Designing Neighborhood-Scale Green Infrastructure (GI) to Improve the Health and Well-Being of Industry-Adjacent Communities through Air Pollution Mitigation in Joppa, Texas

by

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ABSTRACT

Designing Neighborhood-Scale Green Infrastructure (GI) to Improve the Health and Well-Being of Industry-Adjacent Communities through Air Pollution Mitigation in Joppa, Texas

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Ambient outdoor air pollution kills roughly 4.2 million people every year worldwide and is linked as a contributing factor to diseases such as asthma, cancer, infertility, and neurological disorders. In the United States, minority communities are more likely to live near sources of air pollution, such as highways and industrial sites, and therefore face higher risks of developing the associated health difficulties. According to the Environmental Protection Agency (EPA), people of color (POC) are exposed to disproportionately higher levels of ambient fine particulate matter (PM) air pollution, regardless of income levels or region. While the EPA monitors and enforces outdoor air quality standards across the US, there are not regulatory standards for the distances between air pollution sources and neighborhoods. There is a need for site-specific and short-term solutions. The EPA recommends tree planting as a strategy for improving air quality, with total annual air pollution removal by US urban trees estimated to be 711,000 metric tons, a $3.8 billion value. This design thesis explores the benefits of Green Infrastructure (GI) in addressing air pollution as well as secondary benefits including but not limited to decreased flood risk, increased access to open green space, and increased-community value. A multi-method approach is used to study the issues of air pollution and vegetation, employing GIS-mapping, case-studies, expert interviews, and i-Tree planting calculator to produce findings which can inform a design. The GIS findings resulted in a map of Dallas revealing where PM air pollution and asthma rates are highest. Case studies revealed how landscape architecture has addressed air pollution in other scenarios and informed the development of design principles: greener edges, green gradient, green lots and green corridors. Expert interviews resulted in recommendations on site specific solutions for addressing air pollution, by sharing maps and data with the interviewees. Lastly, i-Tree planting calculator produced from a list of trees the quantifiable benefits of a planting plan, such as PM captured, Ozone removed, Stormwater intercepted, and Carbon sequestered. Then, the design principles, the planting palette, and other findings of this research are then applied to a master plan design for Joppa, Texas, a low-income Dallas freedmen’s town that is currently exposed to high levels of air pollution and secondary health risks such as flooding, lack of public transit and lack of immediate access to grocery stores.

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DEDICATION

The list of those I would like to give thanks to for their support along my journey of writing this thesis is much longer than this paragraph allows. My largest support group has been my family and I am grateful for their patience and understanding as I've navigated this path without always knowing exactly where it would lead me. My partner Jordan has supported me through both talk and action, providing a never-ending flow of supportive words and mugs of coffee. Extensive gratitude to all of my friends for encouraging me on this path, even when they wanted me to help them design their backyard and I had to tell them not until after I graduate. Special appreciation for the Joppa community as they welcomed the UTA community into their neighborhood on many occasions. It was thanks to their willingness to collaborate with us that I decided to focus on Joppa in my thesis research. Special shoutout to my dog, Layla, and my cats, Frank and Nala, for being constant reminders of the importance of taking naps, staring out of windows, and going for walks. Finally, this is all in service of my higher power whom I choose to call God, for it feels miraculous that I have made it this far. I am grateful every day to be alive and to be able to do meaningful work.

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1 INTRODUCTION

1.1 Background

Air pollution is the single greatest environmental risk to health, with ambient outdoor air pollution killing roughly 4.2 million people every year worldwide (EPA, 2020; Schraufnagel, et al., 2019; World Health Organization, 2016). While air pollution contributes to the growing problem of a warming climate by producing climate-altering pollutants, it also negatively impacts the health of individuals who inhale polluted air (Downwinders at Risk, 2021; EPA, 2020; Wark, Warner & Davis, 2007; World Health Organization, 2016). Air pollution takes many forms, depending on how it is produced. Particulate matter (PM) are ultra-fine particles which contribute to air pollution, produced by any processes which use combustion, such as gas-powered engines and cement kilns (Downwinders at Risk, 2021; EPA, 2020; Wark, Warner & Davis, 2007; World Health Organization, 2016). These micro particles are much smaller than what the human body is capable of filtering out, able to pass through the lungs into the blood stream to be deposited in other organs (Downwinders at Risk, 2021; EPA, 2020; World Health Organization, 2016). Compounding the health risk is the fact that these particles carry with them many other chemicals used in the combustion process, called "toxic-hitchhikers" (Schraufnagel, MD et al., 2019). Exposure to air pollution has been widely confirmed as a contributing factor to diseases such as asthma, cancer, infertility, and neurological issues. (Downwinders at Risk, 2021; EPA, 2020; World Health Organization, 2016). Historically, due to active practices of segregation in the mid-1900s which have yet to be corrected today, communities of color are more likely to live near areas zoned for industrial plants, railroads, and highways. (EPA, 2021; Perlin, Sexton & Wong, 1999; Rothstein, 2018; Williams & Jackson, 2005). Therefore, minority communities who reside in industry-adjacent neighborhoods also face higher risks of exposure to particulate matter and are afflicted with the associated health difficulties.

Green infrastructure employing phytoremediation has been demonstrated to reduce the negative effects of exposure to air pollution in certain site-specific contexts (Beckett, Freer-Smith & Taylor, 1998; Baldauf, 2017; Escobedo, Kroeger & Wagner, 2011; Lee, Hadibarata & Yuniarto, 2020; Weber, Kowarik & Saumel, 2014; Weyens et al., 2015). Phytoremediation involves the implementation of vegetation and their natural processes to collect and sequester toxins. The use of green infrastructure in urban spaces with high pollution levels is useful as a technique for mitigating poor air quality (Baldauf, 2017; Ferranti et al., 2019). GI has also been shown to provide critical secondary services for communities, protecting them against flooding or excessive heat, helping to improve water and soil quality, providing greenway systems to enable wildlife movement through human settlements, expanding park systems and urban forests, and creating a more sustainable built environment through green streets and green roofs. Additionally, this is all shown to be more cost-effective than outmoded models of grey infrastructure, and also provide far more benefits for both people and the environment (Silverstein & Green, 2022).

1.2 Problem Statement

Air pollution is the greatest environmental health risk in the world, and it disproportionately affects low-income, minority populations. While the EPA has set national standards for air quality, there is no regulatory specification for the minimum safe distance between houses and sources of pollution. This leads to land use patterns where low-income neighborhoods adjacent to industrial polluters. The health effects associated with exposure to air pollution, such as respiratory issues, mental disorders, and reproductive struggles, can all lead to decreased quality-of-life, preventing people from going to work, performing well in school, and spending time outside. The health outcomes of living in these communities can keep people from economic, emotional, and physical well-being, thereby perpetuating low-income and poor health outcomes for future generations of minority populations. There is a need to better address air pollution at a site-specific scale in order to improve the health and well-being of low-income, minority communities living near industrial activity.

1.3 Purpose Statement

This research aims to investigate

1. The extent to which green infrastructure (GI) can be implemented through urban tree planting to improve the health and well-being of those who live in industry-adjacent communities who are exposed to air with high concentrations of pollution, and therefore are at risk to the illnesses associated with pollution exposure.
2. The accompanying benefits which GI can provide to industry-adjacent communities, including but not limited to mitigation of air pollution, decreased flood risk, increased access to open green space, and increased-community value.

1.4 Research Objectives

There is potential for green infrastructure to be utilized at a larger scale to mitigate environmental health risks for a relatively low cost, compared to existing technologies. Therefore, the objective of this research is as follows:

1. Establish a planting palette for an industry-adjacent, minority community – Joppa, Dallas - in the metro Dallas area which can mitigate air pollution and improve the quality of life for this neighborhood.
2. Explore a series of landscape design typologies which can be implemented in various lot shapes and sizes to be adaptable to several industry-adjacent communities for the Dallas metro area.

1.5 Research Questions

Two primary research questions guide this inquiry.

Research Questions 1: How can neighborhood-scale green infrastructure be designed for industry-adjacent communities in North Texas locations to mitigate air pollution?

Research Question 2: How accompanying and tailored benefits can be integrated into proposed GI strategies to help the community address additional environmental and social issue such as reduced flooding, decreased heat island, improvement of water and soil quality, increased wildlife habitats, expansion of park systems and urban forests, and a more sustainable built environment, etc.?

1.6 Definition of Key Terms

This research focuses on the impact landscape architecture can have on the health and well-being of low-income communities through the implementation of green infrastructure. The following definitions provide background information not otherwise provided within the body of the text.

Air Quality - the degree to which the ambient air is pollution-free, assessed by measuring a number of indicators of pollution (EPA, 2020)

Green Infrastructure (GI) –The harnessing of nature to provide critical services for communities, protecting them against flooding or excessive heat, or helping to improve air and water quality, which underpin human and environmental health (Silverstein & Green, ASLA Green Infrastructure 2022).

GIS - A geographic information system is a system that creates, manages, analyzes, and maps all types of data. GIS connects data to a map, integrating location data (where things are) with all types of descriptive information (what things are like there) (ESRI, 2022).

Industry-Adjacent Communities – Land which is zoned as residential which shares an edge with land zoned for industry

iTree - is a collection of urban and rural forestry analysis and benefits assessment tools to quantify and value ecosystem services provided by trees including pollution removal, carbon sequestration, avoided carbon emissions, avoided stormwater runoff, and more (i-Tree, 2022).

Particulate Matter (PM) - a mixture of solid particles and liquid droplets found in the air. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye. Others are so small they can only be detected using an electron microscope. Their chemical composition is determined by their source (EPA, Particulate matter (PM) basics 2020).

1.7 Methodology

A multi-method approach (Sommer & Sommer, 2002) was utilized to allow for synthesis of qualitative and quantitative data. GIS data layers were overlayed to locate industry-adjacent neighborhoods and to assess the levels of particulate matter in those areas. This produced qualitative data to establish an existing pattern and validate the need for further inquiry which this study pursues. Through the literature, types of vegetation which are most effective at mitigating air pollution were identified. This qualitative data informed the green infrastructure design. A review of existing landscape designs which address air pollution produced a series of case studies which informed the incorporation of public space for human use into the green infrastructure design. Tree species were then modeled in iTree to measure the effect different trees have on particulate matter air pollution. The qualitative data produced states how much particulate matter is removed by each species, thus producing a most appropriate evidence-based planting design solution. Finally, a series of interviews conducted with air pollution and green infrastructure experts provided a list of site-specific recommendations to further inform the design.

1.8 Significance and Delimitations

This field of landscape architecture's primary purpose is to serve the health, safety, and wellness for all people. This study contributes to the profession by examining through a landscape lens how vegetation and spatial design can reduce the level of air pollution particulate matter in the air in order to improve the health and wellness of those people who are living in close proximity to producers of air pollution. Ultimately this provides a template for other communities and designers working outside the scope of this research to use in addressing high levels of air pollution in a variety of situations and provides qualitative and quantitative data to show how effective green infrastructure can have multiple benefits for low-income communities. While air pollution is a broad and complex issue, this study focuses solely on particulate matter air pollution in industry-adjacent neighborhoods, therefore it does not examine other forms of air pollution, nor does it look at neighborhoods which do not share a boundary with an industrial land use. These study results are pertinent to metro Dallas area only, however there are a number of industry-adjacent neighborhoods within the Dallas area which could potentially benefit from these findings.

The community of Joppa was chosen as a case study before any of the research methodologies were conducted, because of an air quality study which is currently being conducted in the community. The University of Texas at Arlington's Landscape Architecture program has built up a relationship with Joppa through professor Dr. Austin Allen, who has engaged classes with the community through service learning. I was first introduced to Joppa in the Spring of 2020, when in Studio II we conducted community engagement and created a neighborhood stabilization overlay for Joppa. Therefore the study has been largely shaped to suit Joppa, however there are many other communities with similar conditions which would still benefit from this research.

2 LITERATURE REVIEW

2.1 Air Pollution: An Overview

There are four main categories of air pollution as defined by the Environmental Protection Agency (EPA), the primary environmental regulatory body of the United States: ambient air pollution, indoor air pollution, occupational (industrial hygiene) air pollution, and personal exposure. This research focuses on ambient air pollution, referring to outdoor air pollution. Generally, ambient air pollutants can be broken down into 9 categories:

1. particulate matter
2. sulfur-containing compounds
3. organic compounds
4. nitrogen-containing compounds
5. carbon monoxide
6. halogen compounds
7. radioactive compounds photochemical oxidants
8. other inorganic compounds.

This research focuses on Particulate Matter (PM). Particulate matter as defined by the EPA is “the term for a mixture of solid particles and liquid droplets found in the air” (EPA, Particulate matter (PM) basics 2020). According to the World Health Organization (WHO), the main substances which make up what is categorized as PM are sulphates such as sulfur dioxide, nitrates (nitric oxide and nitrogen dioxide), ammonia, reactive hydrocarbons (often referred to as volatile organic compounds), sodium chloride, black carbon, carbon monoxide, mineral dust and water. The source of the pollution and the chemicals used in the process of creating the pollution will determine the chemical composition. Typical sources of pollution are industrial plants and transportation, which when released are considered “primary pollutants” as they are released directly into the atmosphere. Chemical reactions can continue to take place once these primary pollutants have reached the atmosphere, releasing further toxins known as “secondary pollutants.”

Most particles in the atmosphere form as the outcome of a series of chemical reactions which occur between primary pollutants. Particulate matter is categorized by size in microns, (one millionth of a meter). PM2.5 and PM10 are common forms of classification when measuring particulate matter, with “2.5” signifying a diameter of 2.5 microns and “10” representing ten microns. For reference, a strand of human hair is around fifty microns in diameter. The microscopic size of PM is part of what makes it so dangerous because the human body does not have structures or processes in place to filter particles of that minute size.

To classify air as polluted, one commonly used method begins by looking at the components of “clean” or “normal” air, what is known as dry atmospheric air. This term is used to describe atmospheric air typically found in rural areas or over oceans far away from land masses; it is basically air which is distanced from intense human activity. The chemical composition of dry atmospheric air consists of nitrogen, oxygen, argon, carbon dioxide, neon, helium, krypton, hydrogen, xenon, nitrogen dioxide, ozone, and also contains anywhere from 1-3 percent by volume water vapor as well as trace amounts of sulfur dioxide, formaldehyde, iodine, sodium chloride, ammonia, carbon monoxide, methane, dust, and pollen, all dependent on location (see Table 1).

Table 1 Chemical Composition of Dry Atmospheric Air

Substance	Concentration (ppm)
Nitrogen	780,840
Oxygen	209,450
Argon	9,340
Carbon Dioxide	330
Neon	18
Helium	5.2
Methane	1.2
Krypton	0.5
Hydrogen	0.5
Xenon	0.08
Nitrogen Dioxide	0.02
Ozone	0.01 – 0.04

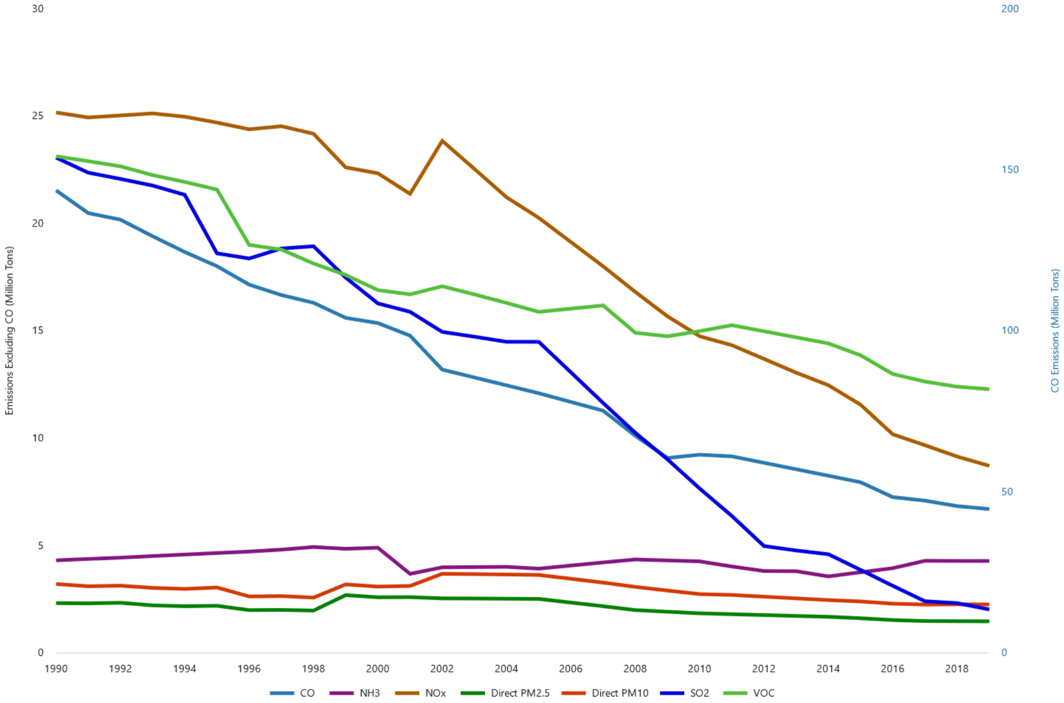
Note. ppm is an abbreviation of parts per million by volume. Adapted From: Handbook of Air Pollution, PHS Publication AP44 [PB 190 247], 1968.

2.2 Air Pollution: Causes and Sources

Combustion is the most common cause of air pollution. Most industrial processes, whether manufacturing, transportation, construction, or waste management, utilize some form of combustion. Theoretically, during ideal or perfect combustion, hydrogen and carbon in the fuel combine with oxygen in the air to produce heat, light, carbon dioxide and water vapor. However, rarely are the actual processes used in industry ideal or perfect. Fuel can be impure, temperatures can be too high or too low, there can be a unbalanced ratio of air-to-fuel, all which lead to by-products such as carbon monoxide, sulfur oxides, nitrogen oxides, fly ash and unburned hydrocarbons. These by-products are what become air pollution (Wark, Warner, & Davis, (2007).

Data collected between 1970 and 1991 by the US EPA show air pollution is caused by a combination of industrial sources, transportation, and fuel combustion, as well as a category which is titled “uncontrollable”. These are emissions which are not of anthropogenic origin. As the table shows, particulate matter, identified here as ‘particles’ is produced by all three major sources. The Clean Air Act in the United States, combined with technological advances, has helped to drastically improve air quality in the US (see Table 2). The Clean Air Act of 1970 was established to address issues of smog present in the major cities of the US. This landmark environmental provision helped to establish a standard for air quality, identifying the most common pollutants and their causes, as well as enacting regulations to curb future emissions.

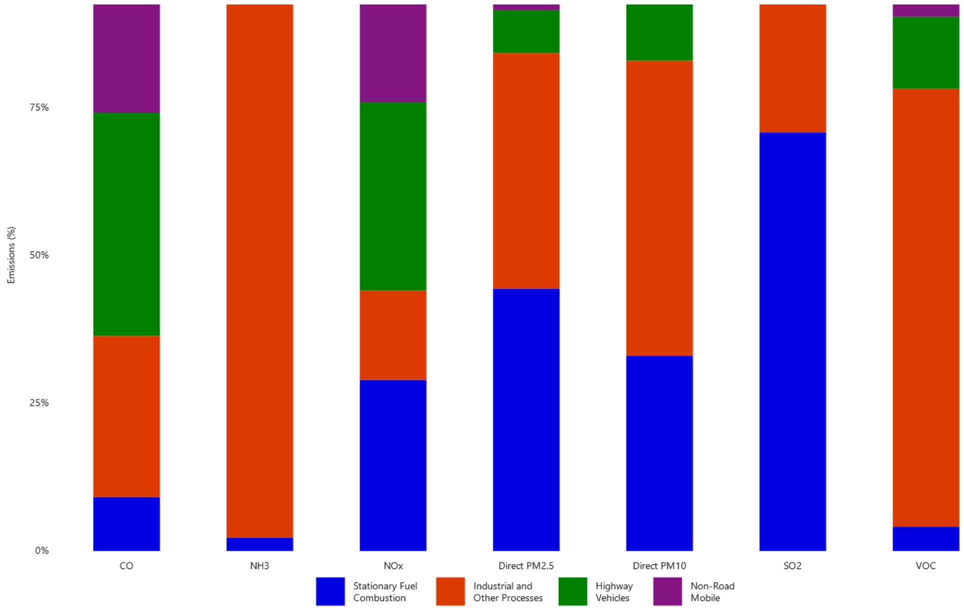
Table 2 Declining National Air Pollutant Emissions



Note. Emissions measured in millions of metric tons, except lead in thousands of metric tons. Metric ton ~ 1.1023 short tons. From “Our Nation’s Air: An annual report summarizing the nation's air quality status and trends” by Environmental Protection Agency. 2019.

Everyday human activities which are known to contribute to air pollution, specifically PM, include water and space heaters, driving, painting, printing, dry cleaning, construction, mills, manufacturing, food production, lawn care, and having a fire in the fireplace, just to name a few. However, these sources are miniscule when compared to industrial scale polluters. The majority of emissions of air pollution come from stationary fuel combustion sources such as electric utilities and industrial boilers; industrial and other processes such as metal smelters, petroleum refineries, cement kilns and dry cleaners; highway vehicles; and non-road mobile sources such as recreational and construction equipment, marine vessels, aircraft and locomotives (see Table 3). PM2.5 and PM10 are primarily produced by stationary fuel combustion in conjunction with industrial and other processes.

Table 3 National Emissions by Source Category

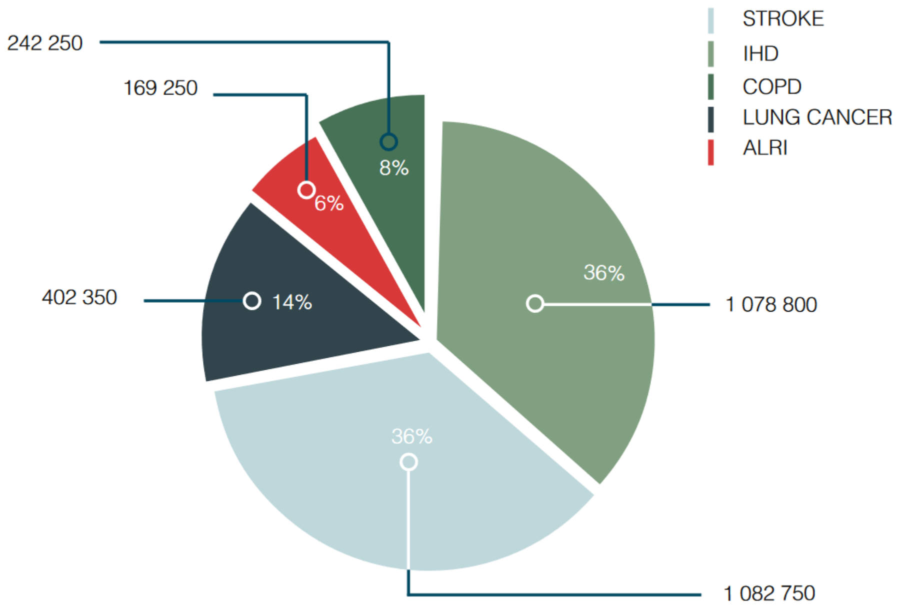


Note. From “Our Nation’s Air: An annual report summarizing the nation's air quality status and trends” by Environmental Protection Agency. 2019.

2.3 Environmental Risks to Health Caused by Air Pollution

The health risks of exposure to air pollution are widely documented, there being robust evidence to correlate ambient air pollution (AAP) with lower respiratory issues, chronic obstructive pulmonary disease, ischemic heart disease, stroke and lung cancer. Additionally, health outcomes such as adverse birth outcomes, childhood respiratory disease, diabetes, atherosclerosis, heart attacks, asthma, infertility, and neurological/developmental diseases (including anxiety, depression, autism, as well as Parkinson's, Dementia, and Alzheimer's) have been associated with exposure to PM in preliminary studies, however there is less comprehensive data at this time (Downwinders at Risk, 2021). Air pollution is the biggest environmental risk to health, responsible for roughly 1 in 9 deaths every year (World Health Organization, 2016) (see Table 4).

Table 4 Deaths attributable to AAP in 2012, by disease

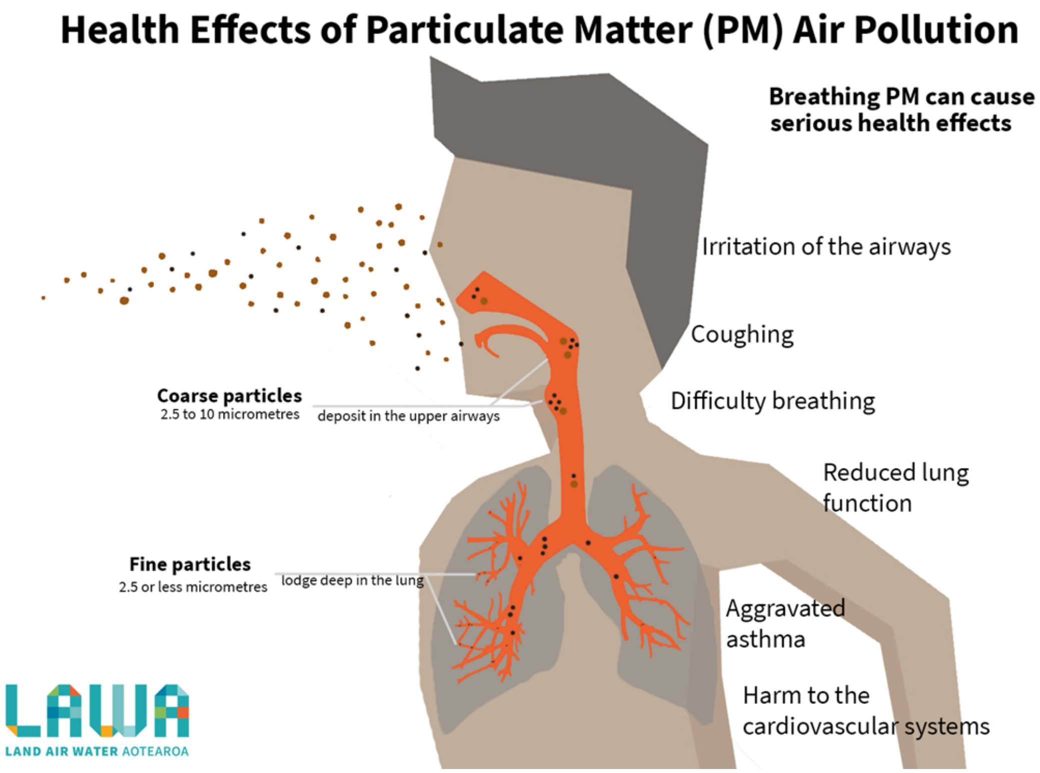


Note. From World Health Organization. (2016). Ambient air pollution: A global assessment of exposure and burden of disease (Publication No. 9789241511353). World Health Organization.

