tell the full state of the site pre-development. However, of the other Chicago sites, this site began with the highest average temperature but ended with a temperature consistent with the other sites.

ID	Infill Site	Min. Temp.	Max. Temp.	Mean
5	2000 – SFH/Commercial	36.23	39.63	37.86
5	2024 – SFH/Commercial	31.67	36.46	34.33
5	SFH/Commercial Change			-3.53

Table 11: *Chicago SFH/Commercial Site, Heat*

The NDVI of this site did not have a significant change from 2000-2024. In total, the average NDVI decreased by .04. This is reflected in Table 12. As reflected by the 2000, 2010, and 2024 average vegetation, there was little change in the NDVI from 2000-2024.

ID	Infill Site	Min. Veg. Density	Max. Veg. Density	Mean
5	2000 – SFH/Commercial	0.1	0.22	0.15
5	2010 – SFH/Commercial	0.06	0.39	0.19
5	2024 – SFH/Commercial	0.01	0.24	0.11
5	2000-2024 SFH/Commercial Change			-0.04

Table 12: *Chicago SFH/Commercial Site, NDVI*

Kenwood Infill Site

Similar to the last site, the Kenwood site had a large average temperature decrease. The site experienced a decrease of 3.24 degrees Celsius from 2000-2024. This is represented in the mean temperatures in Table 13. The lighter blue pixels in Figure 35 also represent a decrease in temperature over time.

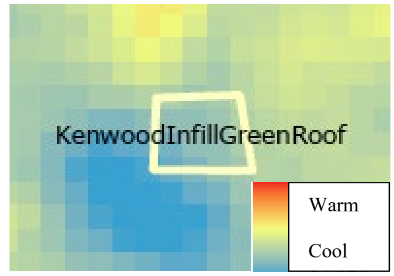

Figure 23*: Kenwood Site Compute Change - Heat 2000-2024*

ID	Infill Site	Min. Temp.	Max. Temp.	Mean
6	2000 – Kenwood Infill	36.44	38.49	37.69
6	2024 – Kenwood Infill	33.5	34.88	34.44
6	Kenwood Infill Change			-3.24

Table 13*: Chicago Kenwood Infill Site, Heat*

Kenwood began with a low average NDVI but experienced an increase by 2024. It is the only Chicago site to experience an NDVI increase. On average, the Kenwood site experienced a .02 NDVI increase from 2000-2024. The lighter grey pixels in the center of the site in Figure 36 represent the NDVI increase.

Figure 24*: Kenwood Site Compute Change - NDVI 2000-2024*

ID	Infill Site	Min. Veg. Density	Max. Veg. Density	Mean
6	2000 – Kenwood	0.08	0.26	0.154
6	2010 – Kenwood	0.03	0.37	0.2
6	2024 – Kenwood	0.099	0.3	0.18
6	2000-2024 Kenwood Change			0.026

Table 14*: Chicago Kenwood Infill Site, NDVI*

Row Homes Site

The Row Homes site experienced an average one-degree decrease in surface temperature from 2000-2024. Comparing this data to Table 3, the site's temperature is comparable to the rest of the sites.

ID	Infill Site	Min. Temp.	Max. Temp.	Mean
7	2000 – Row Homes	35.01	35.01	35.01
7	2024 – Row Homes	33.89	34.15	34.02
7	2000-2024 Row Homes Change			-0.98

Table 15: *Chicago Row Homes Site, Heat*

This site experienced the greatest decrease in NDVI of all the Chicago sites at .17. Like the other Chicago sites, the Row Homes experienced an increase in NDVI from 2000-2010. Due to construction, the NDVI then decreased again by 2024.

ID	Infill Site	Min. Veg. Density	Max. Veg. Density	Mean
7	2000 – Row Homes	0.3	0.32	0.31
7	2010 – Row Homes	0.57	0.58	0.57
7	2024 – Row Homes	0.13	0.14	0.13
7	2000-2024 Row Homes			-0.17

Table 16: *Chicago Row Homes Site, NDVI*

In total, two of the seven Chicago sites experienced an average surface temperature warming while five of them cooled. Similarly, six of the seven sites experienced a decrease in vegetation density. The Kenwood site was the only Chicago site to experience an increase in vegetation density, as summarized in Table 17 below. For the full raw data, see Appendix A.

Infill Site	Type	Parcel Size (Acres)	Distance to Water (Miles)	Heat Change (2000-2024)	Veg. Change (2000-2024)	Additional Characteristics
South Loop	Commercial	54	1	1.04	-0.08	Commercial and green space
Stadium Near S Side	Mixed: Housing & Commercial	24	0.5	-2.26	-0.07	Borders redlined neighborhood
Housing	Housing	9	1.3	-0.26	-0.019	Redlined
Apt/Business	Mixed: Housing & Commercial	7	1.3	3.16	-0.12	Borders redlined neighborhood
SFH/Comm.	Mixed: Housing & Commercial	4	0.6	-3.53	-0.04	Redlined
Kenwood Infill	Mixed: Housing & Commercial	1.83	0.38	-3.24	0.02	Redlined
RowHomes	Housing	0.83	1.2	-0.98	-0.17	Redlined

Table 17: *Compiled Heat and Vegetation Density of All Chicago Sites, 2000-2024*

Seattle

Statistical results of Seattle's seven selected sites revealed general temperature warming. Comparing surface temperature and historical air temperature, July 2024 displayed warmer temperatures. July 30, 2000, experienced a high air temperature of 85 degrees Fahrenheit (29º Celsius) and a low of 62 degrees Fahrenheit (16º Celsius) (*Seattle Weather in 2000*, n.d.). Similarly, July 8, 2024, had a high air temperature of 95 degrees Fahrenheit (35º Celsius) and a low of 67 degrees Fahrenheit (19º Celsius) (*Seattle Weather in 2024*, n.d.). Here, the air temperatures increased by about five degrees Celsius, consistent with the land surface temperature increases summarized in Table 18 below. The higher 2024 temperature most likely impacted these higher surface temperatures. As shown in Figure 37's heat map representation of the city, the sites' temperatures are consistent with each other. For the full map see Appendix B.