According to the report Air Pollution and Noncommunicable Diseases, each type of pollutant carries with it its own health risk depending on its chemical makeup. The matter of which tissues of the body are affected by the PM is determined largely by the size of the particles. Larger or courser particles, referring to particulates between PM10 and PM2.5, may be visible with appropriate lights, and will affect mucous membranes and upper airways, causing coughing and tearing. Fine particles, referring to PM2.5 to PM0.1, are small enough to enter into lung alveoli and bronchioles. Ultrafine particles, those smaller than PM0.1, pass through the alveolar-capillary membrane to be picked up by cells and carried to virtually all cells in the body, causing systemic tissue reactions. In addition to the size of the particles, one must also consider the chemical makeup. “Toxic hitchhikers” - remnants of other chemicals used in the combustion process - can attach to the particulates surface, adding insult to injury.

Elements such as arsenic, lead, cadmium, sulfuric acid, or polycyclic aromatic hydrocarbons can also be carried through the combustion process, into the body on the surface of particulate matter. Particles of similar size without the added toxins are found to be less harmful. Exposure to pollution, in addition to the direct harm of attaching to an organ, can also lead to inflammation with systemic effects. Furthermore, the lungs filtration process can lead to accumulation of soot in the lungs if the level of exposure is greater than the lungs capacity. The ability of the body to clear out particulates will play a determining factor in the individual’s ability to cope with exposure. Furthermore, immune and inflammatory responses, which are regulated by genetics, can be affected due to PM’s potential effect on epigenetics, that is the mechanism which mediate genetic and physiologic response to air pollution (see Figure 1).

Figure 1 Pollution damage by systemic inflammation



Note. Air Quality. Land, Air, Water Aotearoa (LAWA). (n.d.). Retrieved May 9, 2022, from https://www.lawa.org.nz/explore-data/air-quality/

Sleep quality is negatively affected by increased exposure to PM, with studies finding that air pollution is associated with symptoms of sleep apnea. Sleep is also disrupted by other chronic diseases associated with air pollution, such as asthma and chronic obstructive pulmonary disease (COPD).

Children are especially susceptible to the health effects of ambient air pollution, as children breathe more air per unit body weight, as stated in Air Pollution and Noncommunicable Diseases. They are also biologically more at risk because their bodies are still developing. Air pollution is found to affect growth trajectories of the lung during childhood, which can influence the level of respiratory health achieved in adulthood, while also running the risk of developing childhood asthma.

For expectant mothers and their babies, there are also health risks in exposure to air pollution. Exposure to PM during pregnancy is associated with lower infant head size, low birth weight infants, preterm birth, small for gestational age infants, while the expectant-mothers are at an increased risk of intrauterine inflammation and preeclampsia. The risk has been found to be highest for exposure during the first trimester of pregnancy. However this all becomes relevant when a couple is able to conceive, which can also be hindered by air pollution exposure. Studies have discovered a correlation between PM and reduced fertility rates and increased risk of miscarriage. Meanwhile studies suggest the quality of semen or sperm is decreased in areas with high rates of pollution (Schraufnagel, MD et al., 2019).

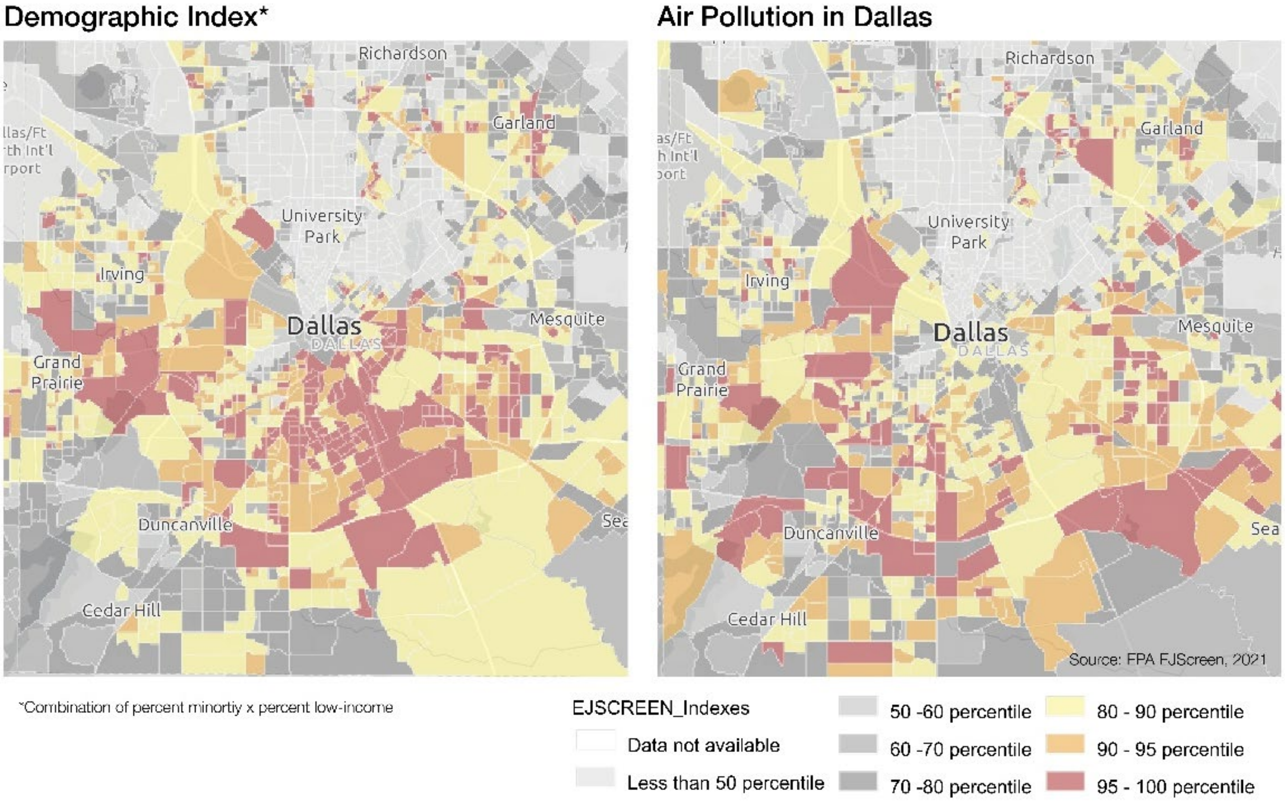
2.4 Environmental Justice: Inequality of Exposure to Air Pollution

Compounding all the health disorders associated with air pollution is the societal problem of environmental injustice. Environmental Justice is the pursuit of a “fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to development, implementation, and enforcement of environmental laws, regulations, and policies” (EPA, 2022) There is a growing body of evidence to show minority populations are disproportionately found to face higher levels of environmental health risks in the US, which includes exposure to toxic air pollution. In a study funded by the EPA, researchers found that people of color (POC) are exposed to disproportionately higher levels of ambient fine particulate air pollution, regardless of income levels or region (Tessum, et al., 2021). These patterns can be attributed to the lasting legacy of segregation, whereby black americans were prevented from living in burgeoning middle-class communities throughout the country, simply because of the color of their skin. This was done-so through real-estate clauses, homeowners associations (HOA), zoning maps, and mortgage lending restrictions. This led to communities of color building up their own communities, often on land on the outskirts of economic centers. As these economic centers grew into major urban centers landfills, industrial facilities, railroads, and highways were all situated outside the downtown center, oftentimes directly adjacent to these communities formed by black indigenous people of color (BIPOC) populations. Therefore exposing them to the toxic byproducts of these polluting facilities and the underlying health impacts (Rothstein, 2018).

In a study conducted by George Mason University, the sociodemographic characteristics of people living near industrial sources of air pollution in three US cities were assessed and compared with data from the 1990 Toxics Release Inventory (TRI). It was determined that in all three cases African Americans and those living in households which are defined based on census data to be below the established poverty level are more likely to live in proximity to a TRI facility. In comparison, white people and those living above the established poverty level are more likely live farther from the nearest TRI facility than their black and low-income neighbors (Perlin, Sexton, & Wong, 1999).

People of color in the US are at a higher risk of being exposed to the negative health effects of Particulate Matter (Downwinders at Risk, 2021). Minority communities are oftentimes living in conditions with poorer housing options and violent crime, with a lack of access to healthy food, green space, and good quality health care. Blue-collar jobs are also more likely to require interacting with noxious substances, increasing exposure to vapors, dusts, gases and fumes (Schraufnagel, MD et al., 2019). As well, elevated levels of stress reported by people of disadvantaged social status can contribute to negative health outcomes, exacerbating preexisting conditions (Williams & Jackson, 2005). The cumulative impacts of environmental and social factors on health are well-documented and when taken together, reveal an intertwined relationship between race, health/well-being and economic productivity. The literature shows that living as a low-income minority person in the US leads to health outcomes which keep a person from being able to improve their economic status. In the City of Dallas, the areas where low-income, minority populations reside are the same areas where air pollution is highest (See Figure 2).

Figure 2 Need for Environmental Justice in Dallas

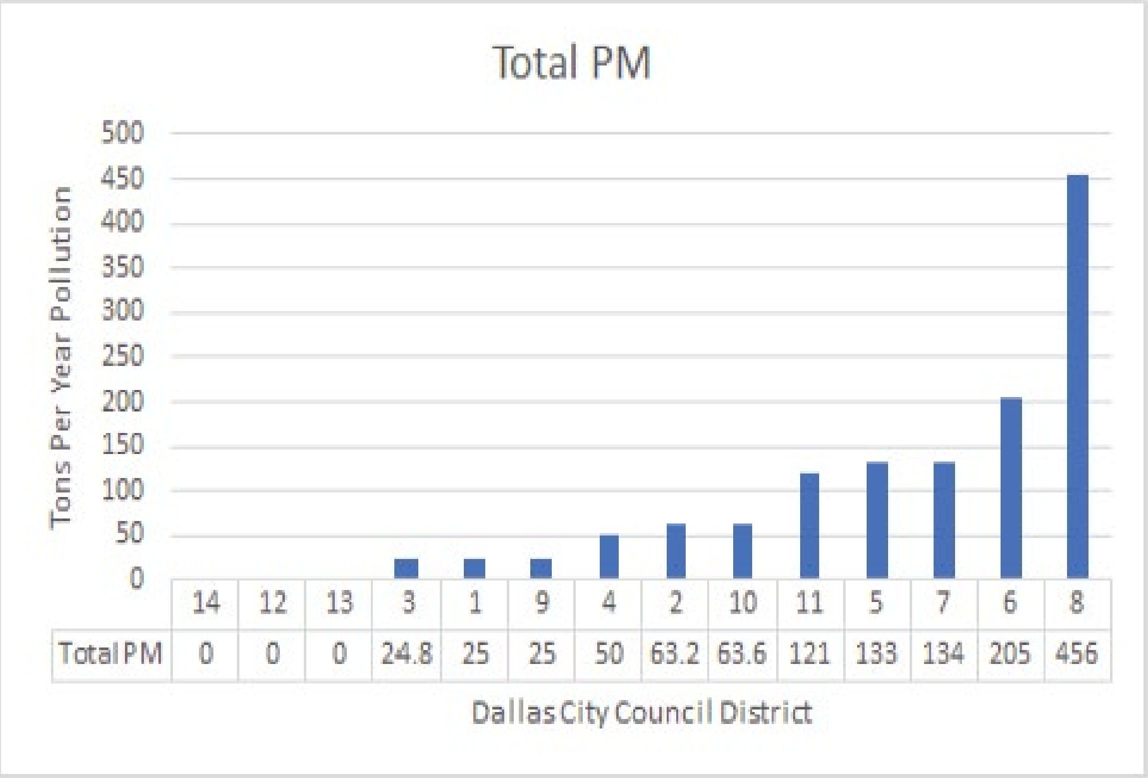


Note. Adapted from Arc GIS Pro and EPA Environmental Justice Index

Dallas has been rated by the American Lung Association as having an ‘F’ in ozone quality and a ‘C’ in particle pollution levels in their 2021 State of the Air report. Among those findings, the report also disclosed people of color to be over three times as likely to be breathing the most polluted air when compared to white people (American Lung Association, 2021). According to a 2019 report, Poisoned by Zipcode, which studied health disparities caused by air pollution in the

City of Dallas, there was found to be a 15-year difference in life expectancy depending on which zip code a person lives in. Furthermore, the zip codes which have low life expectancy and high rates of asthma also tend to have heavy industrial operations intertwined with residential zones. Distribution of particulate matter pollution in Dallas vary widely depending on city council districts, with districts 8, 6, and 7 being the top three districts for air pollution burden (see Table 5) (Mayo et al., 2019).

Table 5 PM Levels by Dallas City Council District



	14	12	13	3	1	9	4	2	10	11	5	7	6	8
Total PM	0	0	0	24.8	25	25	50	63.2	63.6	121	133	134	205	456

Note. From Mayo, E., McAfee, B., Whitley, P., Estrada, J., Estrada, N., Evans, Q., Givens, B., Hardrick, D., Hatley, K., Medlock, D., & Nehlum, K. (2019). (rep.). Poisoned by Zip Code: An Assessment of Dallas' Air Pollution Burden by Neighborhood. Dallas, TX: Paul Quinn College

As a growing body of research has begun to shed light on these issues, communities and advocacy groups across Dallas have started taking direct action, advocating for the unequivocal right to breathe cleaner air, for all (Martinez, 2020). While there are many communities in Dallas which exemplify these issues, this research focuses on one such community – Joppa, Dallas - which serves as a case study for the larger region.

2.5 Air Pollution Control: Existing Technologies

Currently, a number of technologies exist to mitigate and lessen the impacts of air pollution. According to Phytoremediation Mechanisms in Air Pollution Control: a Review (2020), 12 studies have verified successful mitigation of air pollution by using specific technologies. There are 5 existing techniques for mitigating PM, 2 of which utilize the biological processes of plants and their microorganisms. Filtration removes particles with air passing through a fibrous material. Electrostatic precipitation (ESP) traps charged particles with an electric field. Botanical purification degrades pollutants with microorganisms and/or plants with direct transfer to planted soil or on the plants. Biofiltration biodegrades pollutants by passing them through a packed medium filled with microorganisms. Lastly, non-thermal plasma produces ionized gas that binds with pollutants to form non-toxic decomposition products. Many of these non-biological technologies are expensive, require high maintenance, and have a high likelihood of pollutant remission (Lee, Hadibarata, & Yuniarto, 2020). The most preferable solution to unhealthy rates of air pollution is reducing emissions and extending the distance between sources and receptors, however world leaders have largely been unable to achieve such changes (Han et al., 2020).

2.6 The Use of Vegetation to Mitigate Air Pollution

Vegetation and green infrastructure has been shown to have overall health benefits including increased physical activity, lower obesity, improved mental health, overall improved birth outcomes, lower adverse cardiovascular illness, and decreased mortality (James et al., 2015, 2016). The use of plants and their biological processes to improve living conditions for humans is the implementation of phytoremediation, a form of bioremediation (Shmaefsky, 2020). This is a viable method for capturing certain pollutants in an inexpensive and sustainable way. Ultimately, phytoremediation is broken down into different mechanisms depending on which parts of the plant are employed (Kennan & Kirkwood, 17).

Phytoremediation has been researched and applied heavily in the process of removing contaminants from soil and water. Explorations into utilizing phytoremediation in the cleansing of air pollutants is less researched, however it is generally agreed that phytotechnology can be used in the removal of coarse particulate matter in air pollution (PM10), nitrogen dioxide, sulfur dioxide, carbon dioxide and ozone. Phytoremediation of air pollutants involves phytoaccumulation or deposition (collection of pollutants on the leaf surfaces). From a landscape architecture approach, “all phytotechnology projects have to be pollutant specific and plant specific” (Kennan & Kirkwood, 2017).

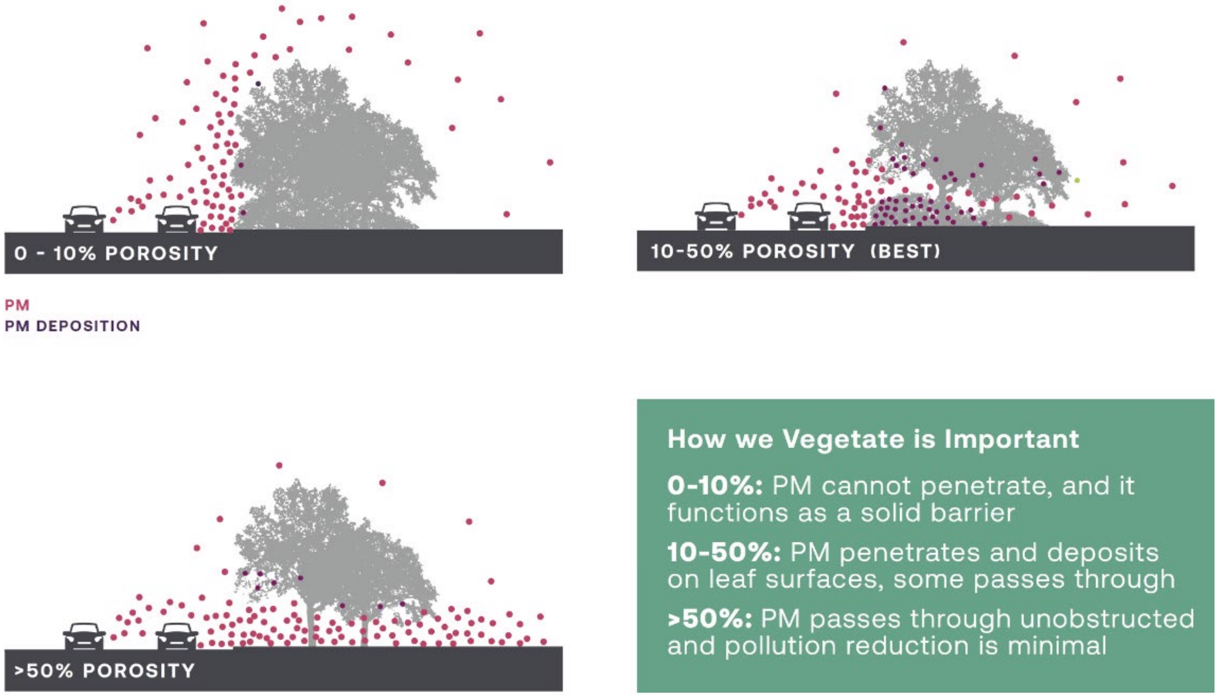
Employment of Phytoremediation in Green Infrastructure for Reducing Air Pollution

Due to the general inability of authority figures to reduce pollutant emissions to a healthy level through reduction or extension, a third-order option which is considered a win-win for all involved parties is Green Infrastructure (GI) (Hewitt, Ashworth, & MacKenzie, 2020). GI consists of all types of vegetation (trees, hedges, individual shrubs, green walls, and green roofs) being strategically used to employ phytotechnologies, i.e. utilizing natural biological processes in the service of solving urban and climatic challenges. GI can be used in various capacities, including flood risk mitigation, microclimate regulation, carbon sequestration, improved health and wellbeing and air pollution abatement (Kumar et al., 2019). Urban trees remove large amounts of air pollution that consequently improve urban air quality, with total annual air pollution removal by US urban trees estimated to be 711,000 metric tons, a $3.8 billion value (Nowak et al., 2006), leading the US EPA to list tree planting as a recommended strategy for improving air quality in 2004 (US EPA, 2014). There are two main approaches through which vegetation can mitigate air pollution: dispersion and deposition. Dispersion is the process of wind flow in how it transports and dilutes air pollutants at different scales, while deposition physically traps pollutant particles on plant surfaces, removing them from the air. This dynamic plays an important role in how pollutants move and are carried through the air. Barriers between the pollution source and sites of human activity can be implemented to influence wind systems to encourage dispersion and deposition of pollutants onto vegetation.

GI Phytotechnology Techniques: Dispersion & Deposition

Dispersion occurs when the flow of air is deflected by trees, hedges, and other herbaceous plants, introducing turbulence and increasing dilution of the air, essentially extending the distance between the pollution source and the people who would be inhaling that air. Dispersion rates are determined by factors such as plant height and leaf shape, which influence the interaction between air flow and vegetation (See Figure 3). It is important to allow adequate space for air to flow through the vegetation, if the canopy is too dense, pollutants can become trapped in urban areas (Hewitt, Ashworth, & MacKenzie, 2020).

Figure 3 Interaction between Vegetation and Air Pollutants



How we Vegetate is Important

0-10%: PM cannot penetrate, and it functions as a solid barrier

10-50%: PM penetrates and deposits on leaf surfaces, some passes through

>50%: PM passes through unobstructed and pollution reduction is minimal

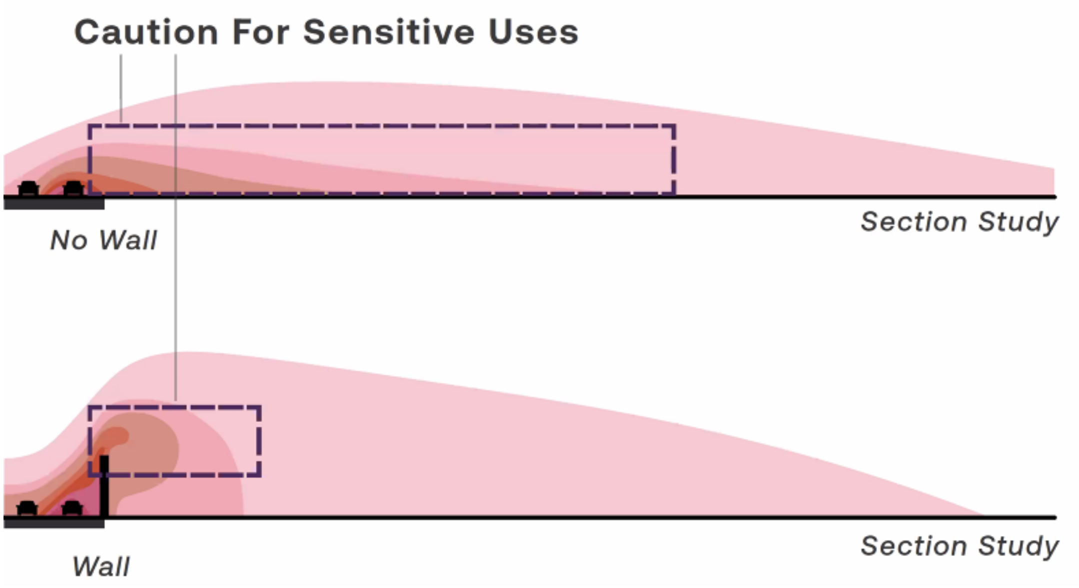
Note. *Harvey, A., & Adams, A. (2022, March). Investigating Contaminant Accumulation in Landscapes Adjacent to Highways. LAF Research Grant in Honor of Deb Mitchell.*

Deposition (or phytoaccumulation) results in a permanent reduction in air pollutants from the atmosphere, whereby pollutants are trapped on the plants surfaces and removed from the air. Wet deposition occurs during precipitation events and rates are equivalent across all surface types. Dry deposition, however, is highly influenced by the characteristics of individual plant species. Vegetation with higher surface area, surface aerodynamic roughness, greater rates of transpiration, and longer in-leaf periods have been found to incur the greatest rates of deposition (Hewitt, Ashworth, & MacKenzie, 2019). Deposition employs the techniques of phytoremediation to physically filter particulates out of the air, by transporting the pollutants from their original source to a plant surface. Particle size is a significant component in determining how this process plays out. The texture of the surface which the particle is being deposited on also plays a key role.

Designing GI for Dispersal and Deposition

The geometry of a barrier will largely influence the level of air quality. The literature suggests the barrier should be placed close to the pollution source, as proximity increases concentration and thus deposition. Another key finding is ensuring that air passes *through* the green barrier, not *above*. Therefore barriers should be high enough and porous enough to allow air to pass through, but dense enough to ensure air passes close to vegetation surfaces. In assessing the mechanisms of dispersion and deposition as it relates to the physical effects vegetation has on air quality, the existing methods of modeling and formulating design and vegetation choices for mitigating air pollution were documented. While fluid dynamics and physics are scientific processes which can be easily modeled in a controlled environment, vegetation features are parts of complex natural systems, making them difficult to study when considering effects on air pollution (See Figure 4). Climate consideration of wind, precipitation, quantity, and composition of the contaminants in the atmosphere will also have an effect.

Figure 4 Interaction between Air Pollutant, Wind, and the Built Environment



Note. Harvey, A., & Adams, A. (2022, March). Investigating Contaminant Accumulation in Landscapes Adjacent to Highways. LAF Research Grant in Honor of Deb Mitchell.

Designing for street canyons versus open-road settings where buildings are far away from the pollution source is also something to consider (Janhäll, 2015). For open-road situations, it is important to plant the green infrastructure between the source and the spaces inhabited by people. There should be no gaps in spacing to provide better reduction of exposure, and the barrier is recommended to have a height of 16’ with a minimum of 5’ (See Figure 5).

Figure 5 Effective Versus Ineffective Vegetated Buffers

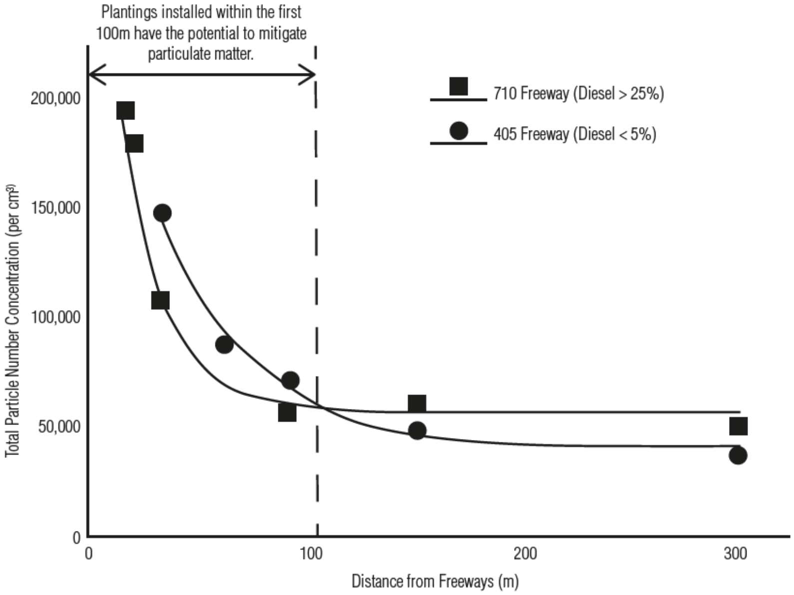
Effective Buffers:
Low (50%) Porosity, Thick Barrier, High Buffer produce greatest reductions in air pollution

Ineffective Buffers:
High Porosity, Thin Barrier, and Buffer Gaps do little to improve air quality

Note. Baldauf, R. (2016). (rep.). Recommendations for Constructing Roadside Vegetation Barriers to Improve Near-Road Air Quality. US EPA. Retrieved February 5, 2022, from https://www.epa.gov/air-research/recommendations-constructing-roadside-vegetation-barriers-improve-near-road-air-quality.

A study done by the Health Effects Institute concluded that the area most affected by air pollution is the band within roughly 0.2 to 0.3 miles (~1000’ to 1500’) from the pollution source (Health Effects Institute, 2010) however, it is noted that plantings placed within the first 330’ of a pollution source have the greatest potential for air pollution mitigation (see Table 6). When it comes to green barriers for mitigating pollution, the taller and the wider the better (Kumar et al., 2019).

Table 6 Particulate concentration is directly related to distance from source, fuel type, and wind direction



Note. From Kennen, K., & Kirkwood, N. (2017). Phyto: Principles and resources for site remediation and landscape design. Routledge.

Researcher Ridge Baldouf, who works for the EPA studying air quality and vegetation, assessed various studies on GI and air pollution and cross-examined the studies to determine the characteristics of a GI buffer that make it effective versus ineffective. The following list was produced (see Table 7).

Table 7 Factors affecting the effectiveness of roadside barriers in mitigating near-road air pollution impacts

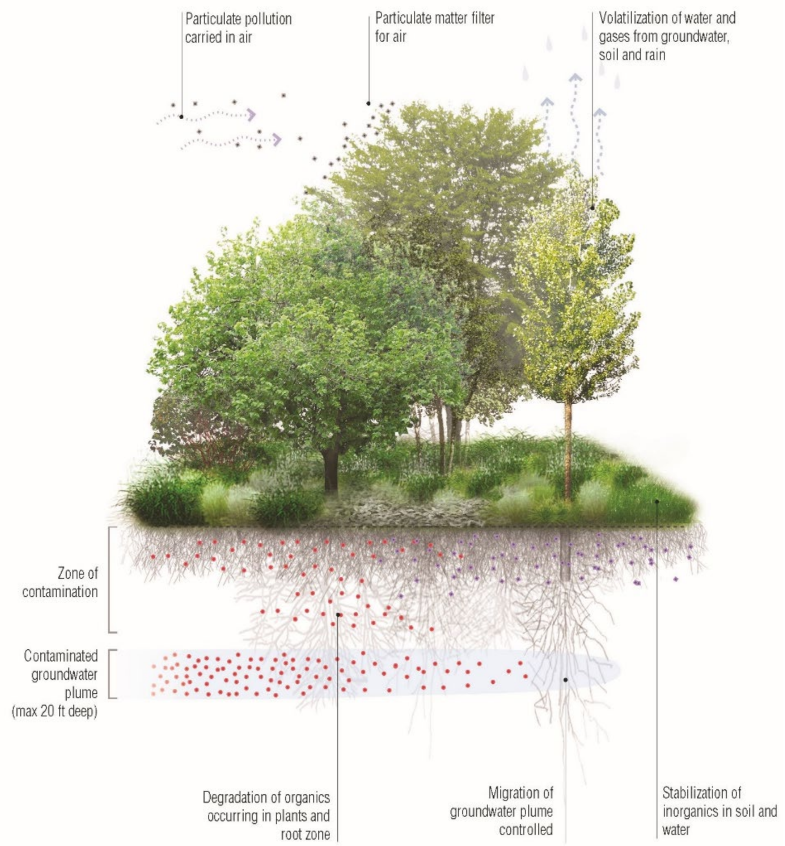
Barrier characteristic	Recommendation	Description
Physical characteristics		
Height	5 m or higher (or extend 1+ meter above an existing solid barrier)	The higher the vegetative barrier, the greater the pollutant reductions. A minimum of 5 m will provide enough height to be above typical emission elevations for vehicles on the road (4 m if little to no trucks use the road). However, heights of 10 m or more would provide additional pollutant reductions
Thickness	10 m or more	The thicker the vegetative barrier, the greater the pollutant reductions. A minimum thickness of 10 m should provide enough of a barrier to remove particulate and enhance dispersion. However, gaps in the barrier should be avoided. Multiple rows of different types of vegetation (e.g. bushes, shrubs, trees) should be considered for maximum coverage and pollutant removal during all stages of the barrier. A thickness of as little as 5 m may be sufficient with low porosity (high density) vegetation
Porosity	0.5–0.9	Porosity should not be too high to allow pollutants to easily pass through the barrier or cause wind stagnation. As the porosity gets lower, the vegetation barrier will perform similarly to a solid barrier, which may limit the amount of particulate removal since air is forced up and around the plants
Length	50 m or more beyond area of concern	Extending the barrier beyond the area of concern protects against pollutant meandering around edges. May also consider constructing the barrier perpendicular from the road depending on land availability

Note. From Baldauf, R. (2016). (rep.). Recommendations for Constructing Roadside Vegetation Barriers to Improve Near-Road Air Quality. US EPA. Retrieved February 5, 2022, from https://www.epa.gov/air-research/recommendations-constructing-roadside-vegetation-barriers-improve-near-road-air-quality.

Designing GI: Considerations for species selection

Filtration capacity of particulate matter is affected by plant characteristics and climatic factors. Considering the plant itself, surface roughness, thickness, ultrastructure, pubescence, wax content, leaf size and structure all play a role in determining effectiveness. Microbes in the soil have a positive correlation with PM uptake, as microbial content will increase biomass in plants, increasing the surface area through which PMs can be absorbed. Additionally, microbes function as bio-fertilizers, improving the health and tolerance to environmental stressors of plants by increasing bioavailability of nutrients. That is in addition to the role microbes play in degradation and detoxification processes (Lee, Hadibarata, & Yuniarto, 2020). (See Figure 6).

Figure 6 Air Pollution Interactions with Air, Vegetation, and Soil



Note. Kennen, K., & Kirkwood, N. (2017). Phyto: Principles and resources for site remediation and landscape design. Routledge.

Numerous studies exist to test the effectiveness of different types of plant forms on air quality. Trees and shrubs are widely touted as effective plants, with specific studies looking at individual tree species and the effects particulate pollution have on various tree types (Beckett, Freer-Smith, &; Taylor, 1998), as well as overall urban forests (Escobedo, Kroeger, & Wagner, 2011), looking at their strengths as well as their drawbacks in mitigating pollution.

Researchers in the UK have produced a list of species potentially effective for incurring deposition and dispersal of air pollution based upon experimental findings, an exhibition of beneficial traits, or a combination of both. Studies have also been conducted to examine the use of herbaceous perennials, as they have been less frequently touted as useful in mitigating particulate matter (Weber, Kowarik, & Säumel, 2014). The interactions between plant and microbe have also been explored in the search for phytoremediation tools (Weyens et al., 2015). Key findings revealed the preference for coniferous trees due to their evergreen nature which allows for year-round collection of pollutants, while deciduous trees stand leafless for a few months each year (Kumar et al., 2019). However, the relevance of that finding to a Texas climate required future research, as Texas has a very short winter season, and plants tend to drop their leaves late in autumn and leaf-out early in spring. Furthermore, considerations of demand on the electrical grid as it varies widely by region will alter the seasonality of air pollution production, as states which have longer winters tend to require indoor heating more, while our Texas region relies heavily on the electric grid in summer when we seek air cooling. It was found that generally, the effectiveness of particle uptake by trees is elevated if the trees have leaf and bark structure which are rough or sticky (Kumar et al., 2019; Nowak et al., 2006). Taken together, these studies show the complexity of using green plants to capture toxins in the air. The research demonstrates that a layered approach must be taken. Considering urban form will strongly influence the most suitable approach to installing GI in the effort of reducing air pollution (Ferranti et al., 2019, Kumar et al., 2019).

When considering the design of a green barrier, the characteristics of each individual plant will be crucial in ensuring optimal filtration. In one study conducted in Singapore, the leaves of twenty-five trees were evaluated under simulated conditions to measure effective consolidation of PM2.5 and PM10. The study focused on three key functional traits of leaves – leaf hairiness, average leaf area (ALA) and specific leaf area (SLA). ALA is the total leaf area divided by the number of leaves, while SLA is the total leaf area of each portion of vegetation divided by their dry weight. The results were then used to form a hypothesis for which leaf characteristics were most useful in filtering air pollution. Results suggest that greater upper-surface hairiness and low SLA were correlated with higher PM deposition, while no correlation was found between ALA and PM collection. Hair density, length, type and direction of hairs are also factors which play a role. Water repellence of leaves is also something to consider, as washing is the process used in this study to measure PM concentration levels (Chiam, Song, Lai, & Tan, 2019).

One primary set of researchers - K. Paul Beckett, P. H. Freer-Smith, and Gail Taylor – have established themselves as experts in this specific field through a series of studies. Together and individually, they have produced more than a dozen research studies whose findings address the specific question – “Which plant species are most effective at capturing (and sequestering) particulate matter from the air?” In 2000, articles were published to share the findings of a study conducted in the United Kingdom where different tree species were planted and their effectiveness at capturing PM was measured (Beckett, Freer-Smith, & Taylor, 2000). This study focused on five types of trees – pine (*pinus)*, cypress (*cupressus*), maple (*acer)*, whitebeam (*rosaceae*), and poplar (*populus*). While the species used in this study may not be viable options for growing in every location, the characteristics which showed to be most effective can be found in a variety of biomes. Conclusively, it was found that conifers, i.e., pine and cypress, were most effective at capturing PM, with pine trees capturing a significantly greater amount of

PM compared to cypress trees. This difference in PM accumulation was attributed to the conifer trees having more complex leaf systems.

Researchers have established a methodology which clearly and repeatably uncovers which tree species are best suited for sequestering air pollution. However, one must also consider the negative effects exposure to particulate matter can have on the tree. Researchers in the UK utilized a simulation methodology to test the effects of different air qualities on plants natural processes (Honour, Bell, Ashenden, Cape, & Power, 2009). This study found a significant link between exposure to a cocktail of air pollutants and delayed natural plant processes such as flowering and leaf senescence, in addition to potentially damaging changes in leaf surface characteristics and growth. However, a study conducted in Ohio which looked at the roadside flowering plant, Chicory, and focusing specifically on plant reproduction found no interference by PM on the plant's pollen germination rate (Jaconis, Culley, & Meier, 2017). Further exploration into the effects that PM has on the health of individual species is required. Conversely, some plants, such as the Sweetgum (*liquidambar*), have been found to emit pollutants, such as volatile organic compounds (VOCs), which can enhance the formation of ozone, and high-allergy pollens. Both can exacerbate respiratory effects and should be avoided for roadside barriers (Baldauf, 2016).

Overall, the general recommendations at the individual species scale for suitable plant characteristics are -

1. coniferous and evergreen
2. have complex, waxy and/or hairy leaf surfaces with high surface area
3. do not emit compounds which can increase air pollution or allergic response
4. non-invasive
5. non-poisonous in highly populated areas

6. maintain safe driving visibility and not impede accessibility
7. resistant to air pollution

Furthermore, species should be suitable for specific site conditions, should be selected with size and form in mind, and should have a reasonable maintenance plan. The evolution of plant communities over time as the planting matures is also important to consider.

2.7 Various Benefits of Green Infrastructure

Green Infrastructure provides economic, ecological, and social benefits. Exposure to nature has been shown to have overall health benefits including increased physical activity, lower obesity, improved mental health, overall improved birth outcomes, lower adverse cardiovascular illness, and decreased mortality (James et al., 2016). GI is an effective and cost-efficient tool for absorbing and sequestering atmospheric carbon dioxide (C02); filtering air and water pollutants; stabilizing soil to prevent or reduce erosion; providing wildlife habitat; decreasing solar heat gain; lowering the public cost of stormwater management infrastructure and providing flood control; and reducing energy usage through passive heating and cooling (Silverstein & Green, 2022).

2.8 Summary of the Chapter

In conclusion, air pollution is the single greatest environmental risk to health, with outdoor ambient air killing roughly 4.2 million people worldwide each year. Comparatively, 3.3 million people have died from COVID-19 since the start of the coronavirus outbreak (Johns Hopkins University & ArcGIS). That is to say, death by air pollution is a pandemic. Particulate matter is one form of air pollution which is of great concern due to its microscopic size and its ability to carry with it other toxins. Communities of color and minority groups are statistically more at risk to be exposed to air pollution and therefore to suffer the negative health consequences of that exposure. The design of green belts between pollution producers and residential areas is a viable option to reduce exposure to PM and the associated health risks. Research suggests that with the implementation of a green belt consisting of coniferous trees and herbaceous plants, installed in close proximity to air pollution sources can improve air quality and reduce environmental health risks.

3 METHODOLOGY

3.1 Introduction

The objective of this research was to explore how green infrastructure could be implemented in landscape design to reduce levels of particulate matter in the air of industry-adjacent neighborhoods in North Texas. Both qualitative and quantitative methods were utilized including interviews with air pollution experts and modeling of design alternatives using iTree. This chapter details the research design, study population, data analysis methods, site plan design process, and acknowledges limitations, bias, errors, and/or significance of the research.
Two primary research questions guided this inquiry.

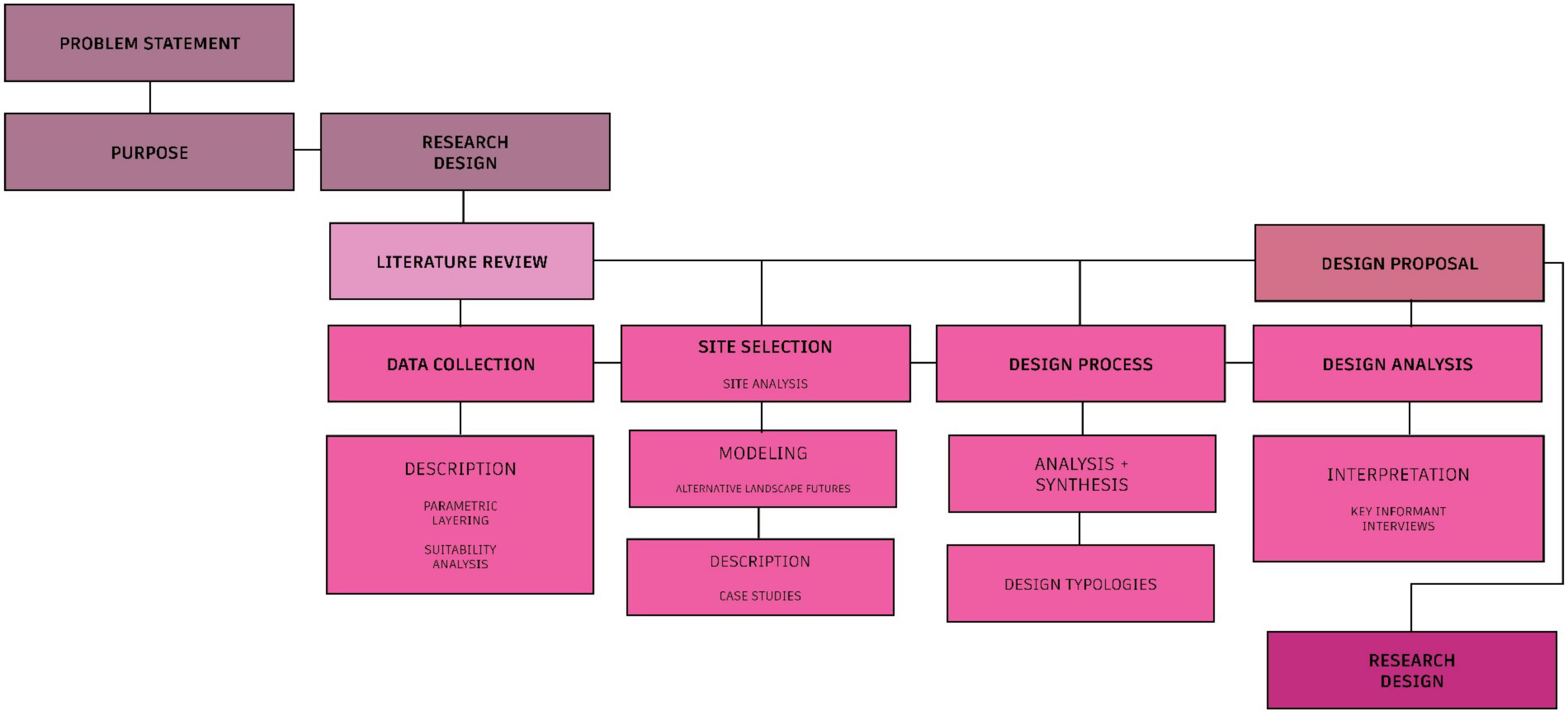
Research Questions 1: How can green infrastructure be designed for in industry-adjacent neighborhoods in North Texas locations to mitigate air pollution?

Research Question 2: How accompanying and tailored benefits can be integrated into proposed GI strategies to help the community address additional environmental and social issue such as reduced flooding, decreased heat island, improvement of water and soil quality, increased wildlife habitats, expansion of park systems and urban forests, and a more sustainable built environment, etc.?

3.2 Research Design

A multi-method approach (Sommer & Sommer, 2002) was utilized to allow for synthesis of qualitative and quantitative data. GIS data layers was overlayed to locate industry-adjacent neighborhoods and to assess the levels of particulate matter in those areas. This produced quantitative data to establish an existing relationship between locations of pollution sources, presence of particulate matter air pollution, and asthma rates, thereby justifying the need for this research study. A buffer analysis was conducted to identify communities which fall within 1500’ of a site producing high rates of PM, revealing neighborhoods which could benefit from this research. Through the literature, qualities of planting design which are most effective at mitigating air pollution were identified. This data informed the development of planting designs which were incorporated in the green infrastructure typologies for the selected site. A series of interviews conducted with air pollution and green infrastructure experts provided a list of recommendations to further inform the site selection, plant species, green infrastructure design, and a maintenance plan. Alternative landscape futures were modeled in iTree Planting Calculator to measure the effect that different tree species have on levels of particulate matter air pollution for the selected site. The quantitative data produced states how much particulate matter is removed by each tree species, as well as carbon sequestered, ozone removed, and stormwater captured thus producing a most appropriate evidence-based planting design solution. Additionally, a review of existing landscape designs which address air pollution produced a series of case studies which informed the incorporation of public space for human use into the green infrastructure design. All of the data collected was then analyzed and synthesized to then inform a series of design typologies for the selected site (See Table 8).

Table 8 Diagram of research process



3.3 Study Population

The study population consists of two groups. One of which provides data to support the research and the other which the research serves. Industry experts were interviewed to provide data and knowledge to inform the green infrastructure design. Low-income community members in an industry adjacent neighborhood are the population which the design services.

Collecting Knowledge through Key Informant Interviews

Interviewing experts took place right before beginning the design process, in order to develop the design solutions with evidence of what is and is not viable through their validation of the research topic and methods. The interviewees are experts in the fields of relationships between air pollution, green infrastructure, and urban forests. They are researchers at various institutes and have a history of published work which relates to the topics at the intersection of air pollution, green infrastructure, and landscape design.

Research in service of low-income minority communities

As documented in the literature (see section 2.1.3), African Americans and those living in households which are defined based on census data to be below the established poverty level are more likely to live in industry-adjacent neighborhoods have and therefore people of color in the US are at a higher risk of being exposed to the negative health effects brought on by Particulate Matter and other air pollutants. This research sought to find a low-cost solution to reduce the negative effects of living near polluting industry, thereby the research is in service of these communities. There are many communities made up of people who fall under the demographic category of low-income minority and are industry adjacent.

3.4 Study Location

This study focuses on the City of Dallas, utilizing a case study focused on one community- Joppa, Dallas - to extrapolate solutions for communities with similar circumstances throughout the entire region.

3.5 Data Collection Methods

Five research methods are utilized to collect and analyze data for this study (See Table 9).

Table 9 Diagram of Data Collection Methods

Methodology	Outcome
Literature Review	Existing knowledge of particulate matter abatement utilizing GI
GIS parametric layering	Overlaying spatial data to identify neighborhoods with high rates of air pollution as potential sites for GI
Case Studies	Examining existing landscape designs which address air pollution to inform the design of a space for human use that will be incorporated into the green infrastructure design
iTree modeling alternative landscape futures	Measuring outcomes from a list of trees native to the Trinity forest to determine the planting design most effective at removing particulate matter
Key informant interviews	Bring knowledge perspectives gained through first-hand experiences as they relate to the experts' respective field of focus (air pollution, urban forestry, landscape design, etc.)

3.6 Search of the Technical Literature

The literature review provided for this research an overview of air pollution: its sources and the associated health risks, the inequality of exposure, and current technologies which exist to mitigate air pollution.

3.7 GIS Analysis of Spatial Data

Overlaying spatial data of the Dallas region aids in establishing patterns and relationships between demographics, particulate matter air pollution, and green cover to document and analyze existing conditions within the area. Arc GIS Pro was used to perform this inventory and analysis. This program utilizes graphic information systems (GIS) which are systems that connect data to a map, integrating location data with descriptive information. Utilizing these systems informs the research by showing where the issue of high levels of particulate matter are most significant in the Dallas areas. The sites which experience the highest rates of particulate matter air pollution, have the highest rates of asthma, and have neighborhoods intertwined with industrial zones were considered suitable locations. Sixteen data layers were utilized in this methodology (See Table 10).

Table 10 GIS Data Layers used for Parametric Layering

Data Layer	Purpose	Source	Date
Dallas Parcels	Land use	City of Dallas	2013
Environmental Justice Dallas	Where in Dallas exposure to PM is the highest compared with minority and low-income populations	EPA	2020
Dallas Asthma	Where in Dallas rates of asthma are highest	CDC	2020
Dallas PM Permits	Sites with air pollution permits and emission outputs	TCEQ	2021
Flood Map	At risk of flooding	City of Dallas	2021
Railroads	At risk of pollution from railroad	NCTCOG	2017
Impervious Cover	Sites lacking green cover	City of Dallas	2009

Bus Routes	Accessbility	Koordinates	2019
Hydrology	Areas at risk of flooding; areas where pollution may leach into water systems	City of Dallas	2009
Roads	Transportation-Related Air Pollution	City of Dallas	2019
Dallas Parks	Access to open green space	City of Dallas	2013
City of Dallas Boundary	Defines geographic study area	City of Dallas	2021
City of Dallas Census Block	Method of breaking down land area	City of Dallas	2013
Building Footprints	Sites of homes, industrial plants	City of Dallas	2009
2’ Contour Lines	Viability of sites for different plantings	City of Dallas	2009
Trails	Potential to plug in to existing trails	City of Dallas	2021

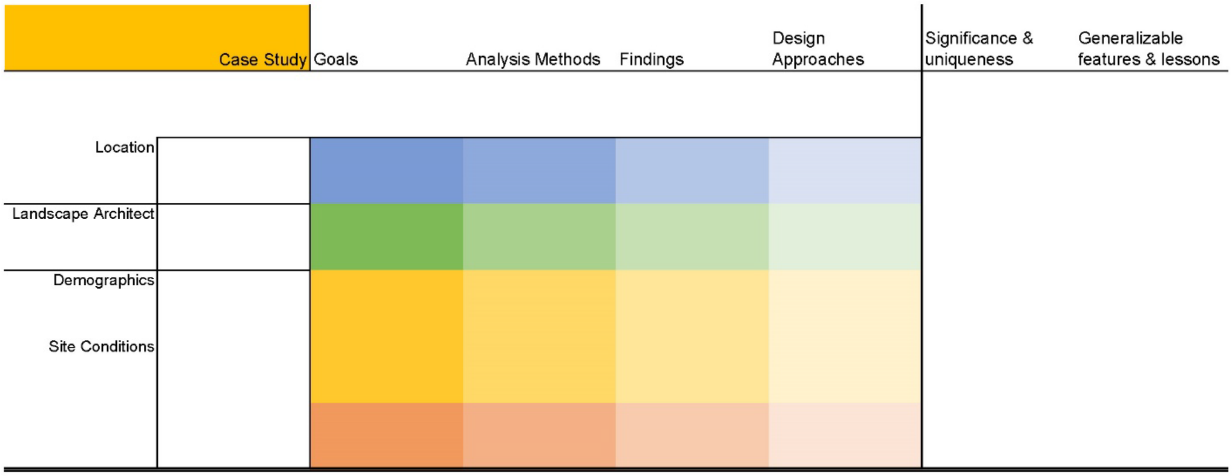
3.8 Case Studies

Case studies were utilized to examine how previously completed landscape design projects have addressed air pollution. Studying existing projects through case studies helped to inform the design of the green infrastructure in how it can serve as a space for passive recreation by human users in addition to mitigating particulate matter (Deming & Swaffield, 2011).

Design Strategies

Landscape architecture projects were chosen for their emphasis on GI as a tool for mitigating air pollution in landscape design, and the specific type of design contribution they create. Case studies were organized into the following design categories include: Master Plan, Planting Palette, Planting Design, Methodology, Site Specific Design, Engagement. The case studies were analyzed in a matrix to examine lessons learned from each approach in a comparison of design characteristics which fall under the following categories: location, demographics, existing site conditions, design goals, analysis methods, findings, and design approaches. Based on the matrix of case studies, a series of generalizable features and lessons were arrived at.