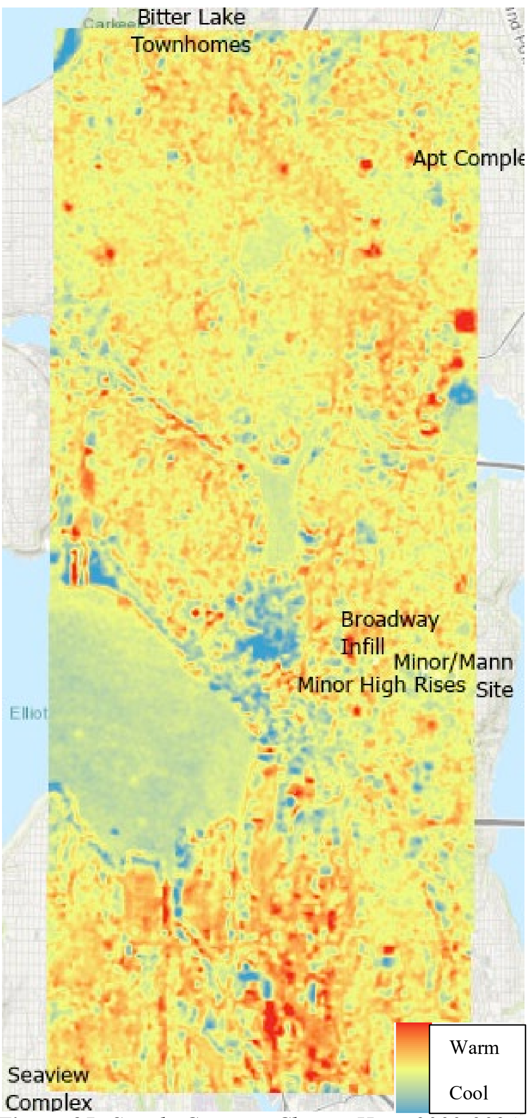

Figure 25: *Seattle Compute Change Heat, 2000-2024*

ID	Infill Site	Min. Temp.	Max. Temp.	Mean
1	Bitter Lake Townhomes	4.63	4.63	4.63
2	Apt Complex	0.71	2.49	1.72
3	Mann Apt Complex	0.92	3.48	2.46
4	Mann Housing	4.07	4.58	4.37
5	Minor High Rises	4.37	5.65	5.02
6	Broadway Infill	2.1	5.68	3.35
7	Seaview Complex	5.73	5.85	5.79

Table 18: *Seattle Selected Sites, Heat Compute Change 2000-2024*

In contrast, four of the seven sites experienced a decrease in average NDVI. Average NDVI decreased by .03-.17. The other three sites experienced a small increase in average NDVI from 2000-2024. Average NDVI increased by .03-.18.

ID	Infill Site	Mean
1	Bitter Lake Townhomes	-0.09
2	Apt Complex	0.18
3	Mann Apt Complex	-0.03
4	Mann Housing	-0.13
5	Minor High Rises	-0.17
6	Broadway Infill	0.03
7	Seaview Complex	0.03

Table 19: *Seattle NDVI Compute Change, 2000-2024*

Bitter Lake Townhomes Site

The Bitter Lake Townhomes site experienced an average temperature increase of 4.63 degrees Celsius from 2000-2024. The four-degree warming translated to a July 2024 average surface temperature of 43.22 degrees Celsius.

ID	Infill Site	Min. Temp.	Max. Temp.	Mean
1	2000 - Bitter Lake Townhomes	38.59	38.59	38.59
1	2024 - Bitter Lake Townhomes	43.22	43.22	43.224
1	Bitter Lake Townhomes Change			4.63

Table 20: *Seattle Bitter Lake Townhomes Site, Heat*

The Bitter Lake Townhomes site's average NDVI decreased by .09. This is similar to the other Seattle sites that experienced a decrease in NDVI. In total, this decrease in vegetation health and density led to an average 2024 NDVI of .23.

ID	Infill Site	Min. Veg. Density	Max. Veg. Density	Mean
1	2000 - Bitter Lake Townhomes	0.33	0.33	0.33
1	2024 - Bitter Lake Townhomes	0.23	0.23	0.23
1	Bitter Lake Townhomes Change			-0.09

Table 21: *Seattle Bitter Lake Townhomes Site, NDVI*

Apartment Complex Site

The Apartment Complex site experienced the least amount of warming of the Seattle sites. The Complex experienced an average warming of 1.72 degrees Celsius. Despite warming at a lower rate, the Apartment Complex was the warmest of all studied infill sites.

ID	Infill Site	Min. Temp.	Max. Temp.	Mean
2	2000 - Apt Complex	42.72	44.48	43.3
2	2024 - Apt Complex	44.22	45.49	45.02
2	Apt Complex Change			2.46

Table 22: *Seattle Apartment Complex Site, Heat*

The Apartment Complex site experienced the greatest increase in average NDVI across all Chicago and Seattle sites. The site experienced an average NDVI increase of .18. This is reflected in Table 23 and Figure 38. The lighter grey pixels within the site represent an increase in vegetation health and density over the 24-year period.

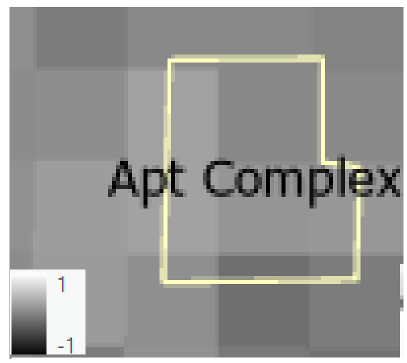

Figure 26: *Apartment Complex NDVI Map Representation, 2000-2024*

ID	Infill Site	Min. Veg. Density	Max. Veg. Density	Mean
2	2000 - Apt Complex	0.079	0.267	0.157
2	2024 - Apt Complex	0.19	0.44	0.339
2	Apt Complex Change			0.18

Table 23: *Seattle Apartment Complex Site, NDVI*

Mann Apartment Complex & Mann Housing Sites

The Mann Apartment Complex and Mann Housing Sites are in the same neighborhood, allowing them to be reported together. Both sites experienced an increase in surface temperature from 2000-2024. Specifically, the Apartment Complex warmed by 2.46 degrees Celsius and the Housing site by 4.37 degrees Celsius. This is reflected in Figure 39 as the yellow pixels indicate a slight warming. The Apartment Complex depicts some green pixels as it warmed at a lower rate than other Seattle sites.

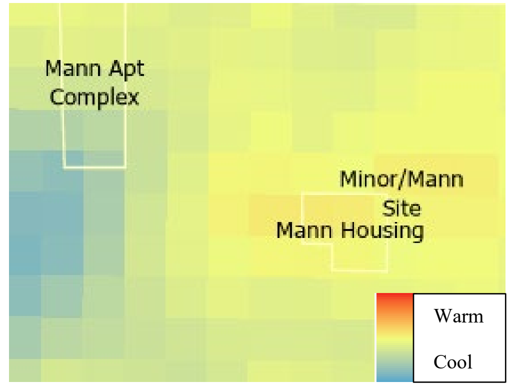

Figure 27: *Mann Sites Heat Compute Change Map, 2000-2024*

ID	Infill Site	Min. Temp.	Max. Temp.	Mean
3	2000 - Mann Apt Complex	40.39	42.44	41.18
3	2024 - Mann Apt Complex	43.37	43.87	43.64
3	Apt Complex Change			2.46
4	2000 - Mann Housing	37.6	37.96	37.84
4	2024 - Mann Housing	42.03	42.43	42.21
4	Mann Housing Change			4.37

Table 24: *Seattle Mann Housing Sites, Heat*

Both sites experienced a decrease in average NDVI. The Apartment Complex's NDVI decreased by an average of .0325. Similarly, the housing site's NDVI decreased by an average of .131.