Table 11 Case Study Analysis Matrix



Case Study		Goals	Analysis Methods	Findings	Design Approaches	Significance & uniqueness	Generalizable features & lessons
Location							
Landscape Architect							
Demographics							
Site Conditions							

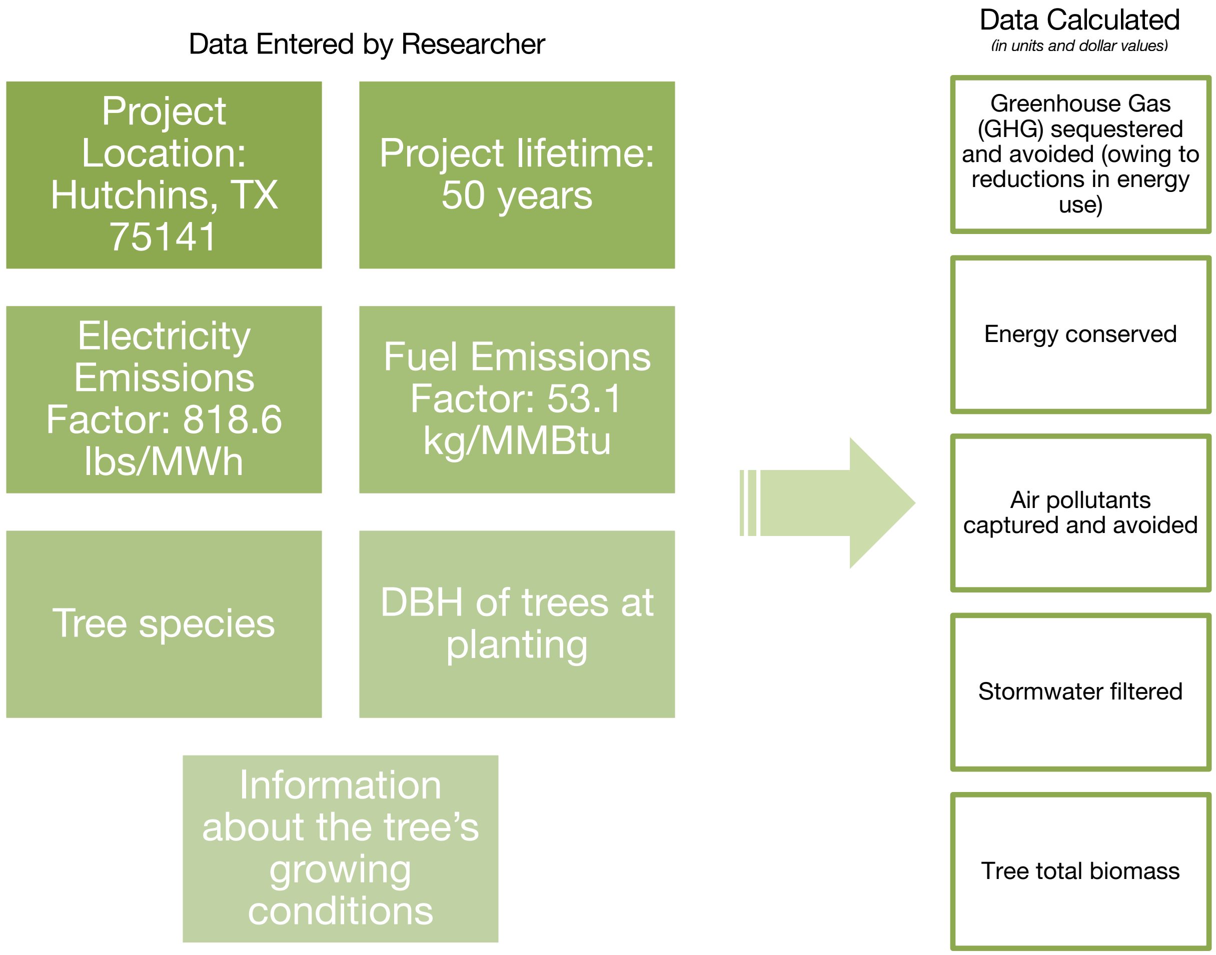
Planting Typologies

The case studies which produced planting design typologies were analyzed in a matrix where they were organized under the following classifications: vegetated wall, woodland, bioswale, hedges, lowland hedgerow, multi-mechanism buffer, and row of trees. These classifications were chosen because these typologies appeared at least once in the case study review, and oftentimes appeared in more than one case study. These groups were then used to filter through the various case study typologies, assessing them by the following categories: benefits and design considerations. From these a list of generalizable features and lessons were once again produced to be used in designed typologies for Joppa.

3.9 iTree modeling

With the data collected from the literature review, the analysis of spatial data, and the expert interviews, informed decisions were made about which species to plant and where to plant them. A series of potential tree species were arrived at, and those plant species selections were entered into iTree Planting Calculator. iTree is a peer-reviewed software suite from the USDA Forest Service that provides urban and rural forestry analysis and benefits assessment tools. The iTree Planting Calculator is one of the programs they offer, and it is available as a free web-based software designed to help estimate the long-term environmental benefits from a tree planting project for a specified geographic location. The methodology of iTree is available on their website. Selected species were then used as input for the program, and the geographic location was set to take into consideration climatic patterns and prevailing winds (See Table 12). From there the program quantified the benefits of each tree species on reducing particulate matter, mitigating ozone, capturing stormwater, and sequestering carbon, producing a numerical list stating which species are most successful within the geographic setting. This ultimately provided the researcher with a plant palette to be used in the design of GI for the site.

Table 12 Data Input and Outputs of iTree Planting Calculator



3.10 Interviewing experts

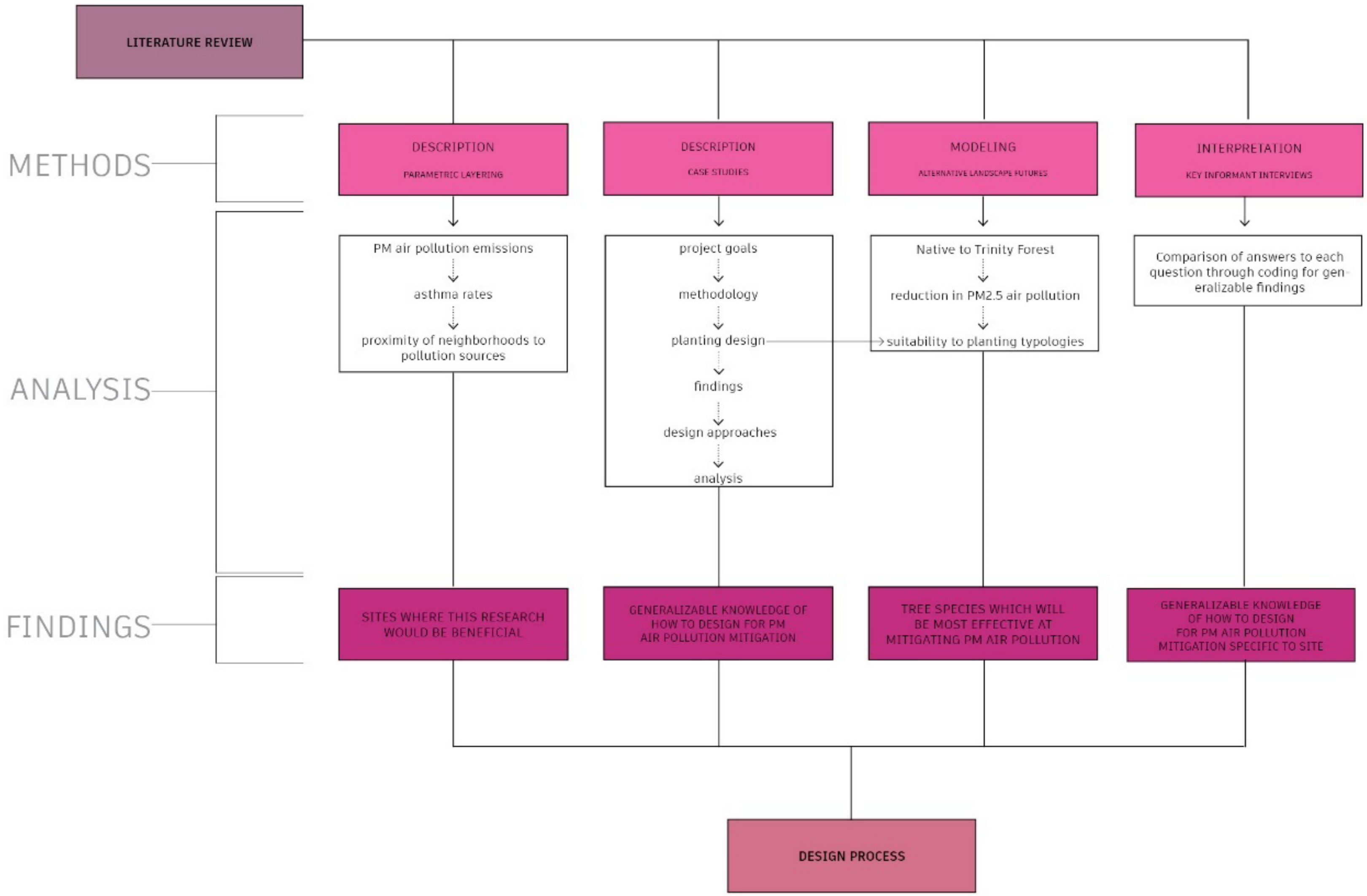
Knowledge experts were interviewed to gain insight into their knowledge of green infrastructure in the service of mitigating air pollution. Each expert has specific knowledge gained through their research and applications which will inform the design and maintenance plan of the green infrastructure. Upon acceptance of an interview request, the researcher asked them questions related to their fields of expertise. Questions fell under the following categories: mitigating particulate matter using vegetation, selecting an appropriate site to implement the GI, measuring the effectiveness of the GI on health outcomes overtime, maintenance, human use.

Please see Appendix A for the full list of interview questions. The interviews were approved by IRB as Minimal Risk (See Appendix D). Interviews were assessed through narrative analysis to highlight important aspects of the interviewees insights. Each question and answer were put into a table to compare answers, then the key takeaways were found through comparison to the literature review and relevance to Joppa.

3.11 Data Analysis Methods

From each methodology data was gained which ultimately informed the design of green infrastructure for the Joppa community. The Parametric Layering done in GIS will be filtered by highest levels of PM air pollution emissions, asthma rates, and closest proximity of neighborhoods to pollution sources. Case Studies will be analyzed by project goals, methodology, planting design, findings, design approaches, and analysis. Modeling of Alternative Landscape Futures in iTree will be filtered for being native to the Trinity Forest, for highest levels of reduction in PM2.5, and by suitability to planting typologies which were arrived at in through the Case Studies. Key Informant Interviews will be processed by comparing the answers of each expert to one another and coding the answers to produce generalizable findings. See Table 13 for analysis processes for each methodology.

Table 13 Data Analysis Methods



3.12 Design process

The goal of this study was to inform a research-based design which will mitigate particulate matter air pollutio to the greatest extent possible using vegetation through the implementation of green infrastructure for a low-income community in the Dallas area. The methods discussed above all contributed knowledge which when combined informed the design in a way which make it an effective design that promotes the quality of life for residents. The design of green infrastructure must take into consideration many factors, as it is a constructed system made of living organisms, employing the naturally occurring mechanisms of those living organisms to meet a specific goal. The goal in this case is to reduce particulate matter air pollution while improving urban ecology and increasing access to open, green space. The site selection process was informed by the GIS analysis which designated the areas in Dallas where there is the greatest amount of particulate matter in the air and which is directly adjacent to a neighborhood. This study is focused on industry-adjacent neighborhoods and as such a land use map will reveal where in Dallas there exists neighborhoods which are in close proximity to industry producing PM. Cross-referencing the land use data with the GIS air quality data ultimately informed the most appropriate site to focus on. Next a series of case studies were analyzed using a matrix to generate findings from each. The case studies which include design typologies were also analyzed through a matrix to determine a series of GI typologies and their appropriate application. iTree modeling were conducted to determine the tree species which are most effective at mitigating air pollution. A tree inventory of the site helped to inform species which grow well in the area and those were then used as inputs into iTree. iTree then produced quantitative data on each tree species. Interviewing experts were then used to translate the case studies, GIS mapping, and iTree modeling into design solutions for Joppa, Dallas which address human needs in addition to mitigating air pollution.

3.13 Chapter Summary

This research used various qualitative and quantitative methods to measure the benefits various scenarios of green infrastructure can have on particulate matter for industry-adjacent communities. By utilizing a multi-method approach, the research was an iterative process which built on and refered back to the various data collected at each method, producing a more informed and knowledge-based solution. This chapter covered the research design, study population, study location, data collection methods, data analysis methods, and the design process.

4 ANALYSIS AND FINDINGS

4.1 Introduction

The data collected through the multi-method approach (Sommer & Sommer, 2002) will need to be analyzed and synthesized to produce usable and clear findings to inform the design. The multi-method approach allows for the combination and layering and various findings to create knowledge which is applicable at a geographically specific site. Due to the complexity of this topic, the four methodologies were each chosen with specific findings in mind as a goal.

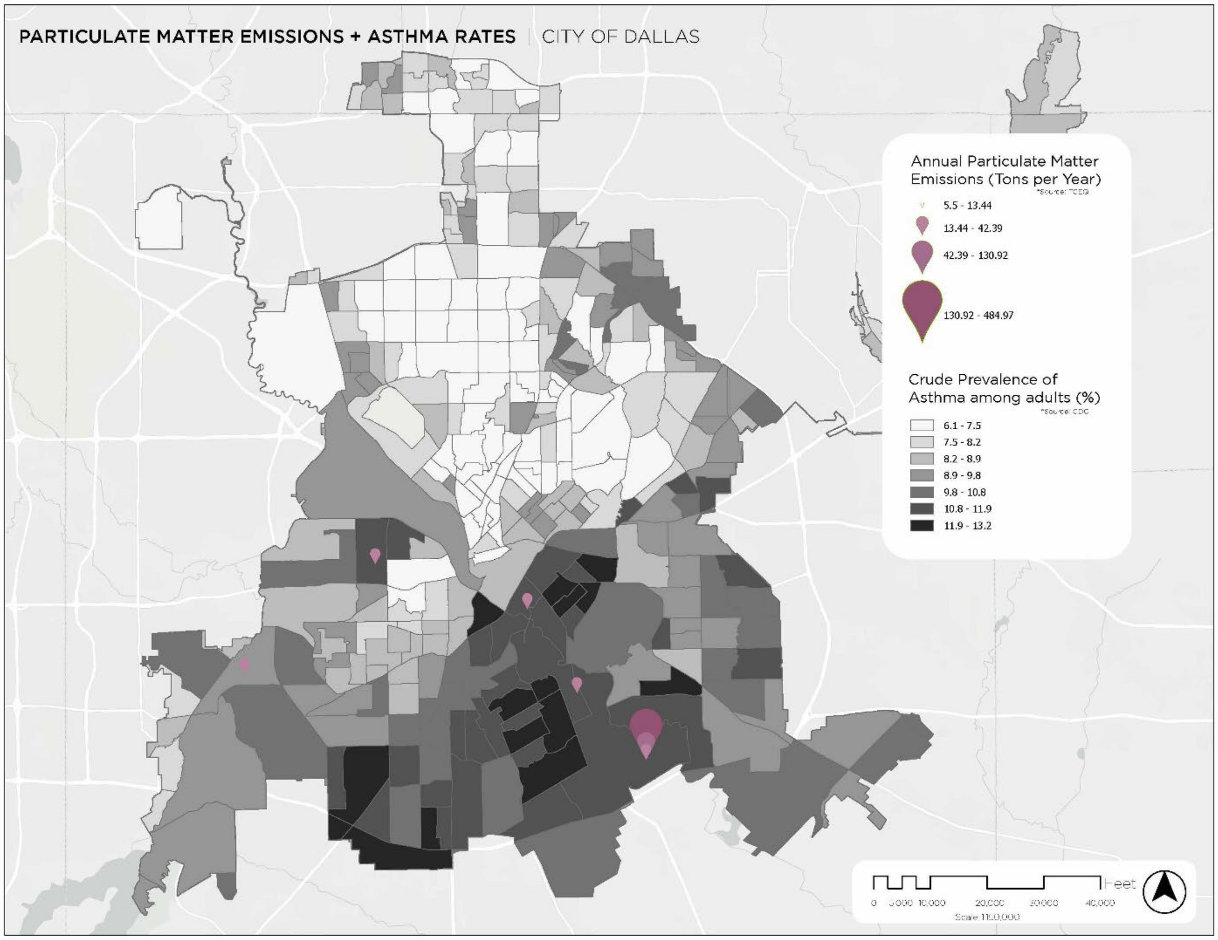
4.2 Literature Review

The literature clearly documents the importance of addressing the issue of particulate matter air pollution, and the need for alternative solutions. The literature review goes on to explore phytoremediation as a viable option for mitigation of particulate matter air pollution, with existing research proving which types of plant species are best at capturing particulate matter. The general recommendations are that the mitigating vegetation be evergreen; that individual trees have complex, waxy and/or hairy leaf surfaces with high surface area; they be non-invasive; they be non-poisonous in highly-populated areas; and they maintain safe driving visibility and not impede accessibility. For the planting design research suggests it is important to plant the green infrastructure between the source and the spaces inhabited by people. There should be no gaps in spacing to provide better reduction of exposure, and the barrier is recommended to have a height of 16’ with a minimum of 5’.

4.3 GIS Parametric Layering: Site Selection

GIS layers were overlayed to begin to study the problem by looking at existing conditions at a regional scale. By layering the various GIS data in chapter 3, it was possible to identify where in Dallas the research problem was found to exist and therefore to begin to map out locations that could benefit from this research. Five sites were identified by using the TCEQ Dallas PM Permits layer in Arc GIS Pro and sorting to pinpoint the locations with the highest levels of Particulate Matter emissions. The CDC data layer which showed asthma rates by census block was then layered underneath to map out where rates of asthma are the highest in Dallas. Those two layers could then be compared to begin to understand which locations were facing the environmental health risks associated with air pollution (see Figure 7).

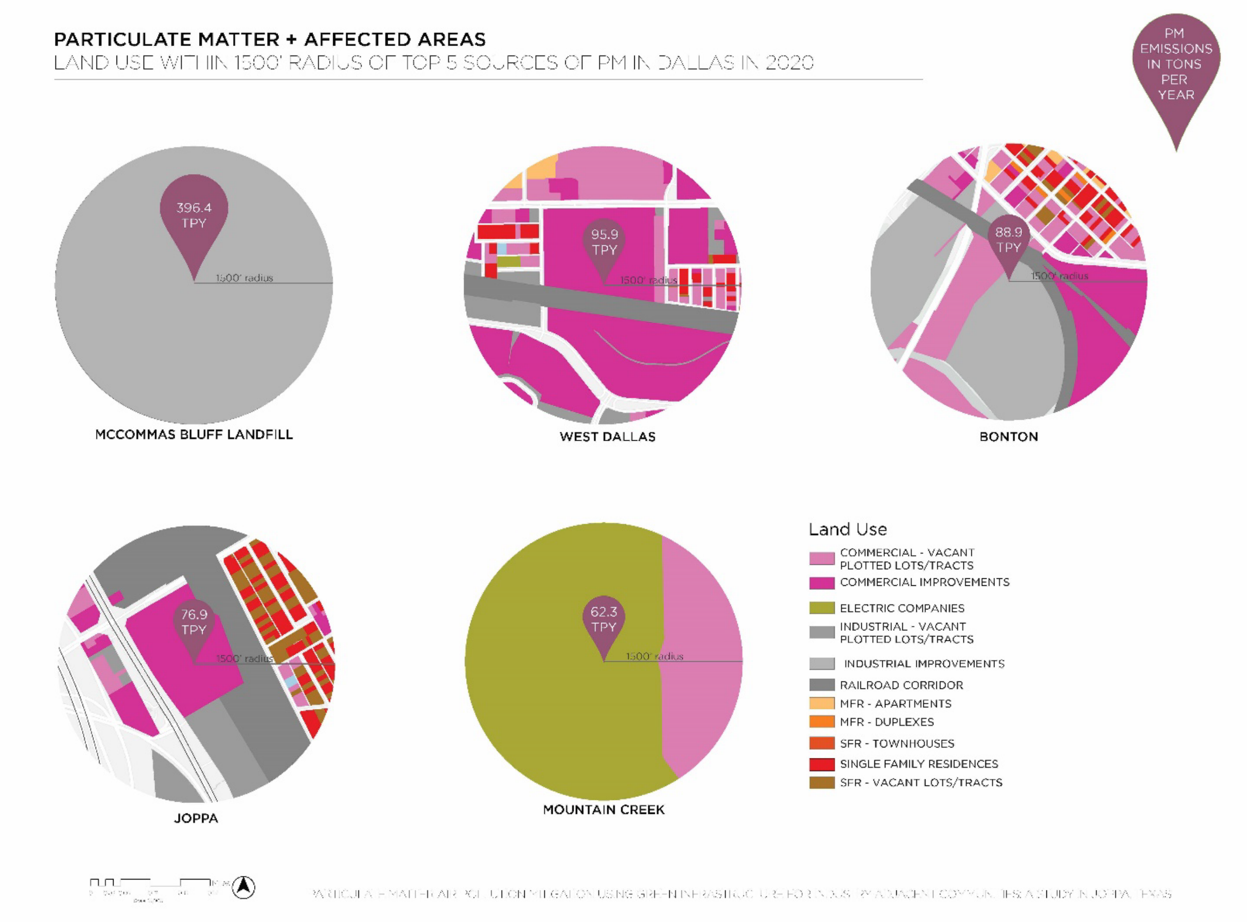
Figure 7 City of Dallas - PM Emissions and Asthma



Note. Adapted from ArcGIS Pro

Earlier findings show that the area most affected by air pollution is the band within roughly 0.2 to 0.3 miles (~1000' to 1500') from the pollution source (Health Effects Institute, 2010) therefore a pairwise buffer analysis at a radius of 1500' was then applied to each of the 5 sites to begin to look at the surrounding land uses. It was found that in 3 out of the 5 sites, residential neighborhoods fall within the 1500' area most affected by air pollution (see figure 8). Note that in the case of West Dallas, Bonton and Joppa (the area of study for this research), there is a neighborhood in close proximity to the pollution source.

Figure 8 City of Dallas - 5 Highest PM Emissions 1500' radius



Note. Adapted from ArcGIS Pro

Finally, in an attempt to understand similarities among these sites, the areas were mapped out to consider other existing conditions. Layers included in this step: flood map, railroads, impervious cover, hydrology, building footprint, roads, and city parks. What was found from this step was that in all of these sites, the land in or near the site falls within the flood plain, are located near a highway, and are located near a railroad, in addition to having industrial sites producing point-source pollution (see Figure 9).

Figure 9 Five Sites and Surrounding Context

Note. Adapted from ArcGIS Pro

4.4 Case Studies

Design Strategies

Case studies were conducted to assess how previous researchers and designers have approached utilizing vegetation to reduce air pollution. 6 projects were examined in the analysis matrix to better understand the goals of the projects, the methods and analysis employed to achieve those goals, and the findings which came out of the process. This information was pulled directly from what the authors wrote about the projects. The researcher then summarized the findings into generalizable lessons which could be transferred to other sites. See Appendix D for full analysis matrix.

Air Quality, Placemaking and Spatial Equity: The Fontana Urban Greening Master Plan

This project based in Fontana, California, United States was an evidence-based design led by Design Workshop, Inc. to address inequality and health risks associated with air pollution through a city-wide master plan. This project is relevant as a master plan study and produces lessons for a neighborhood-scale approach (See Table 14).

Fontana is transected by three major highways and includes heavy commercial and industrial use with large expanses of pavement and tracts of vacant land. The ultimate long-term goal of the project is to increase tree canopy coverage to 5% by 2050. Community engagement was used to educate community members on the benefits of various tree species and a plant palette was developed which took into consideration species characteristics, water consumption, and resistance to drought, wind, and fire. At the city scale, a framework is developed which includes green streets and green places (land use typologies). The design team made a case for a preservation plan of existing trees and established the benefit of that plan by analyzing the city's 71,574 existing street trees using iTree and the National Tree Benefits calculators. At a site scale, the designers utilized case studies of specific sites throughout Fontana to be used as models for the various typologies. The main takeaway from this case study is the emphasis on preserving existing trees by calculating the benefits a tree will have over 50 years on air quality (Design Workshop, 2020).

Table 14 Case Study Matrix: Air Quality, Placemaking and Spatial Equity: The Fontana Urban Green-ing Master Plan

Case Study		Goals	Analysis Methods	Findings	Design Approaches	Generalizable features & lessons
Demographics	71% identified as Hispanic origin	increase citywide tree canopy	Used i-Tree and National Tree Benefits Calculator to assess 71,574 existing street trees for value benefits.	Street tree inventory accounts for $6.8 million of annual benefits, benefits associated with air quality differ significantly among species	Produced a distinct tree palette	Plant Palette
	median household income of $71,000	improve multi-modal mobility	Collaborated with transportation planners to select a series of priority streets	Oversized car-dominant streets	Streetscape design which reorganizes to provide space for trees and understory plantings, improve pedestrian and bicyclist comfort	Make streets more pedestrian friendly
Site Conditions	transected by three major highways	catalyze economic development	Assessment of private v. public land uses and identitfied typologies of land uses	82% of property in Fontana is privately owned	Designed a series of typologies for each different land-use type which maximized potential for urban greening while	Landscape Typologies
	heavy commercial and industrial use	conserve water				Tree preservation

	large expanses of pavement and tracts of vacant land	reduce maintenance			optimizing function (Metrics included canopy coverage, landscape area, permeable and impermeable surface, and greenhouse gas reduction)	Calculating benfits in $ amount
	0.36% of the city’s land area possessing tree coverage	improve air quality				
		consolidate various regulations	Apply the typology best practices and the streetscape designs at a citywide scale	Framework can reduce citywide greenhouse gas by 1.58%	Comprehensive proposal for green streets and green land uses. Northern and southern edge defined as fire hazard zone	
		update policies to improve visual character	Lack of tree preservation enforcement and regulation has resulted in many being removed over the years	Hypothetically, just by preserving existing trees, Fontana could reach 5% of tree canopy coverage in 50 years.	Policy proposal to preserve all existing trees to an average of 24' diameter tree canopy	

Phyto: Principles and Resources for Site Remediation and Landscape Design

Phyto translates current research and field studies carried out by scientists into a format useful for the design practitioner in addressing site pollutants. This project is relevant as a study of planting design typologies (See Table 15).

The research publication was written by Kate Kennan and Nial Kirkwood, both landscape architects in the Northeastern United States. The methods used were a series of literature reviews and expert interviews to distill scientific knowledge around phytoremediation into applicable knowledge for design professionals. The findings include:

1. a survey of contaminants and typical conditions where phytotechnology will be applicable
2. a review of the interrelationships between specific contaminants and specific planting types
3. a review of phytotechnologies
4. a review of scientific processes behind phytotechnology remediation.

From those findings, design approaches were created recommending planting typologies which would be most effective at producing reductions in air pollution, as well as looking at the secondary benefits GI can provide. While this book did not address a specific site, typological land uses were modeled to examine typical contaminants and general recommendations on types of GI which would be most beneficial in each land use were made. The main takeaway from this book are a series of heavily researched planting typologies and their appropriate uses for mitigating pollution. For air pollution, leaf surfaces of vegetation can physically intercept particulate matter from moving air, enhancing the air quality of areas downwind of the vegetation however during heavy rainfall or when deciduous tree leaves fall, the particulates are washed into the stormwater. For this reason, Stormwater Filters should be used to prevent the particles from contaminating the stormwater runoff downstream. Additionally, the book produces a series of usable planting design templates for specific land uses. There are 5 land uses in the book which are applicable to this research: railroad corridor, suburban residential, vacant lands, light industrial, and community gardens (Kennan & Kirkwood, 2017).

Table 15 Case Study Matrix: Phyto

Goals	Methods + Analysis	Findings		Significance + uniqueness		Generalizable features + lessons
Translates current research and field studies carried out by scientists into a format useful for the design practitioner in addressing site pollutants.	Literature Review	Survey of contaminants and typical conditions where phytotechnology will be applicable	Phytotechnology and its applications for various contaminant types	Making productive use of contaminated land	Plants remediate air pollution through phytoaccumulation (collects on leaf surfaces) and phytometabolism (absorbed into the plant)	
		Review of interrelationship of specific contaminants and specific planting types	phytotechnology typologies* and land use typologies	Addresses landscape design through performance at the site design phase	Leaf surfaces of vegetation can physically intercept particulate matter from moving air	Stormwater Filters should be considered with Air-Flow Buffers to prevent the particles from contaminating the stormwater runo
		Review of phytotechnologies	Potential Applications, Efficacy, Future Uses			
		Review of scientific processes behind phytotechnology remediation		Soil Enhancement and Plant Cultivation		

*Note. *while many typologies are explored, this analysis only documents typologies which address air pollution and are applicable to Joppa*

A Simple Tree Planting Framework to Improve Climate, Air Pollution, Health, and Urban Heat in Vulnerable Locations using Non-Traditional Partners

This research study was conducted and implemented in Houston, Texas, making it the case study which is geographically closest to Joppa. The study looked at using tree planting as a tool to provide a multitude of benefits to at-risk neighborhoods, providing a replicable blueprint to improve health, urban heat, flooding, and air pollution via a multisectoral, collaborative, environmental data-driven approach. This project is relevant as a study of methodological approaches and engagement techniques (See Table 16).