ID	Infill Site	Min. Veg. Density	Max. Veg. Density	Mean
3	2000 - Mann Apt Complex	0.199	0.36	0.27
3	2024 - Mann Apt Complex	0.13	0.35	0.24
3	Apt Complex Change			-0.03
4	2000 - Mann Housing	0.53	0.59	0.56
4	2024 - Mann Housing	0.34	0.49	0.43
4	Mann Housing Change			-0.13

Table 25: *Seattle Mann Housing Sites, NDVI*

Broadway Infill & Minor High Rises Sites

The Broadway Infill and Minor High Rises sites are in adjacent neighborhoods, allowing them to be reported together. As shown in Table 26, both sites experienced a warming of their average surface temperature from 2000-2024. Specifically, the Minor High Rises had the second-highest warming of all Seattle sites at 5.02 degrees Celsius. The Broadway Infill site experienced a warming of 3.35 degrees Celsius.

ID	Infill Site	Min. Temp.	Max. Temp.	Mean
5	2000 - Minor High Rises	35.91	37.01	36.46
5	2024 - Minor High Rises	41.38	41.63	41.489
5	Minor High Rises Change			5.02
6	2000 - Broadway Infill	36.37	41.14	39.22
6	2024 - Broadway Infill	42.05	43.39	42.58
6	Broadway Infill Change			3.35

Table 26: *Seattle Minor and Broadway Sites, Heat*

The sites experienced differing NDVI changes. The Minor site had an average NDVI decrease of .17 from 2000-2024. The Minor site's NDVI represents the largest vegetation decrease of all Seattle sites. The Broadway Infill site experienced an average NDVI increase of .03. This is represented through the mean data in Table 27.

ID	Infill Site	Min. Veg. Density	Max. Veg. Density	Mean
5	2000 - Minor High Rises	0.45	0.63	0.54
5	2024 - Minor High Rises	0.28	0.42	0.36
5	Minor High Rises Change			-0.17
6	2000 - Broadway Infill	0.116	0.38	0.195
6	2024 - Broadway Infill	0.1	0.55	0.22
6	Broadway Infill Change			0.03

Table 27: *Seattle Minor & Broadway Sites, NDVI*

Seaview Complex Site

In total, the Seaview Complex warmed the most of all the selected study sites. The site experienced an average temperature increase of 5.79 degrees Celsius from 2000-2024. Seaview's 2024 average temperature is consistent with the other Seattle sites.

ID	Infill Site	Min. Temp.	Max. Temp.	Mean
7	2000 - Seaview Complex	37.47	37.47	37.47
7	2024 - Seaview Complex	43.2	43.32	43.26
7	Seaview Complex Change			5.79

Table 28*: Seattle Seaview Complex, Heat*

In contrast, the site did experience an increase in average NDVI. The site experienced a .03 increase in NDVI from 2000-2024. This is represented in the average data from Table 29.

ID	Infill Site	Min. Veg. Density	Max. Veg. Density	Mean
7	2000 - Seaview Complex	0.3	0.34	0.32
7	2024 - Seaview Complex	0.28	0.43	0.35
7	Seaview Complex Change			0.03

Table 29*: Seattle Seaview Site, NDVI*

In total, all seven Seattle sites experienced average temperature warming. Comparing Chicago and Seattle data, Seattle's 2024 surface temperatures ran warmer by four-eight degrees Celsius. On the other hand, four of the seven sites experienced a decrease in vegetation density, while three sites experienced an increase in vegetation density. All of Seattle's vegetation and heat characteristics are summarized in Table 30 below. For the full raw data, see Appendix A.

ID	Infill Site	Type	Parcel Size (Acres)	Distance to Water (Miles)	Heat Change (2000-2024)	Veg. Change (2000-2024)
1	Bitter Lake Townhomes	Housing	0.24	1.2	4.63	-0.09
2	Apt Complex	Housing	0.8	1	2.46	0.18
3	Mann Apt Complex	Housing	1.24	0.95	2.46	-0.03
4	Mann Housing	Housing	0.79	0.83	4.37	-0.13
5	Minor High Rises	Housing	1.39	1.39	5.02	-0.17
6	Broadway Infill	Housing	0.96	1.5	3.35	0.03
7	Seaview Complex	Housing	0.58	0.5	5.79	0.03

Table 30*: Summary of Seattle Heat and NDVI Change, 2000-2024*

Analysis

Chicago and Seattle are cities with a lot of development. As such, identifying infill developments within each city was difficult, resulting in varying parcel sizes for each site. However, in comparing findings from the cities, there are several similarities and differences in the heat and vegetation makeup. The data of each site is summarized in Table 31 below for ease of analysis.

ID	Infill Site	Veg. Change	Veg. 2024	Temp. Change (Celsius)	Temp. 2024	Use	Relationship
1-Chi	South Loop	Down .08	0.12	Up 1	34.58	C	***Inverse***
4-Chi	Apt/Business	Down .12	0.21	Up 3	36.65	M	***Inverse***
6-Chi	Kenwood	Up .02	0.18	Down 3.2	34.44	M	***Inverse***
1-Sea	Bitter Lake	Down .09	0.23	Up 4	43.22	H	***Inverse***
3-Sea	Mann Apt Complex	Down .03	0.24	Up 2	43.64	H	***Inverse***
4-Sea	Mann Housing	Down .12	0.43	Up 4.37	42.21	H	***Inverse***
5-Sea	Minor High Rises	Down .17	0.36	Up 5	41.48	H	***Inverse***
2-Chi	Stadium	Down .07	0.14	Down 2	32.78	M	*Both Down*
3-Chi	Housing	Down .01	0.17	Down .26	35.66	H	*Both Down*
5-Chi	SFH & Commercial	Down .04	0.11	Down 3	34.33	M	*Both Down*
7-Chi	Row Homes	Down .17	0.13	Down 1	34.02	H	*Both Down*
2-Sea	Apt Complex	Up .18	0.33	Up 2	45.02	H	*Both Up*
6-Sea	Broadway	Up .03	0.22	Up 3.35	42.58	H	*Both Up*
7-Sea	Seaview	Up .03	0.35	Up 5.79	43.26	H	*Both Up*

Table 31: *Summary of Chicago and Seattle Findings*

Table 31 caption: The data presented in the "Veg. Change" and "Temp. Change" are a summary of each site's change from July 2000 to July 2024. The primary use of each development is summarized by 'C' – Commercial, 'M' – Mixed: Housing and Commercial, and 'H' – Housing.

The land use of each city's infill sites differed. In total, all seven Seattle infill sites are mainly comprised of housing. While other infills exist within the city, housing was the most prominent infill in each neighborhood. Chicago's infill sites placed an emphasis on mixed-use developments. Only two of the seven Chicago sites were mainly comprised of housing complexes. All seven Chicago sites offered some housing, but the five remaining sites provided a mix of housing, commercial, or recreational uses. Most frequently, commercial uses would occupy the ground level up to the third floor, and the rest of the development was used for housing. Also, on average, the Seattle sites were smaller parcels, ranging from .25 to 1.5 acres vs. Chicago's .83 to 54-acre range in site size. While neither city prioritizes infill developments more than the other, Chicago has more variety in their infill offerings.