The researchers, Hopkins, et al., used GIS to map out sites most at risk to flooding, urban heat, and air pollution. I-Tree planting calculator was used to create a planting palette listing out trees which would have the biggest impact on mitigating the various environmental health risks. The study also sought to engage “non-traditional” partners such as leaders around the Port of Houston Ship Channel to start a conversation amongst major oil companies and businesses such as Shell, ConocoPhillips, Dow Chemical, NRG and Port Houston Authority. These partnerships were crucial in bringing the relationship between climate and health to the meaningful attention of health, government, and industrial and business partners, who began to see the critical connections between targeted re/afforestation and enhancement of ecosystem services for community health, such as reduced flood risk, reduced heat island, and improved air quality. The results of this study were then used to inform the City of Houston’s Resilient Houston Plan of planting 4.6 million trees by 2030. The main takeaway of this study is the use of iTree and GIS to determine a planting palette and site selection. Additionally, the engagement with multisectoral leadership acted as a catalyst for a conversation around the interconnected relationships between climate and health (Hopkins, January-Bevers, Caton, & Campos, 2021).

Table 16 Case Study Matrix: A Simple Tree Planting Framework to Improve Climate, Air Pollution, Health, and Urban Heat in Vulnerable Locations using Non-Traditional Partners

Case Study		Goals	Methods + Analysis	Findings	Significance + uniqueness	Generalizable features + lessons
Location	Houston, Texas	Provide a replicable blueprint to improve health, urban heat, flooding, and air pollution via a multisectoral, collaborative, environmental data-driven approach.	Identification of optimal native trees for climate change mitigation using Center for Urban Forest Research (CUFR) Tree Carbon Calculator and i-Tree planting calculator	Rank of a native tree species provides guidance and education on which trees have the maximum climate and health benefits based on the specific needs in Houston	Collaboration between multisector leadership was instrumental in bringing the relationship between climate and health to the meaningful attention of health, government, and industrial and business partners, who began to see the critical connections between targeted re/afforestation and enhancement of ecosystem services for community health	Development of plant palette which ranks trees by their ability to provide climate change benefits to communities
Researcher	Loren P. Hopkins, Deborah J. January-Bevers, Erin K. Caton, Laura A. Campos		Identification of large-scale tree planting locations where populations are disproportionately experiencing health or other effects that are exacerbated by increased air and water pollution,	These maps highlighted the intimate connection between climate and adverse pollution-based health effects and are continuing to be used to inform locations for		Used all native trees
Phase	Adopted by the City of Houston					

Site Conditions	in the upper quartile for rate of cardiac arrest and asthma attacks		flooding, and climate change using GIS	future large-scale native Super Tree plantings.	participation in the initial tree planting acted as a catalyst for other environmental projects within the same community	Used GIS to map out sites where tree planting would be most beneficial
	in the upper quartile of the proportion of census tract that flooded during hurricane Harvey		engagement of multisectoral leadership to implement the mitigation and adaptation interventions and to expand the educational opportunities at the nexus of climate change, public health, and the environment	The lead environmental group, Houston Wilderness, worked with the health department and local government officials as well as owners/operators along the Port of Houston Ship Channel to bring major oil companies and business partners, such as Shell Oil, ConocoPhillips, Dow Chemical, and NRG and Port Houston Authority, together for this program.		Engaged with leaders in multiple sectors to expand education and awareness of the links between climate change and health, and what steps to take
	upper quartile for NO2(in proxy for NOx), O3,PM2.5or SO2 air pollutants				the City of Houston's Resilient Houston Plan's goal to plant 4.6 million trees by 2030 is using this three-part framework to determine where to plant these native trees and which tree species to plant	
	upper quartile for temperature.					

A Breath of Fresh Air: The Delray Carbon Forest as a Template to Address Ecologic, Social, and Economic Inequity

This project is situated in Delray, a neighborhood in Detroit, Michigan which is a community with high levels of air pollution due to unhealthy land use patterns where residential areas are squeezed between heavy industry. A series of green infrastructure prototypes are designed which are developed utilizing research on plant forms and physiology. This project is relevant as a study of site specific design using vacant lands (See Table 17).

While the deliverables of the project did not contain literature sources, and therefore this design can not be taken as evidence-based, the main takeaway from this project is the phased master plan which breaks down the design into three parts, ultimately achieving the “Delray Carbon Forest” which can be used as an economic resource for harvesting lumber (A Breath of Fresh Air, ASLA 2020 Student Awards).

Table 17 Case Study Matrix: The Delray Carbon Forest as a Template to Address Ecologic, So-cial, and Economic Inequity

Case Study		Goals	Methods + Analysis	Findings	Design Approaches							Significance + uniqueness	Generalizable features + lessons
Location	Delray, Detroit, Michigan	knits incompatible land uses together, providing spaces to inhabit that simultaneously fortify its inhabitants, cleaning the air they breathe	Site Inventory + Analysis	Air pollution drift is the biggest and most immediate health hazard in Delray. Tight parcels and corridor-dominant spaces	multi-scalar green infrastructure	Macro-scale: 5 landscape prototypes windbreak hedgerow (shrub, understory, and tall canopy layers)	Industrial-Strength hedgerow: Upright, strong, and columnar plant forms that maximize density. Targets land strips bordering heavy industry and factories	Rail Trail hedgerow: Irregular and “wild” forms that fill in awkward gaps along railways while providing a relaxing sense of “being away” from the city. Targets active railway corridors and creates waterways during flood events (mimicking historic marsh water channels)	Doublewide Hedgerow: Thick, bold forms that employ color, feathery forms, and fragrance pleasing to people. Targets residential land strips	Fat-Wet Trail hedgerow: Planted forms and species that recall pre-settlement Detroit larch swamps. Targets the disused railway that runs from Delray’s central active railway toward the Detroit River	Woodland bosque: Varied and lush plantings that maximize species diversity and provide rich habitat for wildlife. Targets contiguous vacant lots that offer abundant space	Phased Master Plan to support economic sustainability	5 landscape typologies to address different land uses and air pollution concentrations

Landscape Architect	Farrah Dang, Associate ASLA					Micro-scale: plant species with waxy surfaces, bundant trichomes (surface hairs), fringed leaf arrangement, and wooly seeds or flowers	Every hedgerow incorporates at least one evergreen species	special consideration for species which effectively phytoremediate the most concentrated pollutants in Delray					Evergreen in every typology
Phase	Concept	target specific "ailments" in Delray's infrastructure, providing an economically self-sustaining foundation that judiciously connects to the city's existing healthy assets	Pollution sources	Phased Master Plan approach is needed to ensure long-term social, ecological, and economic viability. Master plan will revive railways, refine major corridors, infill vacancies, unite lots, and permit ebb and flow of future development	Phase 1: Hedgerows along major transit corridors (including railway). Connect civic assets. Phytoremediate land where new pilot housing development is planned.	Phase 2: Fill in vacant lots with bosques. Hedgerows on secondary corridors. Unite lots. Convert discontinued roads to green space. Begin pilot housing program. Half of the newly constructed homes will be reserved for city employees who will maintain the GI.	Phase 3: Delray Carbon Forest is complete. Resident-workers thin plant growth as needed, where harvests can be sold as lumber and other wood products. Established GI provides stable backbone for development						Reviving historical eco-regions through GI
Site Conditions	3.63 square miles	Refine major corridors											
		Infill vacancies											
		Unite lots											
		Permit ebb and flow of future development											

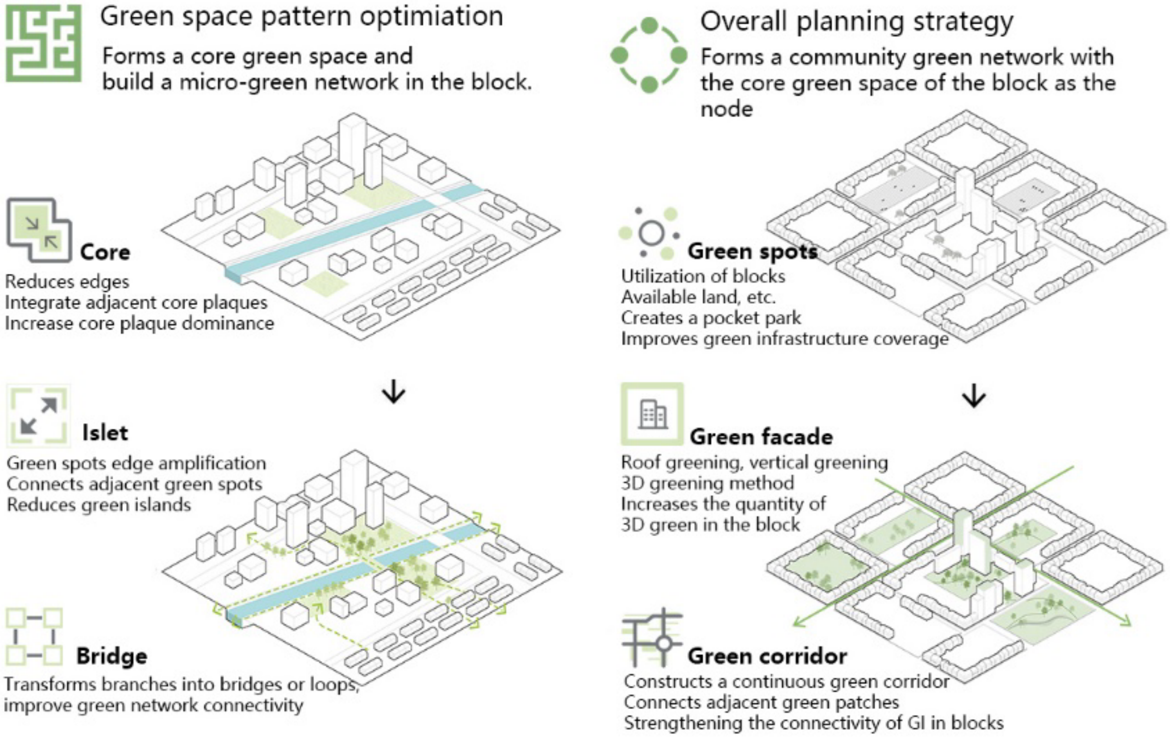
Particulate Matter Mitigation Through Urban Green Infrastructure: Research on Optimization of Block-scale Green Space

This research-based design focused specifically on particulate matter in 5 megacities within China with the research inquiring how green infrastructure can reduce particulate matter. The scale of the research is the urban block, arguing that most research on GI for particulate matter is based on a macro scale and therefore there is a need for research at a micro scale. This project is relevant as a study of methodological approaches and planting design (See Table 18).

Utilizing Remote Sensing Imagery to map existing green coverage and particulate matter 2.5 monitoring stations to document air quality, a relationship was identified which found a negative correlation between green coverage and PM2.5, whereby an increase in neighborhood green cover can effectively reduce particulate matter 2.5. At a block scale, the same relationship was found. The green coverage was broken down into categories to identify which types are most effective at decreasing PM2.5 concentration. What these researchers have identified as “Core”, “Islet”, and “Bridge” are found to have the most significant effect on reduction of PM2.5. The “Core” brings together green cover to increase green space through “Green Spots”. The “Islet” aims to amplify the edges of the “Green Spots” to reduce “Green islands” through 3D greening, such as vertical greening. The “Bridge” creates loops, which improve connectivity among the green spaces, connecting the “Green Spots” from block to block.

The main takeaway from this project is the finding that these 3 typologies are most effective at mitigating air pollution. And while not specifically planting designs, these typologies provide a broader assessment of spatial design and the importance of connectivity in Green Infrastructure (Particulate matter mitigation through urban green infrastructure, ASLA 2020 professional awards).

Figure 10 The “Core”, “Islet” and “Bridge for reducing PM2.5 at the block scale



Note. Particulate matter mitigation through urban green infrastructure: Research on optimization of block-scale Green Space: ASLA 2020 professional awards. Retrieved from https://www.asla.org/2020awards/466.html

Table 18 Case Study Matrix: Particulate Matter Mitigation Through Urban Green Infrastructure: Re-search on Optimization of Block-scale Green Space

Case Study		Goals	Methods + Analysis	Findings	Design Approaches	Significance + uniqueness	Generalizable features + lessons	
Location	Jianghan District, Wuhan, China	Designing green infrastructure at the block scale to effectively mitigate PM2.5	Analyzed PM2.5 mitigation and green infrastructure using PM2.5 concentration, green space coverage, and 3D greening	Increasing the block-scale green space coverage can effectively reduce PM2.5 concentration. Maximum reduction effect occurs when the green space coverage increases to approximately 30%	Create pocket parks through retrofitting vacant land, idle land, and other available land areas at the block scale to innovative green infrastructure designs	Designing GI for the block scale	Most effective green space coverage is 30%	confirm area size which 30% applies to
Landscape Architect	Huazhong University of Science and Technology			increasing 3D greening density to about 1.44 ha per hectare land area can maximize the reduction effect	Increase the 3D greening of urban blocks through roof greening, vertical greening, and other green façade	Spatial analyis methods	Most effective 3D (vertical) greening density is 1.44 ha	
Phase	Conceptual		Morphological spatial pattern analysis (MSPA) to visualize the spatial patterns of green infrastructure, which were overlaid against the urban fabric and were presented as seven pattern classes	five MSPA of them can significantly reduce PM2.5 concentration.	Improve connectivity of green infrastructure in urban blocks through stitching adjacent green patches and make them continuous green corridors and greenways	Organizing GI into pattern classes	To reduce PM concentration, core and bridge classes should be increased while islet classes should be reduced.	
Demographics	Population: 680,000			Increasing the proportions of the core and bridge classes can decrease PM2.5 concentration			Pocket parks in vacant lots to incorporate more GI	
Site Conditions	Hot-summer/cold-winter climate zone			Decreasing the proportion of islet class can also decrease PM2.5 concentration.			Create continuous green corridors by stitching together	

							vacant land using GI	
	extensive urban block units; current green infrastructure is limited and yet, highly fragmented							
	28.29 square km							

First Steps in Urban Air Quality For Built Environment Practitioners

This study, done in the United Kingdom, was performed to determine considerations for built environment professionals in examining air quality at all stages of urban design and development, establishing measures to take which can aid in the dispersal and deposition of air pollution. The study looked at how vegetation influences wind flow, and made recommendations on various types of GI for different scenarios. This project is relevant as a study of planting design (See Table 19).

The study found it is possible to use good urban design to reduce air pollution without knowing the exact pollutant concentrations. Additionally, GI can be used to help Reduce emissions by creating spaces that encourage active transport such as walking and cycling, or the uptake of public transport, which supports the idea of secondary benefits of GI being equally important to mitigating air pollution. The main takeaway from this project is the creation of planting design typologies which show through wind patterns how vegetation can remove more PM, NO2, and O3 from the ambient air than bare surfaces (Ferranti et al., 2019).

Table 19 Case Study Matrix: First Steps in Urban Air Quality For Built Environment Practitioners

Case Study		Goals	Methods + Analysis	Findings	Design Approaches	Significance + uniqueness	Generalizable features + lessons
Location	United Kingdom	Determine considerations for built environment professionals in examining air quality at all stages of urban design and development	Literature Review	Large areas of GI, such as parks, generally have cleaner air as they contain fewer roads and traffic emissions.		Argues for built environment professional's role in mitigating air pollution using GI	it is possible to use good urban design to reduce air pollution without knowing the exact pollutant concentrations.
		establish measures to take which can aid in the dispersal and production of air pollution	Computer Modeling	Trees and other GI influence wind flow. The combination of parklands, buildings, trees, and gardens creates a rough surface of different heights creating turbulence that increases mixing, and pollutant dispersion	Incorporate buildings and GI of different height to create a rough surface and more mixing of air		GI can be used to help Reduce emissions by creating spaces that encourage active transport such as walking and cycling, or the uptake of public transport.
Research Organization	Trees and Design Action Group (TDAG) Birmingham Institute of Forest Research and the School of Geography, Earth, and Environmental Science of the University of Birmingham, Lancaster Environment Centre of Lancaster University			Dense avenue of trees in a narrow, enclosed street (‘street canyon’) reduces mixing between street-level air and the air aloft. On a lightly trafficked street this can protect relatively clean air from the import of polluted air aloft. On a heavily trafficked street it can trap street-level pollution (i.e., fumigation).	Be mindful of street-canyon situations where GI can prevent dispersal by trapping air		GI can be used strategically to mitigate poor air quality on a local-scale to Extend and Protect

Authors	Ferranti, E.J.S., MacKenzie, A.R., Levine, J.G., Ashworth K., and Hewitt C.N.			GI, such as hedges, can be used as a barrier to increase the pathway between pollution source and receptor, which increases mixing and reduces pollutant concentration	Use GI to increase the pathway between source and receptor		
Year Published	2019			In comparison to similarly sized grey infrastructure, GI has a far greater surface area for pollutant deposition and thereby removes more PM, NO2, and O3 from the ambient air than bare surfaces.			

Planting Typologies

Of the projects which were examined in the analysis matrix and of projects documented in the literature review, the various planting typologies which were produced as findings were filtered and sorted into five categories. From there they were analyzed to determine the transferable knowledge which could be used to inform future designs (See Table 20).

The five planting typologies address different relationships between air pollutants, parcel shape/size, and soil types:

Woodland Bosque – Would be applicable in vacant lots with abundant space. Consists of Emergent Trees, Canopy Trees, Understory Trees, and Groundcover. The depth and varying height suited to vacant lots where driving visibility is not as important. Additional benefits include creates of open green space for recreation and increase in wildlife habitat.

Bioswale – Would be beneficial along railroad and streets where stormwater runoff is concentrated. Consists of plants which can tolerate both dry and wet soils. Needs to be planted in tandem with other typologies to treat air pollutants which are washed from leaves during rain events.

Hedgerow – Would be beneficial along a long, narrow site such as a roadway, creating a barrier between air pollution and walkways or homes. Consists of evergreen shrubby plants, to maximize density in a narrow space. Could also be planted with a windbreak and a bioswale for added mitigation strength.

Windbreak – Would be beneficial along thin strips of land where a safe view corridor is necessary and can be layered into multiple rows of trees for added effectiveness. Consists of canopy trees that are proven to withstand air pollution. Needs to be planted with a bioswale.

Table 20 Case Study Matrix - Planting Typologies

Typology	Benefits	Design Considerations	source	Generalizable features & lessons
Vegetated Wall	Open road with a green wall acting as a barrier between traffic emissions and pedestrians	Height of 5m or more. Minimum height of 1.5m is recommended.	Kumar et al., 2019	Requires a structure and regular maintenance Additionally blocks views and noise
	Particulate matter can also be removed via leaves of plants from accumulation	Vine Walls: comprised of climbing vines that are planted at the base or top of the wall.	Kennan & Kirkwood, 17	Requires a structure and regular maintenance Additionally blocks views and noise Depth and varying height suited to vacant lots where driving visibility is not as important Creates open green space for residents to use for recreation Increases wildlife habitat and diversity of species
	Increase the 3D greening of urban blocks	roof greening, vertical greening, and other green facade	Particulate matter mitigation through urban green infrastructure, ASLA 2020 professional awards	
	GI of different height create rough surface and more mixing of air		Ferranti et al., 2019	
Woodland Bosque	Varied and lush plantings that maximize species diversity and provide rich habitat for wildlife	Targets contiguous vacant lots that offer abundant space	A Breath of Fresh Air, ASLA 2020 Student Awards	Depth and varying height suited to vacant lots where driving visibility is not as important Creates open green space for residents to use for recreation Increases wildlife habitat and diversity of species Addresses all pollution concerns while providing

				secondary benefits in self-contained space Requires strategic layering of plant species
	Create pocket parks through retrofitting vacant land, idle land, and other available land areas at the block scale		Particulate matter mitigation through urban green infrastructure, ASLA 2020 professional awards	Depth and varying height suited to vacant lots where driving visibility is not as important Creates open green space for residents to use for recreation Increases wildlife habitat and diversity of species Addresses all pollution concerns while providing secondary benefits in self-contained space Requires strategic layering of plant species Addresses all pollution concerns while providing secondary benefits in self-contained space Requires strategic layering of plant species
	Open road with combined vegetation barriers between traffic emissions and pedestrians	Height of 5m or more. Minimum height of 1.5m is recommended.	Kumar et al., 2019	
	Provide the maximum amount of phytotechnology benefit in a small footprint without the need to harvest any plant materials	In addition to contaminant removal, can also prevent erosion, enhance wildlife habitat and corridors, sequester carbon, increase real estate values and livability and enhance aesthetics and recreational opportunities	Kennan & Kirkwood, 17	
	Should be planted with other single-purpose typologies to prevent the particles from contaminating the stormwater runoff	maximize species diversity within a system and choose plants that maximize biomass production	Kennan & Kirkwood, 17	Addresses all pollution concerns while providing secondary benefits in self-contained space Requires strategic layering of plant species Beneficial along railroad and streets where stormwater runoff is concentrated Needs to be planted in tandem with other typologies
	Open road with a hedge acting as a barrier between traffic emissions and pedestrians.	should be planted between the road and walkways or dwellings and in front of trees	Kumar et al., 2019	

Bioswale	Acts as a barrier to increase pathway from source to receptor		Ferranti et al., 2019	Creates barrier between air pollution, noise, and views Maximizes density in narrow spaces Needs to be planted with bioswale
	Irregular and "wild" forms that fill in awkward gaps along railways while providing a relaxing sense of "being away" from the city	Targets active railway corridors and creates waterways during flood events	A Breath of Fresh Air, ASLA 2020 Student Awards	
Hedgerow	Upright, strong, and columnar plant forms that maximize density	Targets land strips bordering heavy industry and factories	A Breath of Fresh Air, ASLA 2020 Student Awards	Applicable in areas where flooding is a concern
	Open road with trees acting as a filter between traffic emissions and pedestrians.	(*Under some conditions, due to a windbreak effect, pollutants can stagnate behind a sparse row of trees, leading to deteriorated downwind air quality)	Kumar et al., 2019	
	leaf surfaces of vegetation can physically intercept particulate matter from moving air, enhancing the air quality of areas downwind of the vegetation	Multi-layer buffers can be provided near land uses with human habitation, such as near residences, along roadways, parks and open spaces.	Kennan & Kirkwood, 17	Allows for safe view corridor and can be layered to increase effectiveness Needs to be planted with bioswale
	leaf surfaces of vegetation can physically intercept particulate matter from moving air, enhancing the air quality of areas downwind of the vegetation	Multi-layer buffers can be provided near land uses with human habitation, such as near residences, along roadways, parks and open spaces.	Kennan & Kirkwood, 17	Allows for safe view corridor and can be layered to increase effectiveness Needs to be planted with bioswale

Windbreak	Open road with trees acting as a filter between traffic emissions and pedestrians.	(*Under some conditions, due to a windbreak effect, pollutants can stagnate behind a sparse row of trees, leading to deteriorated downwind air quality)	Kumar et al., 2019	Allows for safe view corridor and can be layered to increase effectiveness Needs to be planted with bioswale
				Allows for safe view corridor and can be layered to increase effectiveness Needs to be planted with bioswale

4.5 Alternative Landscape Futures through iTree Modeling

iTree Planting Calculator was used to measure how well various tree species would remove particulate matter air pollution from the air. The Joppa neighborhood was used as an input to ensure proper wind and climate conditions were accounted for. Only 1 tree for each different species category was put in to the calculator, giving an output of how many pounds of particulate matter air pollution 1 tree would remove in 50 years. The trees were ranked by their PM2.5 removal (See Table 21) and then assessed by their suitability for the site and planting typologies by looking at soils in Joppa. See Appendix B for full iTree Report.

Table 21 Tree species and their PM removal

PM removal (lb/1 tree)	Tree Species Botanic Name	Tree Species Common Name
5.8	Juniperus virginiana	Eastern Red Cedar
5.1	Fraxinus pennsylvania	Green Ash
3.4	Quercus shumardii	Shumard Oak
3.2	Quercus muehlenbergii	Chinkapin Oak
3.1	Ginkgo biloba	Ginkgo
2.6	Quercus Buckleyii	Texas Red Oak
2.4	Pinus thunbergii	Japanese Black Pine
2.2	Ilex Vomitoria	Yaupon Holly
2	Ulmus Crassifolia	Cedar Elm
1.9	Fraxinus Texensis	Texas Ash
1.9	Diospyros virginiana	Persimmon
1.7	Maclura pomifera	bois-d'arc
1.3	Taxodium distichum	Bald Cypress
1	cercis canadensis	eastern redbud
0.9	Salix nigra	Black Willow
0.2	Quercus macrocarpa	Bur Oak
0.1	Carya illinoenensis	Pecan
0.1	Populus deltoides	Eastern Cottonwood
0.1	Quercus Virginiana	Live Oak

Note. Adapted from iTree Planting Calculator

4.6 Key Informant Interviews

Semi-structured interviews (Sommer and Sommer, 2002) were conducted with two industry experts, to allow interviewees to direct the flow of conversation as they saw fit. The interviews were then coded and analyzed, producing generalizable knowledge which could inform the design. See Appendix A for full list of interview questions and Appendix D for IRB Approval. Key takeaways from the interviews are the following:

- Mitigating particulate matter using vegetation
    - Vegetation is moderately effective at mitigating air pollution, but it largely depends on what type of pollution and it should be used in tandem with other air quality improvement techniques
    - Plants which are waxy, hairy, dense, and tall are most effective at capturing air pollution
- Planting Design
    - "Prophylactic planting" or preventative planting, should mimic natural plant communities, should allow for diversity succession and plant interaction, should have thick soil media, should be a mixture of height and density, and should consist of trees and underplanted evergreens
    - Sites should be selected based on wind direction in summer and winter, traffic patterns, and the distance between the source and receptor
- Metrics
    - SITES
    - iTree
- Secondary benefits

    - Plants should serve multiple purposes such as reducing the Urban Heat Island, increasing native habitat, improving ecology, and mitigating air pollution
- Additional comments
    - Warning sensors could be installed in key locations throughout the neighborhood to notify residents of when air pollution is high.
    - A misting system could be implemented to put water into the atmosphere, helping to capture pollutants in moisture droplets.
    - Trees could be used to essentially make a roof overhead of the entire neighborhood, protecting them from pollution outside of the neighborhood. However, any pollution created inside of the neighborhood would be trapped there, so driving would have to be discouraged.
    - It is important to look at the physics and the fluid dynamics of the site to understand how the air is moving and mixing with the surrounding environment.