Within each city, the sites' surface temperature stayed consistent with each other by increasing or decreasing at a similar rate. However, the Seattle sites' surface temperature ran consistently warmer and rose at a higher rate than the Chicago sites. This is most likely indicative of Seattle's higher 2024 air temperature compared to Chicago's air temperature. Each of the temperatures studied represents the average temperature on the day of the satellite capture. So, while the entire Seattle 2024 summer may not have been warmer, the individual days measured were. In comparing July 2000 specific data from the satellite capture, there was an increase in temperature for some sites.

Seattle's sites demonstrated warm temperatures and the largest temperature increase compared to Chicago. The Seaview Complex, the site with the largest temperature increases from 2000-2024 in Seattle, warmed five degrees to 43.26 degrees Celsius. Similarly, Seattle's warmest site, the Apartment Complex, warmed by two degrees to a 2024 temperature of 45.02 degrees Celsius. Even Seattle's coolest site, the Minor High Rises, saw a five-degree Celsius temperature increase. The Apartment and Businesses site in Chicago, during the same time, warmed three degrees to 36.66 degrees Celsius. In 2024, this site saw the highest temperature increase and the highest average surface temperature of the Chicago sites. All these sites transitioned to a large amount of dense concrete and housing post development. Concrete typically absorbs and traps heat, so the decrease in vegetation in favor of concrete contributes to a higher overall temperature. These changes are most clearly visualized through street captures as illustrated in Figures 40 and 41 of the Minor High Rises site.

Figure 28: *Minor High Rises Street View, 2011*

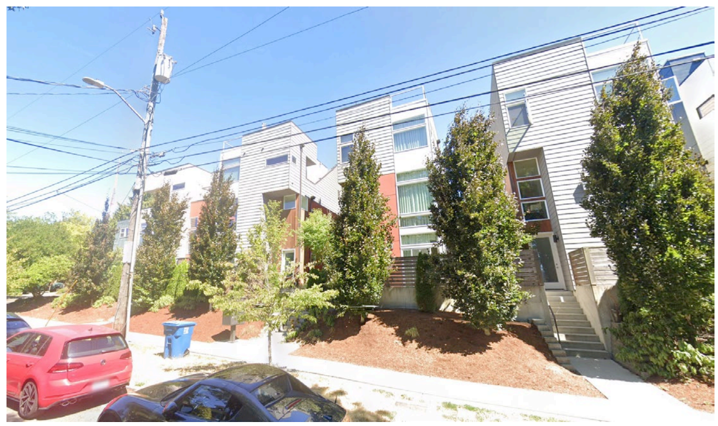

Figure 29: *Minor High Rises Street View, 2025*

Looking closer at Chicago's data, the Single Family Homes and Commercial site was the coolest, decreasing by 3.53 degrees to 34.33 degrees Celsius. This site greatly densified but added landscaping to the area as shown in Figure 42. The site was previously a brown, unvegetated field, which, like concrete, attracts heat instead of cooling. So, adding vegetation contributed to the site's cooling. As evidenced here, the

Figure 30: *SFH/Commercial Site in Chicago, Courtyard Street View 2024*

sites in Chicago had lower temperatures and warmed at a lower rate than the Seattle sites. While Chicago was cooler, both cities are exhibiting high July temperatures.

The NDVI results reflected the opposite of the surface temperature results. The hottest and coolest sites in Seattle continued to have the biggest changes in vegetation. As previously stated, the Minor High Rises's NDVI decreased to an average of .36. The Seattle Apartment Complex's NDVI increased to an average of .34. In Chicago, the Row Homes site had the biggest decrease in NDVI to an average of .13. The Kenwood Infill had the biggest Chicago NDVI increase to an average of .18. In total, the Seattle sites, on average, have higher vegetation density and health than the Chicago sites.

Overall, each city has prioritized adding vegetation to each of the infill sites. Within the small sample size in this study, Chicago was more effective in ensuring the infills had vegetation post construction. Most commonly, the sites had trees or other landscaping added. Additionally, many of the apartment complexes added green roofs to add vegetation to the site.

Comparing all the data, half of the infill sites studied showed an inverse relationship between vegetation and heat. Specifically, the South Loop, Apartment and Business, Bitter Lake Townhomes, Mann Apartment Complex, Mann Housing, and Minor High Rises sites all saw an increase in surface temperature when vegetation density decreased. Each of these sites transitioned from low-density spaces primarily with single family homes or fields to dense infill sites with lots of built materials. Therefore, each site experienced a loss in vegetation density. Typically, vegetation helps to reflect solar radiation, therefore reducing the heat felt on surfaces. Here, the sites prove that lower vegetation density correlates with higher temperatures. Increasing built and absorbent materials within a site contributes to higher temperatures in the region. Absorbent materials trap the solar radiation, causing the temperature within the area to rise, as seen in most of these sites.

The Kenwood Infill was the only site to see an inverse relationship when vegetation increased, causing temperature to decrease. This site transitioned from a few commercial buildings and a large surface parking lot to a single building with a green roof. The vegetation increased here as the previous site did not feature any vegetation. While the site continued to feature a building, the loss in surface parking, typically a large source of heat, also contributed to the decrease in temperature.

The other seven infill sites reacted unexpectedly. The Apartment Complex, Broadway Infill, and Seaview Complex, the remaining of the Seattle sites, all experienced an increase in NDVI and surface temperature. Each of these sites added vegetation, raising the NDVI by .03-.18, but the majority of the sites continue to be made up of concrete. This is most evident by the street view captures of the Seaview Complex in Figures 43 and 44. Here, the increase in concrete through the infill developments raised the temperature despite the vegetation additions. The remaining four Chicago sites faced a similar outcome.

Figure 43: *Seaview Complex Street View, 2007*

Figure 44: *Seaview Complex Street View, 2011*

Figure 31*: Housing Site Street Views, 2024*

Similarly, the Stadium, Housing, Single Family Homes and Commercial, and Row Homes sites all saw a decrease in NDVI and surface temperature. The Stadium, Housing, Single Family Home and Commercial sites predevelopment were all occupied by unused fields or lots. While the vegetation may have been higher there, it would also have attracted heat if there were barren land or high amounts of surface parking or concrete. Post development, many of the pre-existing surface parking lots were removed and replaced with buildings and landscaping, as shown in the Housing site in Figure 45. The combination of landscaping and removal of impervious parking lot material contributed to these sites experiencing a decrease in vegetation and temperature.

The outlier to this cohort is the Row Homes site. Previously, the lot was unused and mainly contained lush trees and grasses. In 2024, despite removing much of the landscaping and adding concrete, the site experienced a decrease in temperature. Each of the homes features several solar panels, potentially making up for the decrease in recorded satellite temperature. Overall, it’s unclear why the site reacted this way, leaving it as an outlier among the data.

While vegetation did have positive impacts on the sites in this study, the predevelopment stage was more indicative of each site’s temperature. Sites that had a high density of surface parking or concrete buildings decreased in temperature even if the new infill was another building. Therefore, the biggest factor in temperature change for each of these infill developments was what inhabited the space pre and post development. So, infill developments do not inherently reduce heat on their own without focused efforts. However, vegetation should still be implemented post development as a mechanism to mitigate urban heat.

Lastly, it's important to note that of the 14 sites selected for study, eight are in redlined neighborhoods and two directly border redlined districts. Across each of the ten sites, there is not one piece of data that singularly connects them. The temperature experience, vegetation, and primary development all vary. However, the variance also indicates a reinvestment into each of the neighborhoods by providing new housing and commercial services.

Recommendations & Limitations

This study yielded several recommendations based on the impact each infill development had on vegetation and surface temperature. These recommendations should be taken into future studies and planning decisions related to infill developments. Similarly, the nature of using satellite imagery created limitations that can be addressed through different study periods and software usage.

Recommendations

Cities prioritizing infill developments should also prioritize preserving or adding vegetation into the design. Of the studied infill sites, those with the highest surface temperature reductions already had or added vegetation on the site over the study period. Adding or maintaining vegetation helps to mitigate surface temperature. Similarly, vegetation improves residents' experiences while also providing additional habitat for local species that may be displaced by the construction associated with new development. Specific strategies, such as green roofing and landscaping, help to mitigate temperatures as seen in Chicago's Kenwood and Single Family Home and Commercial sites.

In addition to vegetation, cities should prioritize green development strategies within their infill sites. High density of impervious concrete, as seen in Chicago's Apartment and Business site and Seattle's Apartment Complex site contribute to higher surface temperatures. These sites exhibited high average NDVI scores, relative to the other sites within their cities, but remained the hottest sites in each of their respective cities. The sites added roads and multiple buildings, contributing to the site warming. To avoid similar warming, future infill sites should prioritize pervious building materials that will reflect or filter rather than absorb heat like concrete does.

Several cities have implemented incentives and faster permit processes to encourage infill development. Cities looking to prioritize infill development should prioritize similar initiatives, especially by incentivizing developers to provide vegetation. Providing faster permit processes or waiving fees in return for developers adding vegetation would positively impact the surface temperature for sites post development. Similarly, it would increase the average NDVI of infill developments if developers were required to implement vegetation.

As the city of Seattle has done, other cities should also investigate comprehensive rezoning measures. Seattle's rezoning designates neighborhoods or regions for higher density, allowing for infill development. Rezoning allows for denser units within the city and therefore disincentivizes sprawl along the city's border. These measures would contribute to denser communities and decreasing reliance on vehicle transportation as more residents are concentrated within the city center.

Similarly, zoning codes can incorporate form-based codes to encourage and ease the process of infill developments. Form-based codes focus on the interaction of buildings and physical space rather than regulating a specific block for one use (Garvin & Jourdan, 2008). Form-based codes rely on graphics and illustrations to make codes accessible to a wider range of developers and citizens. The visual nature of the codes allows for developments to be adopted with less paperwork and bureaucracy (Garvin & Jourdan, 2008). Form-based codes also offer the opportunity for mixed-use development, higher connectivity, differing lot sizes, and diverse physical form (Talen, 2013). In total, form-based codes encourage infill development through easing the zoning and permit processes.

Recommendations for Future Studies

Additional studies on infill's relationship with vegetation and surface temperature should add more data for each city. Additional sites and study dates would create a fuller picture of infill development's impact throughout the cities. As each point gathered data from a single day within each year, it was highly impacted by changing weather. More sites and data points within one year would help to stabilize and create more confidence in the analysis of this study. In-person studies of the surface temperature and NDVI would also limit the error caused by pixel size.

Both cities are concentrating on density, specifically in housing supply. Additional studies should evaluate the effectiveness of infill developments in providing housing and mitigating surface temperature within dense regions. Similarly, studies should continue to investigate the diverse practice of mixed-use development, within infill developments, as the city of Chicago implemented.

Infill developments can be connected to gentrification depending on the context of their presence or implementation. Future studies should identify the role that gentrification plays for each of the individual sites. While gentrification does not directly correlate to the realm of this study on vegetation and surface temperature, it does relate to the character of the greater neighborhood or region. Identifying infill development's place within gentrification could help identify broader implications of encouraging new development.

Limitations

One limitation of this study was the data publicly available through satellite imagery. Accessing data before 2000 was challenging due to the inconsistent rate of satellite captures. Specifically, there were some sites that began development in 2000, making the predevelopment conditions difficult to gauge. This may be solved through focusing the start of research in the

2010s rather than the early 2000s. Similarly, the gap between Landsat 7's crash and subsequent blurry satellite captures, and Landsat 8/9's launch spans multiple years. As such, the broad timeline of this study created a challenge in gathering consistent satellite capture quality. Narrowing the timeline of the study would help in reducing the number of outliers from poor-quality images. So, as each year's data was represented by one day in July, it could be easily impacted by abnormal weather. Therefore, narrowing the timeline and adding multiple days within each year for data would have improved the accuracy of the data collected.

Additionally, GIS and satellite data operate on pixels to store data. All the data used for this study was the average of each of the pixels grabbed. Therefore, as many of the sites were small parcels of land, the pixels may not be the most accurate way of capturing temperature and NDVI change. Larger sites could aid in more accurate data capturing, as the study would have more pixels to add to the capture.

Conclusion

This study set out to determine if there was a relationship between infill developments, vegetation, and surface temperature. By virtually canvassing neighborhoods throughout Chicago and Seattle, 14 infill sites were selected for study. Sites were chosen if they were within the city limits of Chicago or Seattle, underwent an infill development, finished development before or during 2020, were within two miles of a large body of water, and could be completely captured by satellite imagery. Each site's vegetation and surface temperature were studied in ArcGIS and the Copernicus browser over July 2000, 2010, 2017, and 2024. In total, six ArcGIS maps, 16 tables, and 28 graphs were compiled to determine if there was a relationship between vegetation, surface temperature, and infill development. Additionally, the evolution of each site was tracked to determine if the sites themselves underwent significant changes over the 24-year period.

After compiling all the data and scaling the satellite images, each site was ready for analysis. The study revealed that both cities experienced warm July temperatures over the course of this study. While sites within both cities experienced warming and cooling, the site data indicated warming and hot urban summer temperatures. Comparing the sites, Seattle consistently had warmer temperatures but higher NDVI than Chicago's sites.

Additionally, the study found that there was a relationship between vegetation presence and surface temperature on infill sites. Of the 14 sites, seven sites throughout Chicago and Seattle revealed a decrease in vegetation lead to an increase in temperature. While the remaining seven sites had surprising results, they revealed the importance of each site's development conditions. The remaining Chicago sites all had higher NDVI scores predevelopment, causing them to dip with the infill development. However, these sites also decreased surface parking and barren land, which raises surface temperature, contributing to the site's cooler temperature post removal. The remaining Seattle sites slightly increased their vegetation but also added a significant amount of concrete and built materials, contributing to their temperature increase. These sites proved that vegetation is only one aspect of a site's surface temperature. For best results, vegetation should be combined with development to mitigate heat and reduce negative human health outcomes, environmental disasters, and improve the general quality of life. However, infill developments don't inherently reduce heat on their own, as the built materials and vegetation play a significant role. Therefore, the development type and materials are just as important as vegetation density when it comes to temperature impact.