4.7 Synthesis of Findings

The findings, when combined, create a clear vision for how GI can be used in Joppa to reduce air pollution. The Parametric Layer in GIS helped to show sites within the confines of the study area where this research would be most applicable. It also helped to justify the need for this research by revealing of pattern of land uses and environmental conditions which repeatedly put minority populations at risk. Case Studies assisted in largely informing the design approach, as the findings from those studies produced a series of best practices when dealing with air pollution from a landscape architecture approach. The spatial design was informed by adapting the approaches taken in the case studies. Modeling landscape futures through iTree Planting

Calculator produced a quantifiable tree palette which has the greatest impact on reducing air pollution. Finally key informant interviews discuss lessons learned through experience and helped to produce site specific findings by looking at maps of Joppa.

4.8 Chapter Summary

This chapter reviewed the findings of the data collected through the multi-method research approach. This chapter also delved into the analysis of the findings to explain how these findings will be used in creating a landscape design for Joppa.

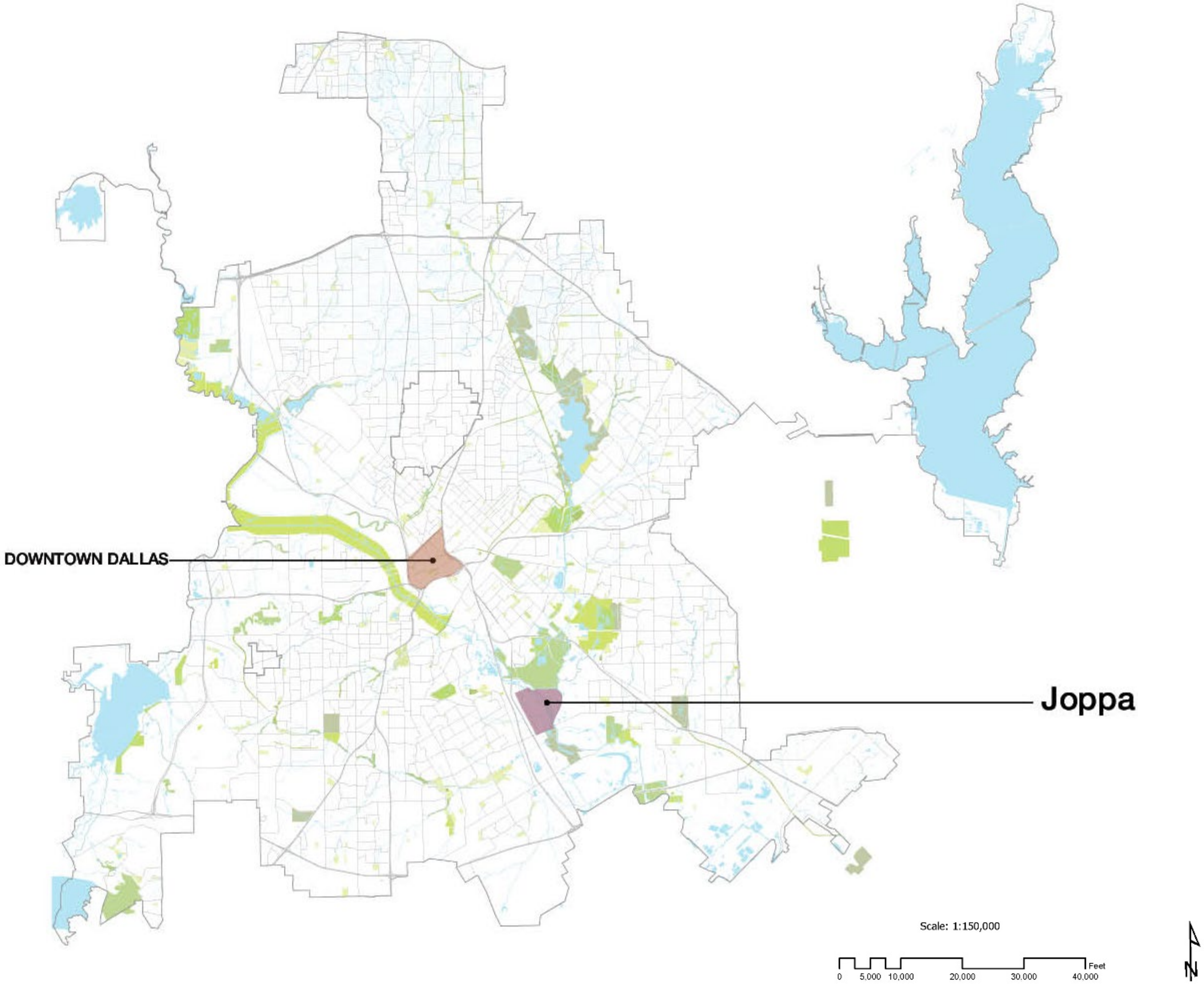
5 DESIGN

5.1 Introduction

The findings from this research were then used to develop an evidence-based design solution for the community of Joppa, a freedmen's town founded by formerly enslaved people in North Texas, six miles southeast of downtown Dallas (See Figure 5). The design will mitigate particulate matter to the greatest extent possible using vegetation through the implementation of green infrastructure and can be scalable for low-income industry-adjacent communities across the Dallas area. The design of green infrastructure must take into consideration many factors, as it is a constructed system made of living organisms, employing the naturally occurring mechanisms of those living organisms to meet a specific goal. The goal in this case is to reduce particulate matter while improving urban ecology and increasing access to open, green space. (See Figure 11).

This community is representative of many of the communities which face previously mentioned issues, as it is a single-family residential community which shares an edge with an industrial rail line, a roofing shingle making plant, a concrete batch plant and a plethora of other various polluting industry, with nothing to create a buffer between the industry and the residents (See Figure 12). Additionally, current air quality data exists for this site, making it possible to measure the difference GI can make. Lastly, the historic significance of this town cannot be downplayed. Joppa is a historically designated town that is an embodiment of the legacy of slavery in the southern United States. There is a need to preserve this neighborhood and lift it up as a model of how we can right the wrongs of the past through the built environment.

Figure 11 Joppa proximity to Downtown Dallas



Note. Adapted from Arc GIS Pro

Figure 12 Images of Joppa

5.2 Site Inventory and Analysis

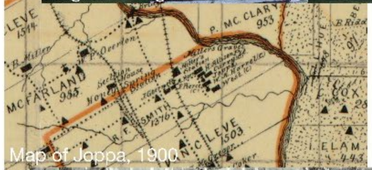
Joppa – The history

The history of Joppa is tumultuous (See Figure 13). Prior to it being settled, it was inhabited by the Wichita, Tawokoni, Jumanos, and Kickapoo tribal nations. In 1840, white settlers claimed ownership over the land, splitting it into 800 acres and gifting it to 2 men as thanks for their service in the Army of Texas. In the 1850s during the boom of the plantation south, the land was used as a part of a roughly 7,500 acre cotton farm, operated by enslaved peoples under the ownership of the Miller Plantation. The United States Civil War broke out in the 1860s, and Texas was seen as a safe place to send enslaved peoples who wanted to protect their "property" from the battles taking place across the southeastern US. Henry Critz Hines was one such enslaved person who was sent to Texas for protection under the Miller Plantation. After the end of the Civil War, Henry Critz Hines settled in Joppa, operating the Honey Springs Ferry to transport people across the Trinity River. In 1872 the Houston and Texas Central Railroad was built in the same place it sits today. In 1882 the first church was opened, New Zion Missionary Baptist church, and by 1900 at least seven families lived in the Joppa area. During that time period from the late 1800s to the mid-1950s, the Jim Crow Era was in effect, and Joppa was victim to many of the racist actions and decisions of that era. By the 1940s the highway was built and industrial land began to develop around Joppa due to the proximity to the highway and the railroad. It was not until 1952 that a school was built to teach the black students of the community and it was not until the 2000s that the City of Dallas began to make investments in the towns infrastructure. Today it is on the Registrar of Historic places and has a massive Juneteenth Celebration every year. Many public institutions are beginning to invest time and resources into the community, with multiple urban planning and design colleges conducting research, such as A&M University, UT Dallas, Paul Quinn College, and UT Arlington. It now sits

Figure 13 Historic Timeline of Joppa

He saw in a vision I an angel of God coming I and when he looked I he was afraid and said: 'What is it, Lord?' And he replied unto him: 'Your prayers are answered now, send men to Joppa." Acts 10:3


Original Shotgun House


Map of Joppa, 1900


Joppa, 1930


Melissa Pierce School


Photo of Melissa Pierce

Juneteenth Celebration, 2021

Land originally inhabited by Wichita, Tawokoni, Jumanons, and Kickapoo tribes

PRE–1840

1845 Land split into 800 acres and split between Robinson F. Smith and Lorenzo Van for their service in the Army of Texas

1850

1850s Miller Plantation farmed cotton on nearly 7,500 acres of land

1860

CIVIL WAR

1861 Henry Critz Hines, an enslaved person sent as property from Missouri or Alabama to Texas for protection by Mr. Miller until the end of the Civil War

RECONSTRUCTION ERA

1870

1872 Houston and Texas Central Railroad built
Henry Critz Hines settles in Joppa

1880

1882 New Zion Missionary Baptist Church is founded

1880s Henry Critz Hines operated the Honey Springs Ferry Company to transport people across the Trinity River

1890

1900

1900 At least 7 families lived in the Joppa area

1910

JIM CROW ERA

1920

1930

1940

1950

1948 South Central Civic League is formed to fight for community programs and services

1952 Melissa Pierce School is built in Joppa to serve black students

1960

1955 Joppa is annexed into the City of Dallas

CIVIL RIGHTS ERA

1970

1970 Integration of Wilmer-Hutchins ISD

1980

1990

2000

1999 *Foster's Crossing* connects the southern and northern halves of Joppa

POST CIVIL RIGHTS – CURRENT ERA

2005

2007 Freedmen's Town Memorial Bridge is built

2010

2015

2015 South Central Park is built

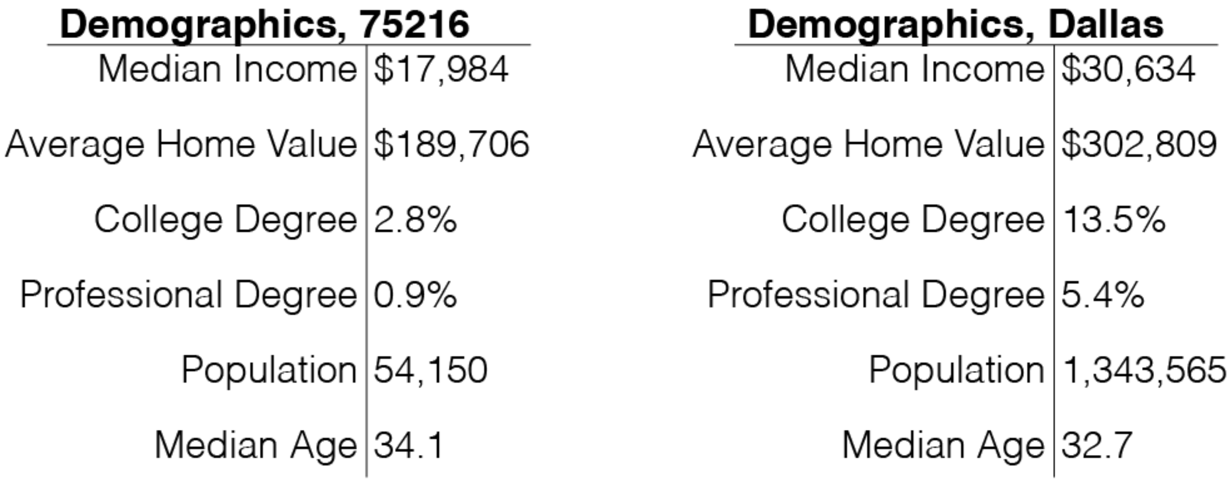
2020

at a precipice where enough public interest exists in seeing this town lifted up and celebrated, that funding and resources are being made available to the community.

Joppa – the people

The Joppa neighborhood falls under District 7, primarily under the zip code 75216, while some of the adjacent industry sits on land with the zip codes 75241 and 75215. The demographics of this community align with many of the others which face high rates of air pollution and industry-adjacent zoning. It is low income and 78% people of color (see Table 22 and 23).

Table 22 Population by Race for zip code 75216

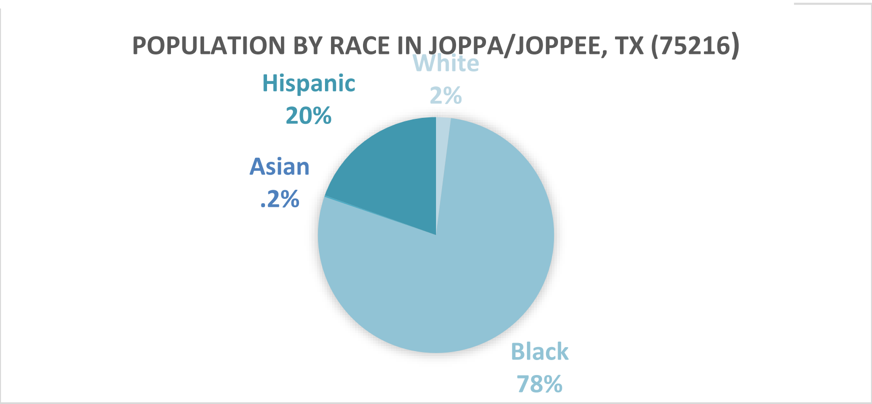


Demographics, 75216	
Median Income	$17,984
Average Home Value	$189,706
College Degree	2.8%
Professional Degree	0.9%
Population	54,150
Median Age	34.1

Demographics, Dallas	
Median Income	$30,634
Average Home Value	$302,809
College Degree	13.5%
Professional Degree	5.4%
Population	1,343,565
Median Age	32.7

Note. Adapted from US Census Data

Table 23 Population by Race for zip code 75216



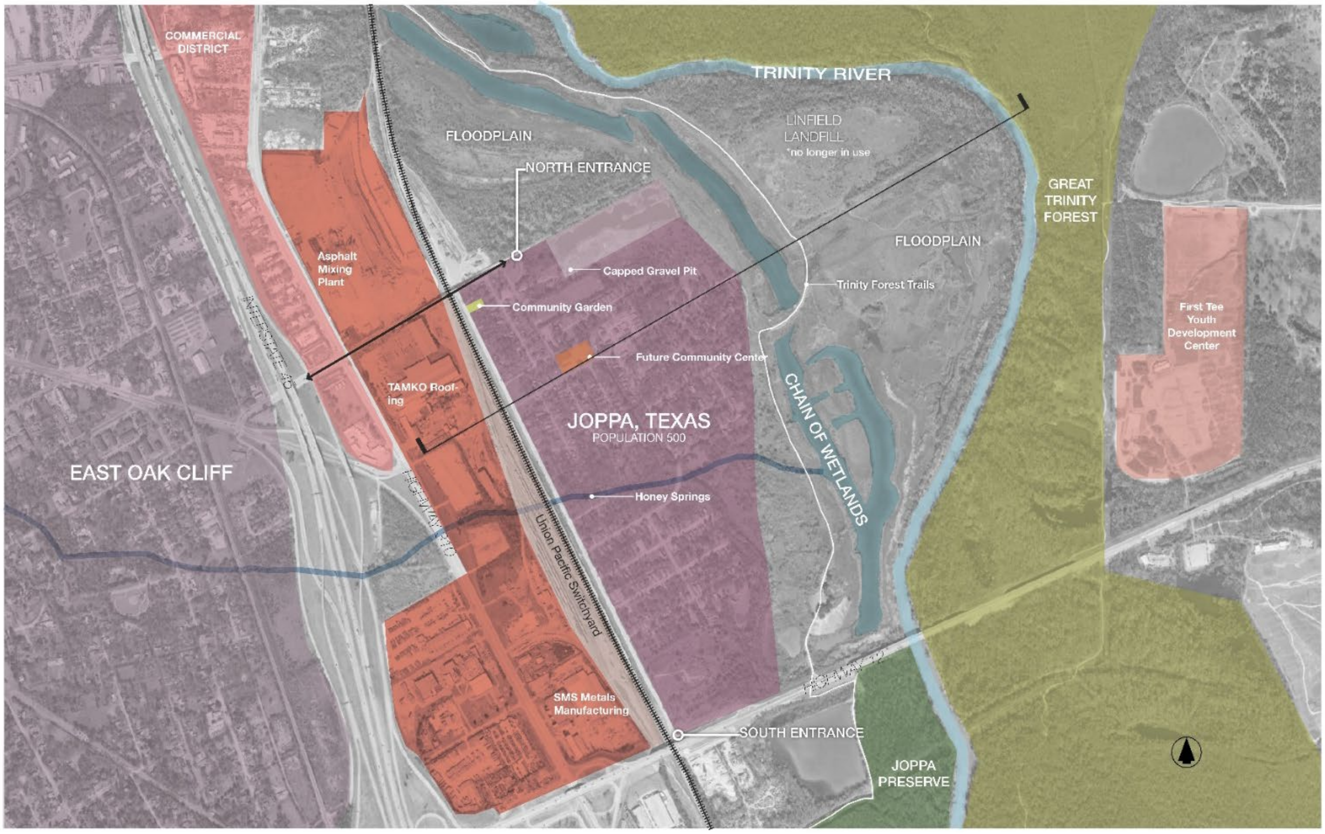
Note. Adapted from US Census Data

The demographics of this community combined with its geographic proximity to producers of high levels of particulate matter make this town a prime location to model a series of green infrastructure designs.

Joppa – the land

Joppa/Joppee is a neighborhood in South Dallas, with a swath of industrial land uses to the west and the Great Trinity Forest to the east (See Figure 14).

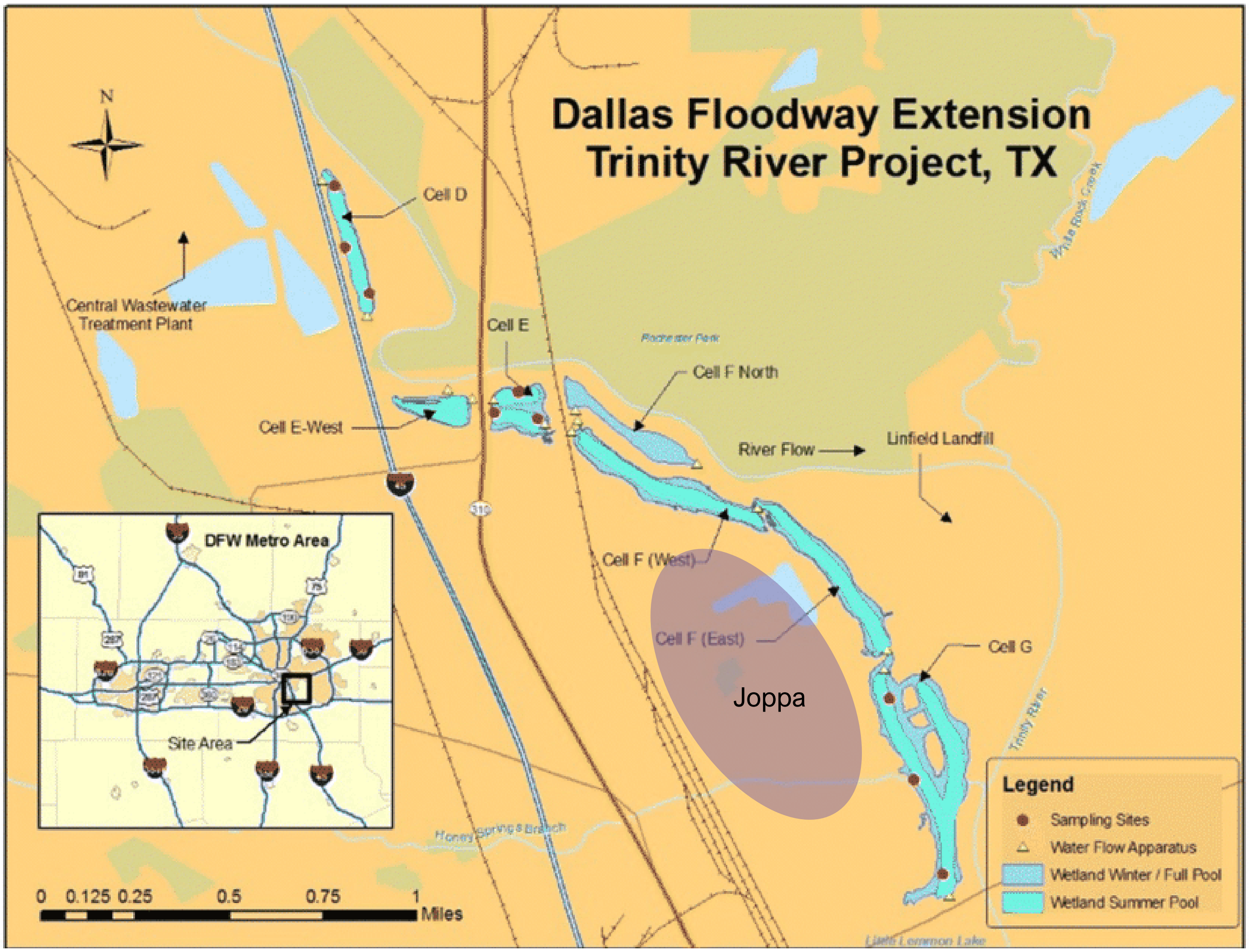
Figure 14 Site Analysis of Existing Conditions in Joppa, Dallas, Texas



Much of Joppa sits within a flood plain, just west of the Trinity River. The Chain of Wetlands, built by the Army Corp of Engineers in 2004 and 2008 under the directive of the Dallas

Floodway Extension (DFE), was designed to permit unimpeded overflow of floodwaters along the west side of the Trinity River from the Dallas Floodway to Loop 12, while at the same time provide quality wetland and grassland habitat during periods of normal water flow (See Figure 15).

Figure 15 Dallas Floodway Extension Chain of Wetlands Map

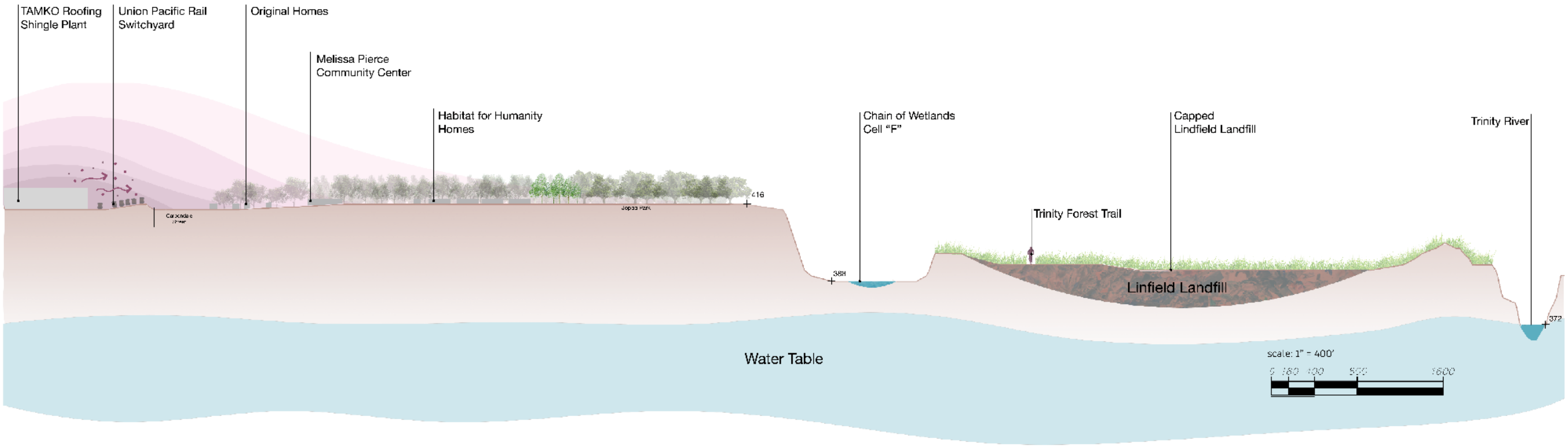


Note. From Dick, G. O., Dodd, L. L., Schad, A. N., Smith, D. H., & Owens, C. S. (2015). Lower Chain of Wetlands and Grasslands Ecological. Lewisville, Texas: USACE ERDC Lewisville Aquatic Ecosystem Research Facility.

The construction of these wetlands helped to bring much of Dallas out of the 300-year floodplain and into the 500-year floodplain, Joppa included. The study conducted in the process of building these Wetland Cells also required the examination of a series of pits surrounding the Joppa community. The pit called the Linfield Landfill is a remnant of a gravel quarrying operation but has in more recent years been used as a site for illegal dumping. Tests were done in 1995 and 1997 using soil and water samples to measure levels of contaminants, and it was confirmed that the soils were consistent with municipal solid waste. The following conclusion was arrived at: "Based on Corps of Engineers Fort Worth District experience, total lead concentration of 310-500 mg/kg would not likely result in Toxicity Characteristic Leaching Procedure (TCLP) Pb > 5.0 mg/l. Thus, material is anticipated to be categorized as Class 1 or Class 2 nonhazardous waste. If later tests confirm the wastes to be hazardous the site will be avoided" (Dick, Dodd, Schad, Smith, & Owens, 2015). A paved trail runs through the wetlands and is used for cycling, hiking, and light recreation. The presence of these lands as flood prevention measures, ecological habitat, and as the site of contaminated soil is important to consider in the overall design of GI for Joppa. Beyond the wetlands, on the east side of the Trinity River, sits The Great Trinity Forest, the largest urban forest in the country, yet largely disconnected from the City of Dallas beyond a few minor trails.

The neighborhood itself sits on higher land, 28' above the Wetland Cells and 44' above the Trinity River (See Figure 16). A small stream, Honey Springs Creek runs through the neighborhood and connects to the wetland cells. The area where the creek runs is depressed and falls within the floodplain and is largely undevelopable. The community takes up about 220 acres of land, with the swath of industry taking up another two hundred acres. In total land use, Joppa is roughly half-residential, half-industrial, with zero separation between the two. The community is framed by HWY 12 directly south of the neighborhood and Interstate-45 one mile to the west, which service the two points of access into the neighborhood.