Overall, infill developments allow cities to increase their density and meet diversity needs. In total, eight of the 14 selected sites were in previously redlined neighborhoods, with an additional two sites directly bordering these neighborhoods. Redlined neighborhoods have historically struggled with funding, higher temperatures, a lack of vegetation, and more. Infill development provides an opportunity for more equitable design, especially in these communities. As shown by the sites in this study, infill developments, granted they add vegetation, increase the amount of greenery within a neighborhood while also increasing housing choice, mixed-use development, and walkability. Each of these aspects of infill development is historically underserved in redlined communities and vital for cities. So, while infill developments are not a fix-all, they do provide the opportunity to reinvest in traditionally underserved communities while simultaneously meeting density, housing, vegetation, and temperature needs throughout the city.

Appendix A

Raw Table Data

Table A1: Chicago Heat Data, July 2000

ID	Infill Site	Min. Temp.	Max. Temp	Range	Mean	STD	Median
1	South Loop	28.60473	38.329	9.72426	33.5369	2.65391	33.0071
2	Stadium Near S Side	32.3919	38.71182	6.31991	35.0578	1.37325	34.8768
3	Housing	34.13851	38.75625	4.61774	35.9303	1.35394	35.4749
4	Apt/Business	32.38164	35.87828	3.49663	33.4934	0.89948	33.0857
5	SFH/Commercial	36.23375	39.6381	3.40434	37.8672	1.02180	37.912
6	Kenwood Infill	36.44909	38.49648	2.04739	37.6934	0.61357	37.9290
7	8RowHomes	35.0101	35.0101	0	35.0101	0	35.0101

Table A2: Chicago Heat Data, July 2010

ID	Infill Site	Min. Temp.	Max. Temp.	Range	Mean	STD	Median
1	South Loop	32.3782	42.55367	10.17544	38.26801	2.941725	39.1527
2	Stadium Near S Side	36.0662	42.45113	6.384861	39.67297	1.349580	39.4535
3	Housing	38.3358	42.52974	4.193910	40.83365	1.248182	41.5966
4	Apt/Business	39.1424	41.60687	2.464392	40.34666	0.720296	40.4686
5	SFH/Commercial	40.7728	42.72457	1.951689	41.92714	0.521591	42.1110
6	Kenwood Infill	37.3377	40.26018	2.922407	39.10328	0.797166	39.3031
7	8RowHomes	36.66442	37.14978	0.485358	36.98685	0.227998	37.1463

Table A3: Chicago Heat Data, July 2024

ID	Infill Site	Min. Temp.	Max. Temp.	Range	Mean	STD	Median
1	South Loop	29.852309	38.742579	8.89027	34.5831	2.14324	34.5708
2	Stadium Near S Side	30.450462	35.358739	4.908277	32.7898	1.106069	32.7986
3	Housing	33.454902	37.436895	3.981993	35.6627	1.265198	35.7757
4	Apt/Business	34.135088	38.229876	4.094788	36.6558	1.101959	36.9635
5	SFH/Commercial	31.670695	36.462759	4.792064	34.3315	1.3979	34.9622
6	Kenwood Infill	33.502754	34.883634	1.38088	34.4493	0.339876	34.5162
7	8RowHomes	33.892408	34.159014	0.266606	34.0257	0.133303	34.0257

Table A4: Chicago Heat Data Compute Change, July 2000-2024

ID	Infill Site	Min. Temp.	Max. Temp.	Range	Mean	STD	Median
1	South Loop	-4.091370	6.1592721	10.25064	1.0462157	2.7026802	1.150163
2	Stadium Near S Side	-4.788646	0.2187532	5.007399	-2.267966	1.2572371	-2.23196
3	Housing	-3.028365	2.3960320	5.424397	-0.267602	1.2724737	-0.24609
4	Apt/Business	0.687022	5.2056446	4.518622	3.1624780	1.0628727	3.175340
5	SFH/Commercial	-7.646110	-0.071778	7.574332	-3.535697	2.281367	-3.10014
6	Kenwood Infill	-4.993727	-1.897001	3.096726	-3.244189	0.8435991	-3.25737
7	8RowHomes	-1.117692	-0.8510869	0.2666056	-0.984389	0.1333028	-0.98438

Table A5: Chicago NDVI Data, July 2000

ID	Infill Site	Min. NDVI	Max. NDVI	Range	Mean	STD	Median
1	South Loop	0.063231	0.401046	0.33781	0.2052	0.09487	0.16764
2	Stadium Near S Side	0.040814	0.369745	0.32893	0.2217	0.09065	0.22111
3	Housing	0.045447	0.383136	0.33768	0.1943	0.09583	0.15497
4	Apt/Business	0.132908	0.433707	0.30079	0.3311	0.06588	0.33085
5	SFH/Commercial	0.105069	0.229148	0.12407	0.1541	0.02708	0.15540
6	Kenwood Infill	0.084338	0.262341	0.17800	0.1540	0.04963	0.16157
7	8RowHomes	0.304292	0.321217	0.016925	0.3127	0.00846	0.31275

Table A6: Chicago NDVI Data, July 2024

ID	Infill Site	Min. NDVI	Max. NDVI	Range	Mean	STD	Median
1	South Loop	0.0031862	0.3613008	0.358115	0.1232	0.0757	0.104614
2	Stadium Near S Side	0.0004926	0.437734	0.437241	0.148637	0.1031	0.1181853
3	Housing	0.0579141	0.4192211	0.361307	0.174753	0.0672	0.1644652
4	Apt/Business	0.0931377	0.3621333	0.268996	0.210059	0.0658	0.2062198
5	SFH/Commercial	0.0106896	0.2490274	0.238338	0.112025	0.0691	0.1151758
6	Kenwood Infill	0.0991878	0.3043242	0.205136	0.18042	0.0614	0.1761079
7	8RowHomes	0.1320318	0.1430017	0.01097	0.137517	0.0055	0.1375168

Table A7: Chicago NDVI Data Compute Change, July 2000-2024

ID	Infill Site	Min. NDVI	Max. NDVI	Range	Mean	STD	Median
1	South Loop	-0.38655	0.175061	0.561613	-0.08209	0.102229	-0.06947
2	Stadium Near S Side	-0.31262	0.284205	0.596821	-0.07316	0.126321	-0.06876
3	Housing	-0.30016	0.153613	0.453775	-0.01964	0.104211	0.009273
4	Apt/Business	-0.25932	0.068265	0.327588	-0.12112	0.088839	-0.11621
5	SFH/Commercial	-0.17186	0.091945	0.263806	-0.04213	0.06961	-0.03255
6	Kenwood Infill	-0.06688	0.169014	0.235889	0.026414	0.079196	0.027559
7	8RowHomes	-0.17822	-0.17226	0.005956	-0.17524	0.002978	-0.17524

Table A8: Seattle Heat Data, July 2000

ID	Infill Site	Min. Temp.	Max. Temp.	Range	Mean	STD	Median
1	Bitter Lake Townhomes	38.59218626	38.59218626	0	38.592	0	38.592186
2	Apt Complex	42.72457244	44.48827076	1.764	43.305	0.65	43.151825
3	Mann Apt Complex	40.39006478	42.44771282	2.058	41.184	0.731	41.03778
4	Mann Housing	37.60096046	37.96327058	0.362	37.843	0.171	37.963271
5	Minor High Rises	35.9158766	37.01989706	1.104	36.468	0.552	36.467887
6	Broadway Infill	36.37047326	41.14886522	4.778	39.223	1.571	39.368077
7	Seaview Complex	37.4710757	37.4710757	0	37.471	0	37.471076

Table A9: Seattle Heat Data, July 2010

ID	Infill Site	Min. Temp.	Max. Temp.	Range	Mean	STD	Median
1	Bitter Lake Townhomes	36.0081631	36.0115812	0.003	36.01	0.002	36.009872
2	Apt Complex	36.7396194	37.8436399	1.104	37.29	0.552	37.29163
3	Mann Apt Complex	36.1209578	37.6693209	1.548	36.87	0.581	36.852414
4	Mann Housing	33.7351798	34.2923171	0.557	34.11	0.263	34.292317
5	Minor High Rises	31.6365156	32.7781342	1.142	32.21	0.404	32.207325
6	Broadway Infill	35.5843287	36.1995723	0.615	35.92	0.271	36.13463
7	Seaview Complex	32.9251091	32.9251091	0	32.93	0	32.925109

Table A10: Seattle Heat Data, July 2024

ID	Infill Site	Min. Temp.	Max. Temp.	Range	Mean	STD	Median
1	Bitter Lake Townhomes	43.22360336	43.22360336	0	43.2	0	43.223603
2	Apt Complex	44.22508322	45.49316864	1.268	45	0.43	45.202637

3	Mann Apt Complex	43.37741426	43.87302716	0.496	43.6	0.17	43.683327
4	Mann Housing	42.0341324	42.43062272	0.396	42.2	0.16	42.184525
5	Minor High Rises	41.3847086	41.63422406	0.25	41.5	0.09	41.473577
6	Broadway Infill	42.0512225	43.39792238	1.347	42.6	0.44	42.500692
7	Seaview Complex	43.20651326	43.32272594	0.116	43.3	0.06	43.26462

Table A11: Seattle Heat Data Compute Change, July 2000-2024

ID	Infill Site	Min. Temp.	Max. Temp.	Range	Mean	STD	Median
1	Bitter Lake Townhomes	4.6314173	4.6314173	0	4.6314	0	4.631417
2	Apt Complex	0.7143662	2.4917367	1.78	1.724	0.701	2.061066
3	Mann Apt Complex	0.9297015	3.4829624	2.55	2.4631	0.895	2.654093
4	Mann Housing	4.0708618	4.5835648	0.51	4.3739	0.219	4.467352
5	Minor High Rises	4.3750658	5.6568232	1.28	5.0211	0.544	5.041579
6	Broadway Infill	2.1020823	5.6807494	3.58	3.3576	1.194	3.132615
7	Seaview Complex	5.7354374	5.8516502	0.12	5.7935	0.058	5.793544

Table A12: Seattle NDVI Data, July 2000

ID	Infill Site	Min. NDVI	Max. NDVI	Range	Mean	STD	Median
1	Bitter Lake Townhomes	0.33110368	0.3311037	0	0.3311	0	0.3311
2	Apt Complex	0.07976807	0.2675292	0.1878	0.1576	0.06	0.14275
3	Mann Apt Complex	0.19930238	0.3654734	0.1662	0.2756	0.06	0.2453
4	Mann Housing	0.53981578	0.5979102	0.0581	0.5665	0.02	0.56171
5	Minor High Rises	0.45045209	0.6328819	0.1824	0.5406	0.06	0.54619
6	Broadway Infill	0.11663502	0.3842478	0.2676	0.1953	0.09	0.14591
7	Seaview Complex	0.3068164	0.3478168	0.041	0.3273	0.02	0.32732

Table A13: Seattle NDVI Data, July 2010

ID	Infill Site	Min. NDVI	Max. NDVI	Range	Mean	STD	Median
1	Bitter Lake Townhomes	0.251725197	0.2517252	0	0.25173	0	0.2517252
2	Apt Complex	0.180912718	0.33373025	0.15282	0.2323	0.053	0.2181017
3	Mann Apt Complex	0.157415658	0.43940291	0.28199	0.31886	0.0896	0.3337608
4	Mann Housing	0.468780965	0.55193001	0.08315	0.52244	0.038	0.5465974
5	Minor High Rises	0.353592664	0.6630981	0.30951	0.49989	0.1	0.4841209
6	Broadway Infill	0.013865194	0.46324137	0.44938	0.16948	0.1435	0.131173

7	Seaview Complex	0.222426713	0.2587162	0.03629	0.24057	0.0181	0.2405715

Table A14: Seattle NDVI Data, July 2024

ID	Infill Site	Min. NDVI	Max. NDVI	Range	Mean	STD	Median
1	Bitter Lake Townhomes	0.235801965	0.23580196	0	0.2358	0	0.235802
2	Apt Complex	0.194048733	0.4437924	0.2497	0.33995	0.1035	0.4002363
3	Mann Apt Complex	0.130589053	0.35576212	0.2252	0.24301	0.0772	0.2568976
4	Mann Housing	0.345279336	0.49778309	0.1525	0.43546	0.0653	0.4633214
5	Minor High Rises	0.281037658	0.42771453	0.1467	0.36183	0.0481	0.3702537
6	Broadway Infill	0.105639815	0.55182272	0.4462	0.2273	0.1513	0.1648898
7	Seaview Complex	0.286049396	0.43235639	0.1463	0.3592	0.0732	0.3592029

Table A15: Seattle NDVI Data Compute Change, July 2000-2024

ID	Infill Site	Min. NDVI	Max. NDVI	Range	Mean	STD	Median
1	Bitter Lake Townhomes	-0.0953017	-0.095302	0	-0.095	0	-0.0953
2	Apt Complex	0.0558396	0.265134	0.21	0.1823	0.08	0.17626
3	Mann Apt Complex	-0.1833343	0.1243751	0.31	-0.033	0.12	-0.03112
4	Mann Housing	-0.2164306	-0.076494	0.14	-0.131	0.06	-0.10013
5	Minor High Rises	-0.2494395	-0.088119	0.16	-0.179	0.06	-0.18737
6	Broadway Infill	-0.0939693	0.167575	0.26	0.032	0.09	0.03114
7	Seaview Complex	-0.020767	0.0845396	0.11	0.0319	0.05	0.03189