Figure 16 Section of existing conditions in Joppa



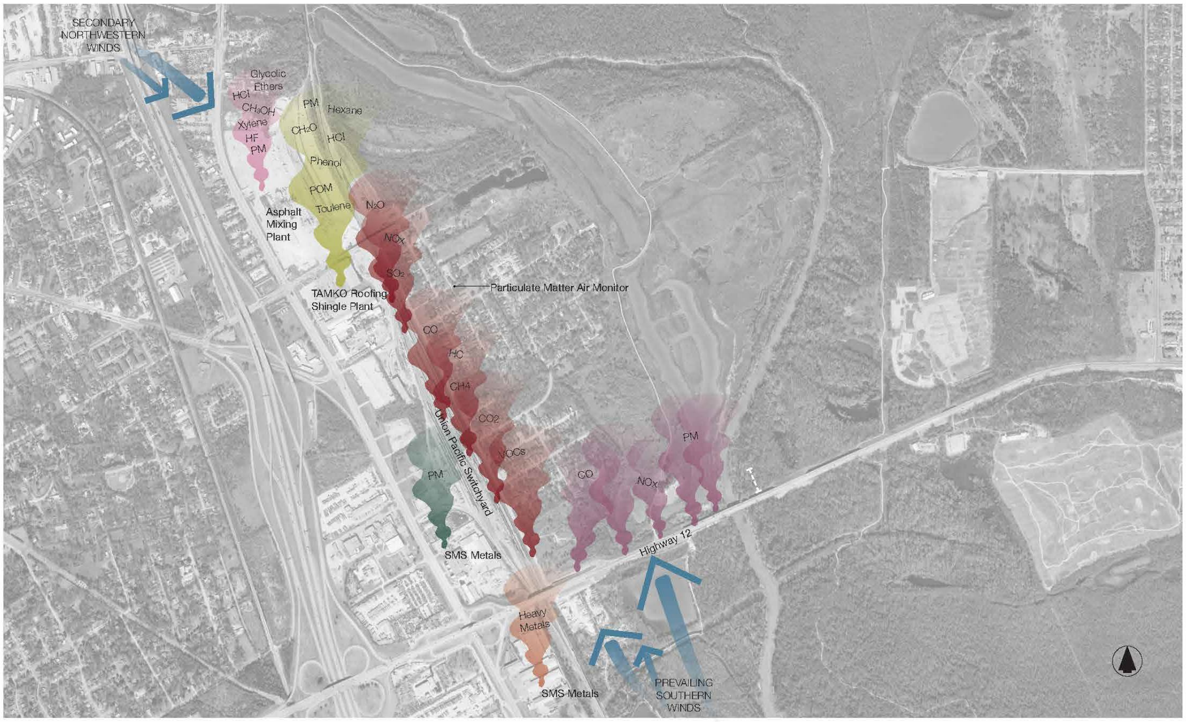
Joppa – Community Engagement, Spring 2020

As was mentioned in the Introduction, UT Arlington has developed a relationship with Joppa over the past few years. In the spring of 2020, as a part of Studio II, a community engagement was conducted to discover the needs of the community as identified by community members. The engagement was conducted using video and maps to begin to understand how people inhabited the neighborhood and what they would like to see improved. They called for changes at all scales, from having more frequent bulk trash days to having a large urban farm. Based on the engagement feedback, the neighborhood desires sidewalks, spaces for children to play, preservation of historically significant architecture, businesses in the neighborhood, ADA accessibility for elderly folks, a community center, safer and more frequent public transit as the bus comes seven times a day and stops running at 8:30PM. Joppa is home to fifteen churches, many of which are attended by people who do not reside in Joppa proper, but elsewhere in the DFW metroplex. In 2021, Joppy Momma Farms, a community garden is opened up along Carbondale Street directly across from the TAMKO roofing shingle plant. Melissa Pierce School is a remnant from the days of segregation in the US on land donated by Ms. Melissa Pierce, the daughter of a formerly enslaved person who saw the need for the black children of the community to attend school when they were not welcomed in white centers of education. The neighborhood is working towards turning this vacant building into a Joppa community center. An added layer to this neighborhood is the involvement of Habitat for Humanity which has built over 100 homes in the neighborhood over the past 20 years and has dramatically altered the physical and demographic makeup of the neighborhood. See Appendix C for full engagement feedback.

Joppa – the air

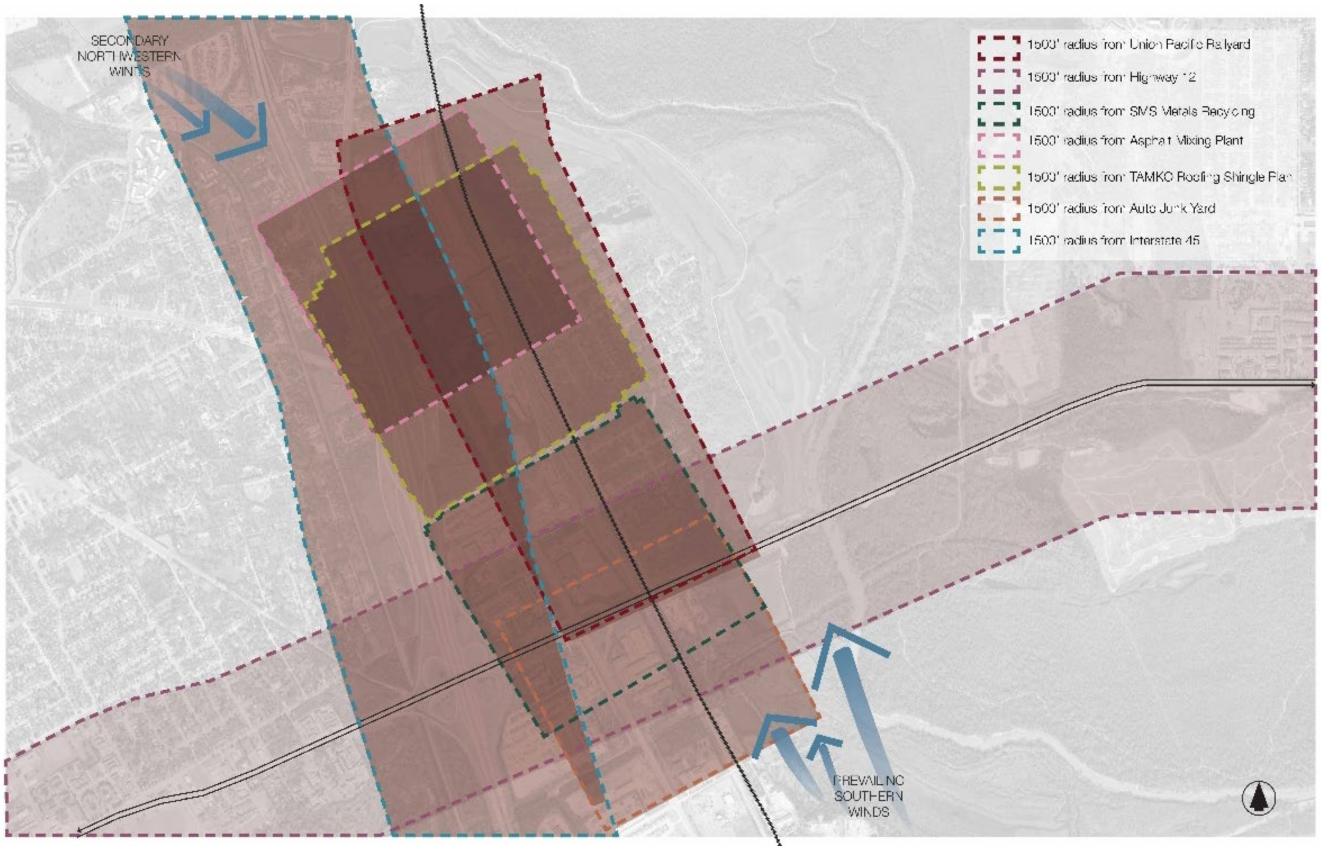
Built directly across the street from Martin Marietta, a concrete batch plant, TAMKO shingle-making plant, and a Union Pacific switchyard, all large producers of particulate matter, Joppa is exposed to high levels of air pollution (See Figure 17).

Figure 17 Air Pollution and Sources Around Joppa



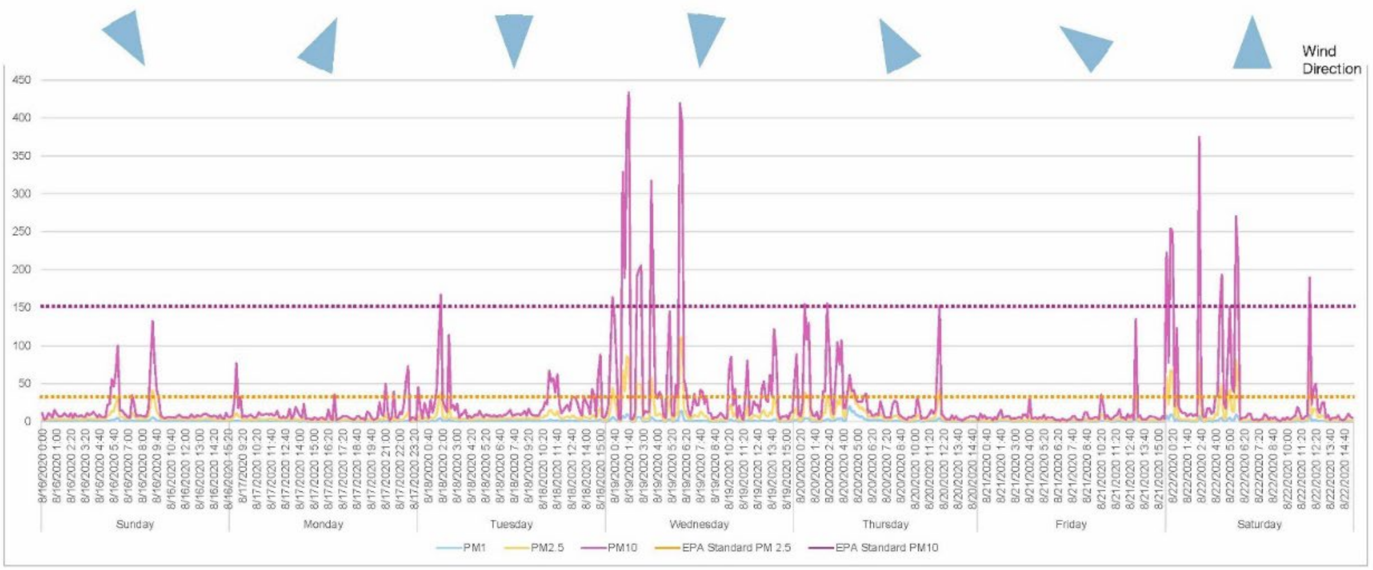
Lands which fall within the 1500' zone of high risk are considered prime locations for neighborhood-scale GI (See Figure 18).

Figure 18 Areas that fall within the 1500' zone of high risk of air pollution from each source



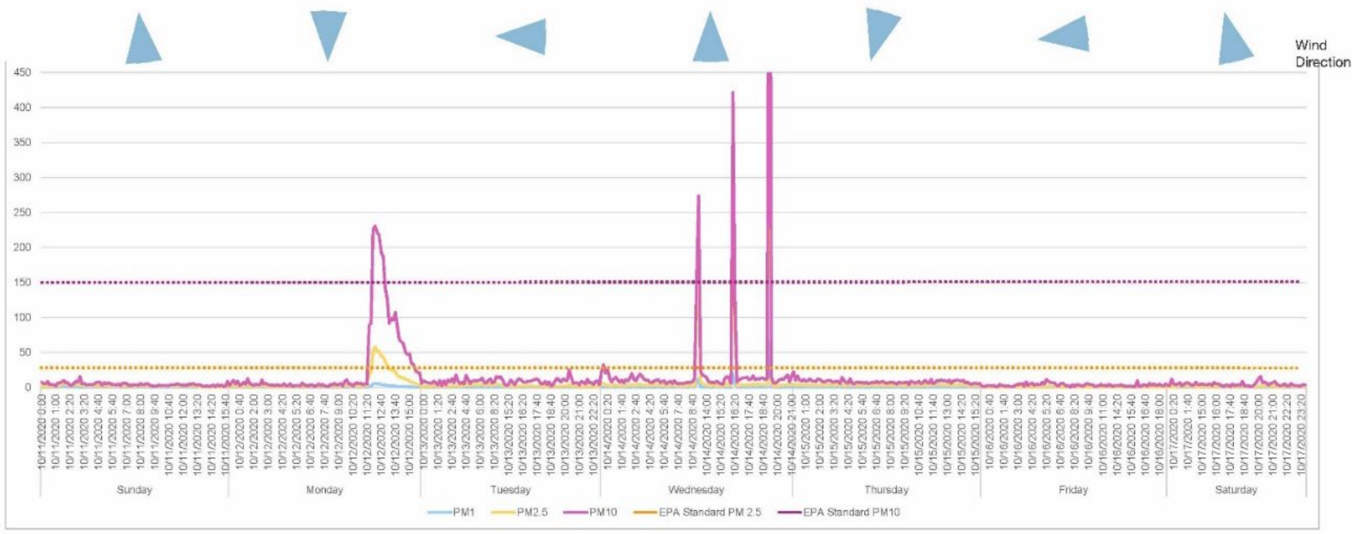
The levels of particulate matter have been documented through air quality monitors which were placed in Joppa/Joppa on August 12, 2020 and are continuing to monitor the air quality at the time of this research. The monitors are being run through SharedAirDFW, an organization seeking to provide the residents of DFW with real time air quality data through a network of 100 custom-built air quality monitors. The data provided by SharedAirDFW monitors in Joppa show higher levels of PM in the summers as compared to the other three seasons of the year (See Tables 24 - 27).

Table 24 SharedAirDFW Air Monitor Data. Summer of 2020



Note. Table adapted from data provided by SharedAirDFW.

Table 25 SharedAirDFW Air Monitor Data. Autumn of 2020

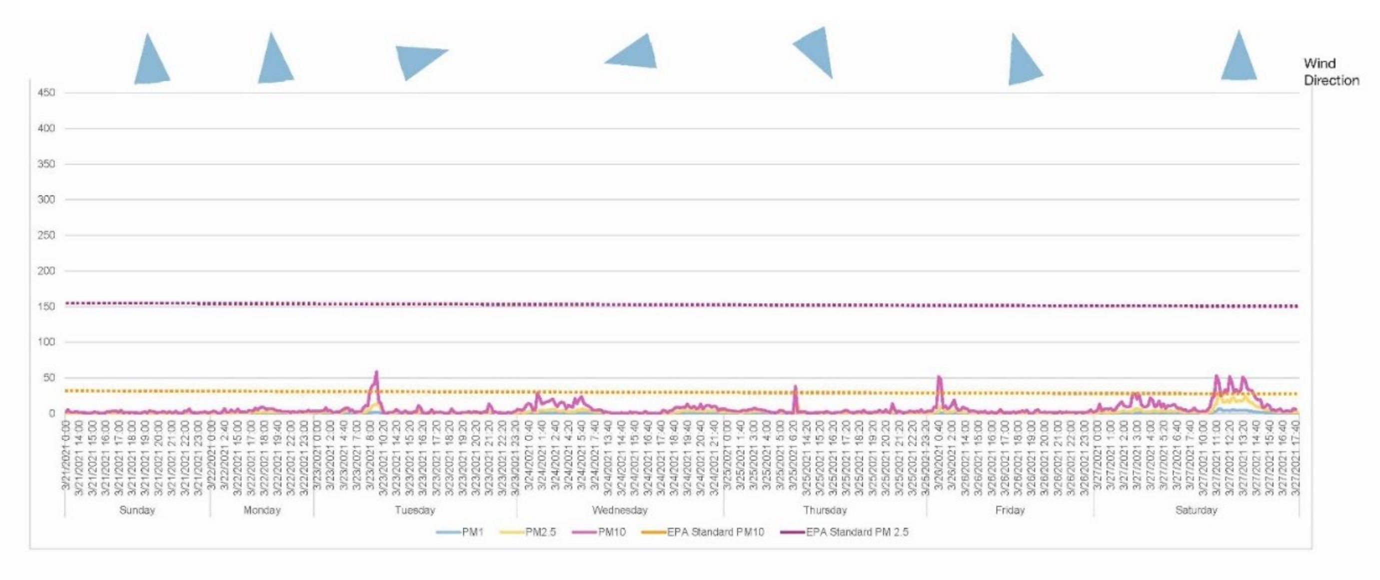


Note. Table adapted from data provided by SharedAirDFW.

Table 26 SharedAirDFW Air Monitor Data. Winter of 2020 – 2021

Note. Table adapted from data provided by SharedAirDFW.

Table 27 SharedAirDFW Air Monitor Data. Spring of 2021



Note. Table adapted from data provided by SharedAirDFW.

5.3 Design Solutions

The design solutions will address the issues of air quality, health, well-being, and equity in the following ways.

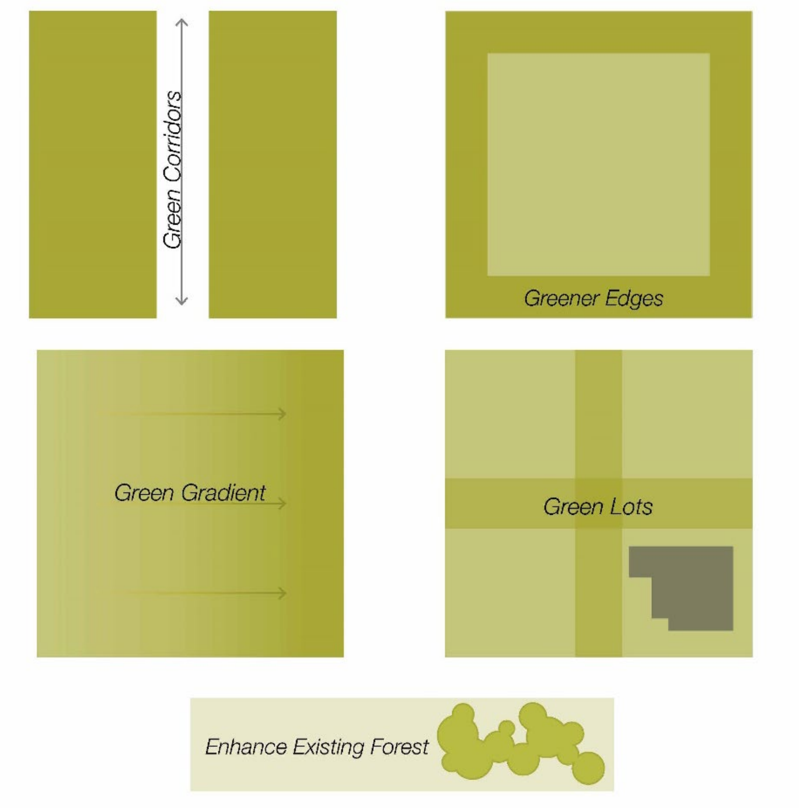
- reduce levels of pollution in the air
- reduce flood risk
- increase access to open green space
- enhance ecological habitat for all species
- elevate character of neighborhood through aesthetics
- stabilize development pressures
    - phased master plan to strengthen build consensus
    - sense of community building through neighborhood planting days

The neighborhood is in need of a green infrastructure plan which can address all of the design goals in a relatively low-cost, high-yield manner. The literature review and research findings produced all of the necessary components of the design.

- Site selection, both regionally and at a neighborhood scale
- Planting palette
- Planting design
- Programming and human-use
- Master plan phasing

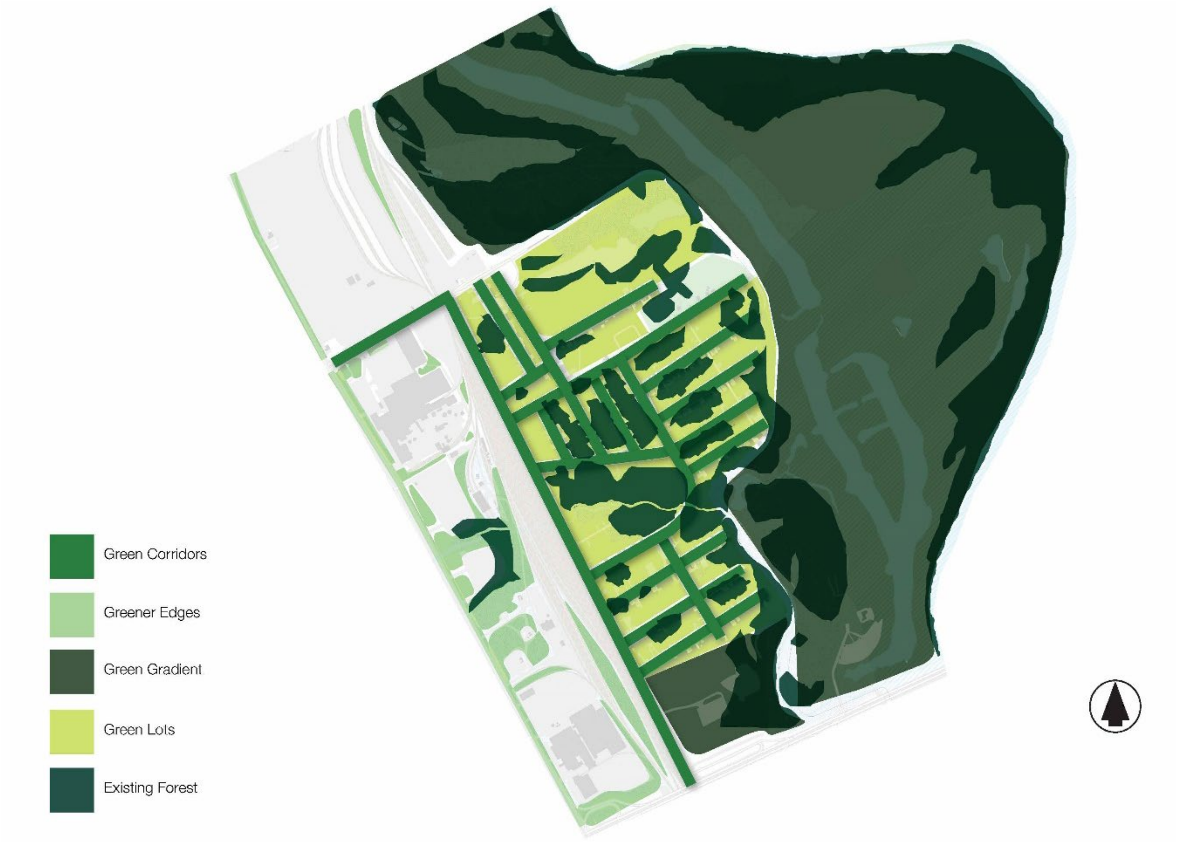
Design principles (See Figure 19) are developed to break down the mechanisms of Green Infrastructure at the neighborhood scale.

Figure 19 Design Principles



The design principles address four concepts which came up in the case studies. Green Corridors is essentially creating green transit networks such as green streets and green trails. Green Corridors will protect from air pollutants pedestrians and people who live near roadways by creating green buffers between pollution sources and potential receptors. A Green Gradient employs the implementation of GI at various densities, to create spaces which are more or less inhabitable by human users, with denser GI being planted closer to pollution sources and less-dense GI being planted near green recreation space. Greener Edges represents the idea of establishing a frame of GI around the neighborhood, to protect it from surrounding pollution sources. Green Lots begins to look at how GI can be installed within individual plots of land to build buffers around individual homes to protect from pollution. While these principles could be scaled to apply to any neighborhood with poor air quality, beginning to envision how these principles apply to Joppa particularly was aided by drawing on a map where each principle would be implemented (See Figure 20).

Figure 20 Design Principles within Joppa



GI Typologies

The GI typologies begin to break down the master plan into site specific designs. The design of the typologies are informed by the series of case studies. Four typologies were designed to address the specific needs of Joppa: A Woodland Bosque, A Bioswale, A Hedgerow, and a Windbreak.

The Woodland Bosque (See Figure 21) is applicable in vacant lots with abundant space, incorporating depth a varying height to increase mixing of air through varied surfaces and porosities. It consists of emergent trees, canopy trees, understory trees, and shrubs, which has the added benefit of species diversity to support a rich wildlife habitat. This typology addresses issues of air quality, flood risk, need for open green space for recreation, increase in wildlife habitat, and stabilization of development pressures through utilization of vacant lots.

Figure 21 Woodland Bosque

A Bioswale (See Figure 22) is beneficial along railroads and streets where it needs to be planted in tandem with other typologies. The bioswale addresses the secondary cycles of air pollutants as contaminants are washed off of leaves during rain events or fall to the soil during leaf drop. By installing bioswales adjacent to the air pollution buffers, a second layer of defense against pollution is provided. This will aid in keeping pollutants out of the water and soil, where it may affect health and environment in ways not documented in this research. It consists of plants tolerant of both dry and wet soils.

Figure 22 Bioswale

A Hedgerow (See Figure 23) is beneficial along long, narrow stretches of land such as a roadway or along the rail corridor, creating a barrier between air pollution and walkways or homes. The barrier essentially increases the distance between sources of pollution and those who are at risk of breathing it in, because the hedgerow forces the pollution to go up and over the hedges. It consists of evergreen shrubby plants, to maximize density in a narrow space, and needs to be planted with a bioswale.

Figure 23 Hedgerow

The Windbreak (See Figure 24) is applicable along thin strips of land where a safe view corridor is necessary and can be layered into multiple rows of trees for added effectiveness. The leaf surfaces will physically intersect PM from moving air, enhancing the air quality of areas downwind of the vegetation. It consists of emergent and understory trees that are proven to withstand air pollution and needs to be planted with a bioswale.

Figure 24 Windbreak

Master Plan

A neighborhood master plan will serve as the framework through which strategic GI can be implemented (See Figure 25 and Figure 26). The master plan will utilize existing vacant lands and ownership of those lands, hydrology, and considerations of the areas which fall within the 1500’ zone of high risk of air pollution exposure to determine areas where planting will be most beneficial in addressing the design goals. The master plan will also be broken in to three phases to allow for consensus building.

Phase One will focus on lands owned by The City of Dallas, implementing the principles of Green Corridors and Green Gradients to begin installing GI in a way which shows the neighborhood the City of Dallas is willing to invest (See Figure 27).

Carbondale Street is a primary access route in Joppa. People have to use Carbondale to access the bus stop and it connects nearly every east-west road in the neighborhood. Carbondale is also 45’ wide and has zero protection from the adjacent industry. Therefore a hedgerow is proposed to create a buffer between the industrial lands and Carbondale Street. A sidewalk is then proposed on both sides of Carbondale, as community members in the engagement called for more sidewalks (See Figure 28 and Figure 29). The rest of the streets throughout the neighborhood will be buffered through the implementation of Windbreaks and bioswales. This will begin to protect all of the homes from pollution which may flow through the streets. Lastly lands to the north, east and south which fall outside of the Chain of Wetlands and which are owned by the City of Dallas are filled in with woodlands bosques to begin to frame the neighborhood with GI to protect against pollutants flowing from Highway 12 to the south and from the railroad to the north. GI will be used to fill-in around already existing forest, enhancing the forest by clearing out overgrowth and invasive species.