Appendix B

Full Map Data

Figure B1: Chicago Compute Change, Heat 2000-2024

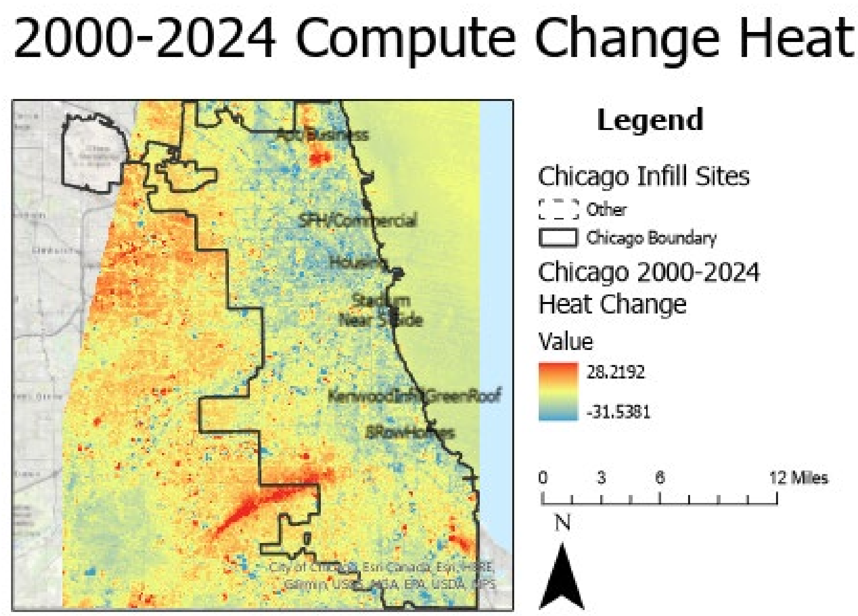

Figure B2: Chicago Compute Change, NDVI 2000-2024

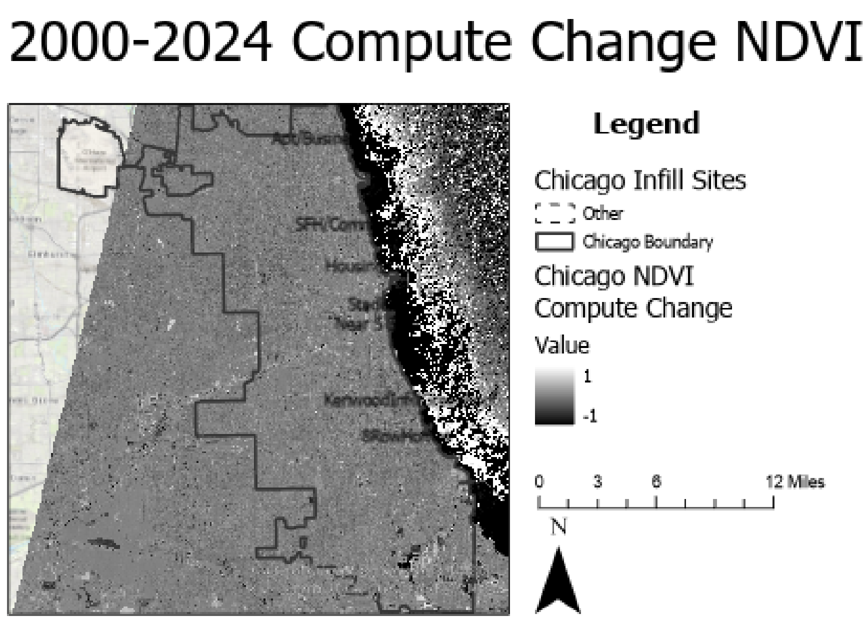

Figure B3: Seattle Compute Change, Heat 2000-2024

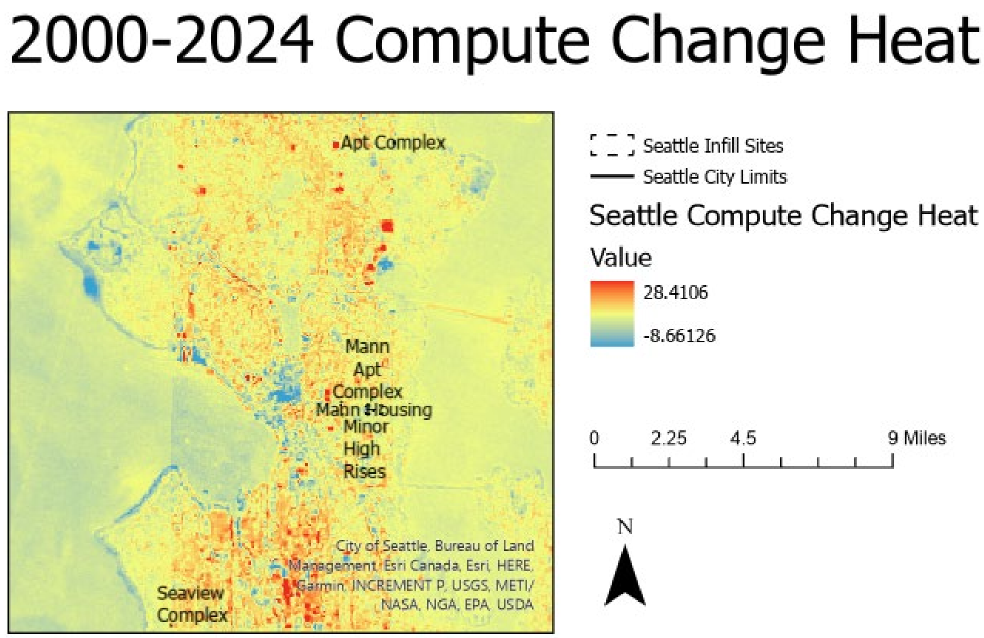

Figure B4: Seattle Compute Change, NDVI 2000-2024

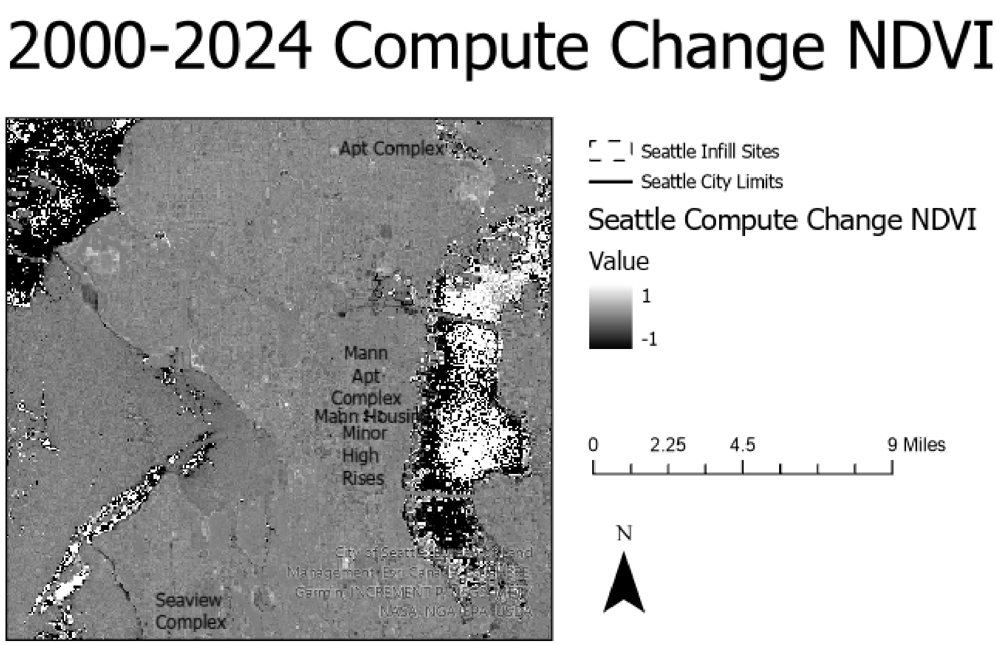

Image Credits

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