Figure 25 Completed Master Plan

TREES	CODE	BOTANICAL NAME	COMMON NAME	QTY
	ACE RBR	Acer rubrum	Red Maple	140
	CER TXA	Cercis canadensis var. texensis	Texas Redbud	65
	GIN BI	Ginkgo biloba	Maidenhair Tree	106
	ILE VOM	Ilex vomitoria	Yaupon Holly	89
	JUN VIR	Juniperus virginiana	Eastern Redcedar	397
	MAG VIR	Magnolia virginiana	Sweetbay Magnolia	66
	MYR CER	Myrica cerifera	Wax Myrtle	110
	QUE MUE	Quercus muehlenbergii	Chinkapin Oak	150
	TAX DIS	Taxodium distichum	Bald Cypress	126
	ULM CRA	Ulmus crassifolia	Cedar Elm	[illegible]

Figure 26 Section of proposed conditions in Joppa

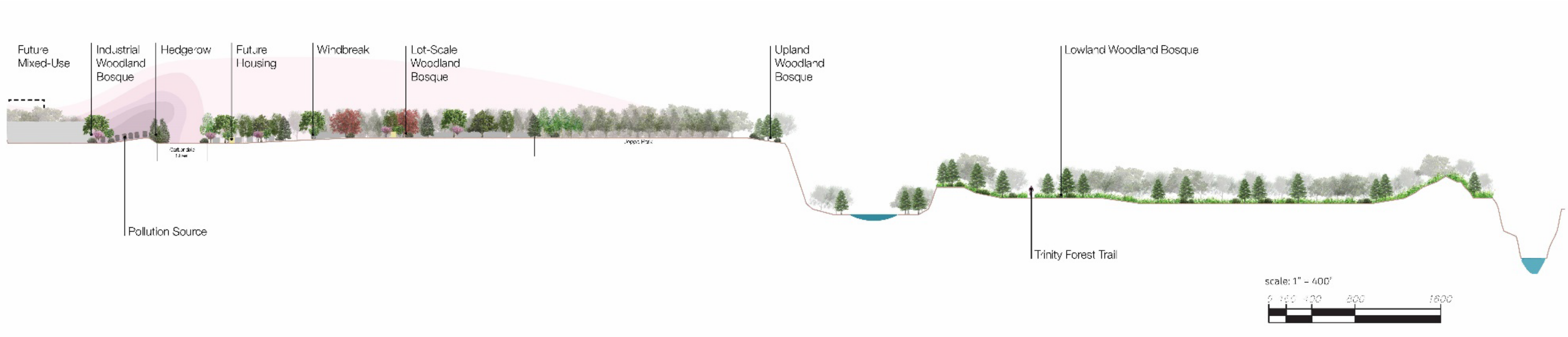
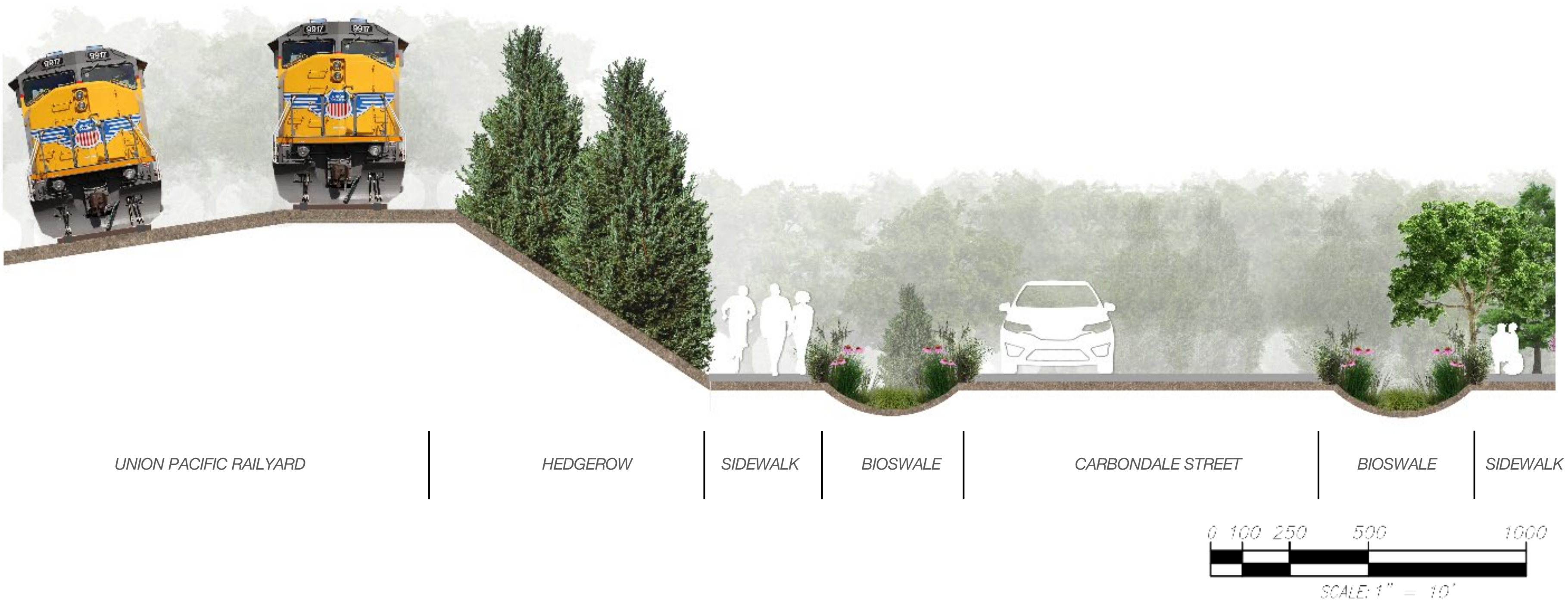


Figure 27 Phase 1 of Master Plan

Figure 28 Perspective of Carbondale Street as a Green Corridor

Figure 29 Section of Phase 1 – GI along Carbondale Street using Hedgerows, Windbreaks, and Bioswales



Phase Two will also introduce the principles of Green Edges and Green Lots, beginning to implement GI within privately owned lands that fall within the high risk 1500’ zone and enhance the existing forest. The industrial sites will have GI implemented wherever vacant patches exist. The homes which are closest to the pollution sources, falling within 1500’ of the industry or highway, will have GI implemented around them, surrounding the homes and the people who inhabit them with a protective buffer against contaminated air that flows near their homes. New housing development is also proposed at this stage to infill the vacant lands which fall outside of the 1500’ zone. Two of the larger scale vacant lots to the north and south of the neighborhood are proposed as future parks, that will be strategically designed using the Green Gradient principle (See Figure 30).

The implementation of GI within land owned by individuals other than the City of Dallas, such as private homeowners and businesses (See Figure 31), will need to be implemented on a case-by-case basis. Determining the risk of each home to pollution exposure and the most appropriate GI solutions. The owners will also have to be willing to have GI installed on their land. The two parks will be created on land owned by the City of Dallas utilizing the principle of a Green Gradient, creating space for recreation while also protecting residents from air pollution (See Figure 32). A trail which runs through the neighborhood will connect at two points to the existing Trinity Forest Trail, creating more access into the neighborhood through alternative modes of transit.

Figure 30 Phase 2 of Master Plan

Figure 31 Perspective of Greening the Industrial Lands

Figure 32 Section of Phase 2 – GI enhances the existing forest through a Green Gradient of a Woodland Bosques

Phase Three will finish out the master plan through Green Lots and Green Gradients, while enhancing the existing forest (See Figure 33 and 34). Private land outside of the 1500’ zone will be planted up with woodland bosques (See Figure 35). Land within the 1500’ zone will be developed with infill housing, however no new homes will be built along Carbondale Street to keep safe distances from residents and the railroad. The land to the west which is occupied by the industrial polluters will be de-industrialized and re-zoned for mixed-use development, to begin to address the need for a community-oriented center of commerce. This could then be used as a catalyst to install a Dallas Area Rapid Transit (DART) Light Rail station, extending the DART network into South Dallas to meet the needs of residents requiring public transit. A smaller-scale development within the neighborhood itself on the large vacant lot to the northeast will add multi-family housing and smaller-scale businesses such as a grocery, laundry, and salon, etc. - all desires identified by community members at the engagement. Land to the east which falls in the Chain of Wetlands will be built up trees, extending the forest through woodland bosques which are suited for low-lying areas with frequent flooding. This extension of the forest will protect the neighborhood from pollution coming from the south and east.

Site Plan

Zooming in to a smaller scale and looking at one section of the neighborhood at a scale of 1”-5’ brought the design into a more detailed form and allowed for the exploration of how the green infrastructure can be tied into a larger network of green open space for human use. The site includes the Honey Springs Creek, existing forest, the railroad, and privately owned homes (See Figure 36). This enabled the design to begin to take shape in a more specific way. Trails are added through the GI to build out circulation paths for pedestrians and cyclist.

Figure 33 Phase 3 of Master Plan

Figure 34 Perspective of GI near the Wetland Cells

Figure 35 Section of Phase 3 – GI protects homes using Woodland Bosques, Windbreaks, and Bioswales

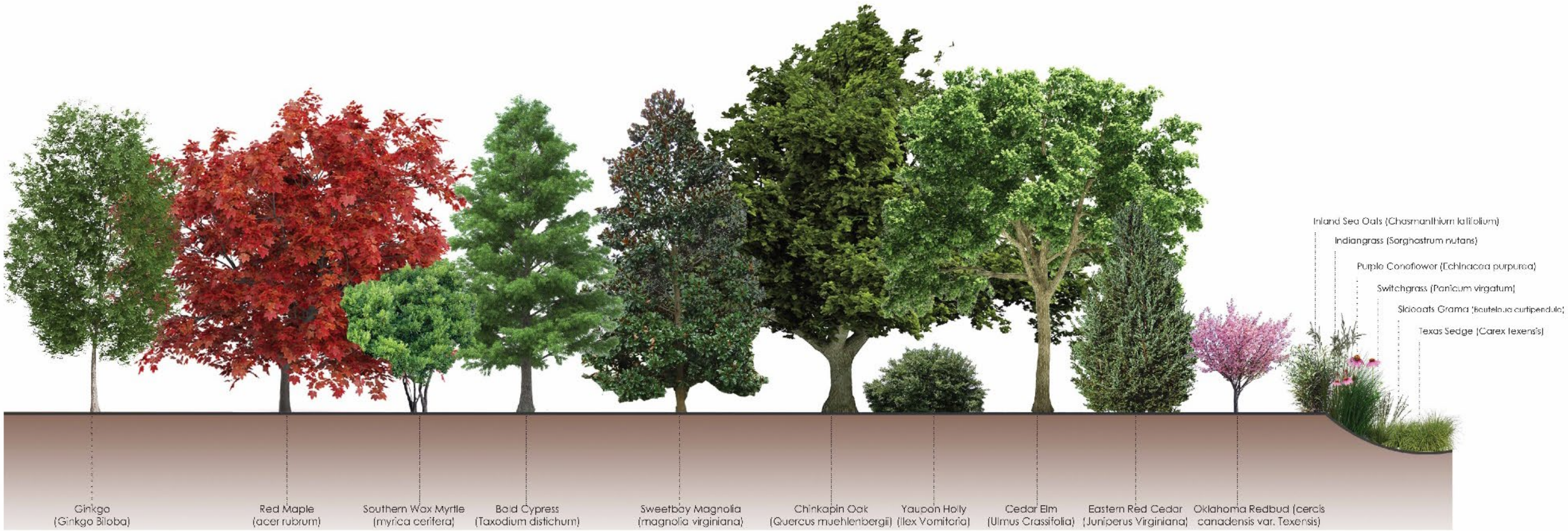
Figure 36 Site Plan Design

5.4 Plant Palette Benefits

The planting palette selected is based on the iTree Planting Calculator report. The trees used as input were selected from a tree inventory of The Trinity River Forest, to ensure the ultimate planting selection would grow well in the Joppa area. The report was then filtered based on trees which would remove the most amount of PM from the air per tree. Ten trees were chosen based on suitability for the site, PM removal rates, and additional ecosystem benefits such as Carbon Sequestration, Stormwater Interception, and Ozone Removal (See Figure 37).

The full planting palette proposes the planting of 2762 trees (See Table 28). iTree only provides trees as input, therefore the PM removal of perennials and grasses for the bioswale could not be measured. The plants were selected for the bioswale based off of recommendations from the Texas A&M Agrilife Extension and from Ladybird Johnson Wildflower Center.

Figure 37 Plant Palette and Associated Benefits



PM2.5 Removed (lb)	3.1	5.8	4.1	1.3	3.5	3.5	2.2	2	5.8	1
Ozone Removed (lb)	79.9	88.9	80	26.4	104.5	108.5	62.5	72.2	114	24.5
Rainfall Interception (gal)	131,770	79,777.5	95,136.9	34,041.7	199,578.4	222,075	104,690.9	166,056.2	138,360.4	38,873.5
CO2 Sequestered (lbs)	9,846.8	27,149	26,219.3	10,313.6	25,892.1	22,112.7	556.8	24,474.7	1,092.6	7280.8

Note. Associated Benefits are adapted from iTree Planting Calculator

Table 28 Planting Palette with Associated Benefits

# of trees planted	Tree species	complex, waxy and/or hairy leaves	Suited for a bioswale	PM Removed (lb/tree)	Ozone Removed (lb/tree)	Rainfall Interception (gal/tree)	CO2 Sequestration (lbs/tree)
130	Chinkapin Oak (Quercus muehlenbergii)	X		3.5	108.5	222075	22112.7
1498	Cedar Elm (Ulmus Crassifolia)	X		2	72.2	166056	24474.7
85	Oklahoma Redbud (cercis canadensis var. Texensis)	X		1	24.5	38873.5	7280.8
412	Eastern Red Cedar (Juniperus virginiana)	X		5.8	114	138360	1092.6
108	Ginkgo (Ginkgo biloba)	X		3.1	79.9	131770	9846.8
82	Yaupon Holly (Ilex Vomitoria)	X	X	2.2	62.5	104691	556.8
128	Bald Cypress (Taxodium distichum)	X	X	1.3	26.4	34041.7	10313.6
66	Sweetbay Magnolia (magnolia virginiana)	X		3.5	104.5	199578	25892.1
110	southern wax myrtle (myrica cerifera)	X		4.1	80	95136.9	26219.3
143	Red Maple (acer rubrum)	X		5.8	88.9	79777.5	27149

Note. Associated Benefits are adapted from iTree Planting Calculator

The tree planting plan would have the following impact on air quality:

- 8,118.6 lbs of PM removed
- 216,854.2 lbs of Ozone removed

Secondary benefits include 400,149,237.2 gallons of rainwater intercepted and 51,511,332.2 pounds of carbon sequestered. Additional improvements which cannot be quantified include improved views as the industrial land is now blocked by vegetation barriers, increased aesthetics of the neighborhood, and access to larger swaths of open green space for recreation.

The results from the research design show that a large scale GI plan can have an impact on air quality, improving the pollution levels to a moderate degree. Based on Air Quality Data from a Purple Air monitor located in the Joppa neighborhood at 4824 Nome Street, spanning 216 days out of 2021 and 2022, it was calculated that the PM produced averaged out over one year is 13.49 lbs per day. This was calculated by taking the 216 days of data, finding the average, then multiplying that average by 365. These steps had to be taken because there is air monitor was down from April 28, 2021 through September 21, 2021. No other data sources were able to provide one year's worth of data at the time of this research. iTree only measures tree benefits at a yearly scale. Therefore some extrapolation had to be done to arrive at what air quality might be over a one year period. Taking the average of 13.5 and multiplying it over one year, the average annual output would be 4926.588 pounds. Over fifty years, that would be 246,329.4 pounds. Based on these numbers, the proposed tree plan would improve the air quality by 3.3 percent.

In the City of Dallas, Ozone reaches levels of 10,305,228 pounds over 50 years. Based on the iTree planting calculator results, the proposed planting plan over a 50 year period would capture 216,854.2 lbs of Ozone, resulting in a 2.1% reduction in Ozone. Based on an average annual rainfall of 36" in DFW, the stormwater captured would also be a 3.6% impact. According to the city of Dallas, roughly 23,000,000 metric tons of GHG were produced in 2020. Based on these numbers the GI plan would remove 0.002% of CO2 out of the air. While these results seem negligible, recall that one industry expert said a 5% improvement would be a highly successful plan. The tree planting plan would have a large positive impact on the air quality and would be a step in the right direction for getting the City of Dallas to address the pollution through rezoning and steeper regulations. The planting plan would also facilitate relationships between the neighborhood and leaders of the neighboring industry, as planting is proposed on industry properties which would create an opportunity to engage and learn. Furthermore, the GI plan would increase neighborhood aesthetics, enhance ecology of the neighborhood, and create a more pedestrian-friendly neighborhood.

6 CONCLUSION

This research has focused on the benefits of using GI to mitigate air pollution, while also exploring secondary benefits that GI can have at a neighborhood scale, all through an environmental justice lens. Both air pollution and vegetation are complex issues and therefore required a multi-method approach to researching how the two interact. The research findings informed the development of a design for Joppa, Texas, a freedmen's town in south Dallas. It was found that this tree plan would have air pollution mitigation with a 3.3% improvement on PM2.5 and a 2.1% improvement on ozone.

6.1 Responses to Research Questions

The first research question asked – How can green infrastructure be designed for in industry-adjacent neighborhoods in North Texas locations to mitigate air pollution?

GI can be designed through a set of design principles developed for the study site included green corridors, green edges, green gradients, and green lots. These approaches could be useful in a neighborhood scale green infrastructure approach that is designed to consider various urban forms from larger scale (linear arterial roads, neighborhood streets, highway access, and overall neighborhood framework) to smaller scale (alleys, backyards, and front lawns). With the synthesized GI strategies found from literature and case studies, the design principles for GI application in this study may provide strategic framework promoting resilient approaches, which benefit the community in multiple ways.

The design principles can be adapted to other communities with similar conditions, using species which are most suitable to the climate and soil.

The second research question asked - How accompanying and tailored benefits can be integrated into proposed GI strategies to help the community address additional environmental and social issue such as reduced flooding, decreased heat island, improvement of water and soil quality, increased wildlife habitats, expansion of park systems and urban forests, and a more sustainable built environment, etc.?

Green Infrastructure provides multiple benefits to industry-adjacent neighborhoods. As found in the iTree calculator, GI can also capture stormwater and sequester carbon. From the literature, it is know that GI improves the environment through cleansing of air, water, and soil. GI also improves the environment by expanding habitats for non-human species, as well as encouraging diversity, at the microbial level of soil and the macro-scale of a woodland bosque. GI can benefit neighborhoods by increasing access to open green space, thereby encouraging outdoor community activities. This was achieved in Joppa through the creation of parks and trails which worked with the proposed GI. GI also adds value to neighborhoods through aesthetics, making a neighborhood more beautiful and attractive for residents. Specific to Joppa, the implementation of GI can assist in reviving cultural landscapes through honoring the agricultural background of Joppa and also can enhance the sense of culture in the community by uniting the community both in physical form and community values.

6.2 Discussion

Air pollution is not something easily solved or controlled. The mechanisms by which we as a society aim to reduce air pollution need to address both why we create it and where we allow it to go. While Green Infrastructure can have an impact on air quality, the issue requires solutions at a political level through regulations and safer zoning practices. This study can be the catalyst for a conversation with industry and community leaders around how we can improve pollution levels. Ultimately this plan is scalable and could be applied to alternate neighborhoods around Dallas which struggle with bad air quality by integrating primarily trees and respecting sociocultural conditions. The plan could also help to get Dallas off of the non-attainment zone list as currently designated by the EPA.

6.3 Relevance to Landscape Architecture

The field of landscape architecture can benefit from this research as a methodology for evidence-based design of green infrastructure. The use of a multi-method approach shows how other designers could use GIS, iTree, and Case Studies to design GI to achieve targeted benefits. Examining Green Infrastructure through a site-specific lens at a neighborhood scale allowed the research to explore the multi-faceted benefits of GI. The relative low-cost and quick returns of GI make it especially suitable to low-income communities who face various environmental risks. As Landscape Architecture (LA) pushes for a more equitable future by addressing climate change and environmental justice, this research contributes to the LA field recommendations on how design can solve both problems in tandem.

6.4 Future Research

There are many questions that arose out of this research that require future exploration. The issue of vegetation producing VOCs is something which needs to be examined more closely. The use of Green Walls as a mechanism for mitigating air pollution seems to be a viable planting typology, however this needs to be studied more closely. A Maintenance Plan needs to planned and adhered to in order to ensure the vegetation is kept in good condition over a long time period. The future of industrial lands needs to be considered so pollutants may be properly remediated, even after industry operations stops, but also to consider more appropriate future land uses. Further exploration into the effects that PM has on the health of plants is needed as well. Other types of vegetation in the service of mitigating health risks also need to be explored, such as prairies and grasslands. Modeling of fluid dynamics and how the air moves through the landscape needs to be examined in detail. While we now know the impact that a tree-planting plan can have of PM2.5, it would be worthwhile to study alternative mechanisms for mitigating air pollution and compare for effectiveness versus cost.

APPENDIX

Appendix A

Expert Interviews

Mitigating particulate matter using vegetation

1. How effective do you think vegetation is to mitigate air pollution?
2. How often is vegetation used to mitigate air pollution?
3. What projects, if any, would you say are successful examples of utilizing green infrastructure and/or phytoremediation to mitigate air pollution?
4. Please rate the plant categories by their effectiveness at capturing air pollution. (1-6 // 6 being most effective, 1 being least effective)
    a. Trees
    b. Shrubs
    c. Grasses
    d. Herbaceous perennials
    e. Groundcovers
    f. Mosses

Planting Design

1. What do you think about the role of planting design in mitigating particulate matter air pollution using vegetation?
    a. In your opinion, is there any planting pattern that you have found to be most effective at mitigating particulate matter air pollution?
        i. Which of the following planting scenario do you believe would be more effective at mitigating particulate matter?
            1. A row of evergreen trees with evergreen shrubs at the base of the trees
            2. A row of evergreen trees with herbaceous grasses around the base
            3. A green wall
2. How would you go about selecting a site to place green infrastructure between a pollution source and a neighborhood?

    a. What is the ideal distance to place green infrastructure between the air pollution source and a neighborhood?

Measuring the effectiveness of the GI on health outcomes overtime

1. How do you define success for a project using green infrastructure to mitigate air pollution?
2. What factors do you measure to determine that success?

Maintenance

1. What is a reasonable length of time to expect one implementation of green infrastructure to be effective at mitigating air pollution?
2. How would you approach maintenance for a project like this?
    a. What might the labor of maintaining this type of project require?
    b. What might the economic cost of maintenance be?
    c. What kind of materials would be necessary to maintain this type of project?

Human use

1. In what ways, if any, can this green infrastructure serve a dual purpose as an open green space for human users to engage in passive recreation?
2. How is this functional vegetation accepted by users?
    a. How do they react to it?
    b. How do they utilize/interact with the vegetation, if at all?

Additional environmental benefits

1. Is there any ecological (current/potential) effect?

Appendix B

ITree Planting Calculator Report

Project Report - i-Tree Planting Calculator

Location: Hutchins, Texas 75141
Electricity Emissions Factor: 1,804.70 pounds CO2 equivalent/MWh
Fuel Emissions Factor: 53.10 kilograms CO2 equivalent/MMBtu
Lifetime: 50 years
Tree Mortality: 0%

All amounts in the tables are for the full lifetime of the project.

Location		CO_2 (Carbon Dioxide) Benefits			
Group Identifier	Tree Group Characteristics	CO_2 (Carbon Dioxide) Avoided (pounds)	CO_2 Avoided ($)	CO_2 Sequestered (pounds)	CO_2 Sequestered ($)
1	• (1.0) Sweetbay (Magnolia virginiana) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	25,892.1	$602.17
2	• (1.0) Bayberry, Southern (Myrica cerifera) at 12.0 inches DBH (Diameter at Breast Height). • Planted 0-19 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	24,626.1	$572.73	26,219.3	$609.78
3	• (1.0) Yucca (Yucca species) at 3.0 inches DBH (Diameter at Breast Height). • Planted 0-19 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	19,385.4	$450.85	3,383.6	$78.69
4	• (1.0) Maple, Red (Acer rubrum) at 36.0 inches DBH (Diameter at Breast Height). • Planted 0-19 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	11,330.3	$263.51	27,149.0	$631.40

Location		Energy Benefits			
Group Identifier	Tree Group Characteristics	Electricity Saved (kWh) (Kilowatt-Hours)	Electricity Saved ($)	Fuel Saved (MMBtu) (Millions of British Thermal Units)	Fuel Saved ($)
1	• (1.0) Sweetbay (Magnolia virginiana) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
2	• (1.0) Bayberry, Southern (Myrica cerifera) at 12.0 inches DBH (Diameter at Breast Height). • Planted 0-19 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	10,292.8	$1,266.01	40.9	$576.06
3	• (1.0) Yucca (Yucca species) at 3.0 inches DBH (Diameter at Breast Height). • Planted 0-19 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	8,092.4	$995.37	32.3	$455.78
4	• (1.0) Maple, Red (Acer rubrum) at 36.0 inches DBH (Diameter at Breast Height). • Planted 0-19 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	5,261.3	$647.14	10.1	$142.98

Location		Ecosystem Services			
Group Identifier	Tree Group Characteristics	Tree Biomass (short ton)	Rainfall Interception (gallons)	Runoff Avoided (gallons)	Runoff Avoided ($)
1	• (1.0) Sweetbay (Magnolia virginiana) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	13.0	199,578.4	18,583.1	$166.06
2	• (1.0) Bayberry, Southern (Myrica cerifera) at 12.0 inches DBH (Diameter at Breast Height). • Planted 0-19 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	7.9	95,136.9	8,858.4	$79.16
3	• (1.0) Yucca (Yucca species) at 3.0 inches DBH (Diameter at Breast Height). • Planted 0-19 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.9	20,957.7	1,951.4	$17.44
4	• (1.0) Maple, Red (Acer rubrum) at 36.0 inches DBH (Diameter at Breast Height). • Planted 0-19 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	14.5	79,777.5	7,428.2	$66.38

Location		Air Benefits							
Group Identifier	Tree Group Characteristics	O_3 (Ozone) Removed (pounds)	NO_2 (Nitrogen Dioxide) Avoided (pounds)	NO_2 (Nitrogen Dioxide) Removed (pounds)	SO_2 (Sulfur Dioxide) Avoided (pounds)	SO_2 (Sulfur Dioxide) Removed (pounds)	VOC (Volatile Organic Compound) Avoided (pounds)	$PM_{2.5}$ (Particulate matter smaller than 2.5 micrometers in diameter) Avoided (pounds)	$PM_{2.5}$ (Particulate matter smaller than 2.5 micrometers in diameter) Removed (pounds)
1	• (1.0) Sweetbay (Magnolia virginiana) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	104.5	0.0	7.5	0.0	1.0	0.0	0.0	3.5
2	• (1.0) Bayberry, Southern (Myrica cerifera) at 12.0 inches DBH (Diameter at Breast Height). • Planted 0-19 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	80.0	2.7	7.7	37.5	0.9	1.2	1.1	4.1
3	• (1.0) Yucca (Yucca species) at 3.0 inches DBH (Diameter at Breast Height). • Planted 0-19 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	14.9	2.1	1.4	29.6	0.2	0.9	0.9	0.7
4	• (1.0) Maple, Red (Acer rubrum) at 36.0 inches DBH (Diameter at Breast Height). • Planted 0-19 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	88.9	1.1	6.8	15.9	0.8	0.5	0.6	5.8

Application v2.2.0, powered by engine v0.7.1 (APIv2) and database v12.0.4.

Project Report - i-Tree Planting Calculator v2.1.3

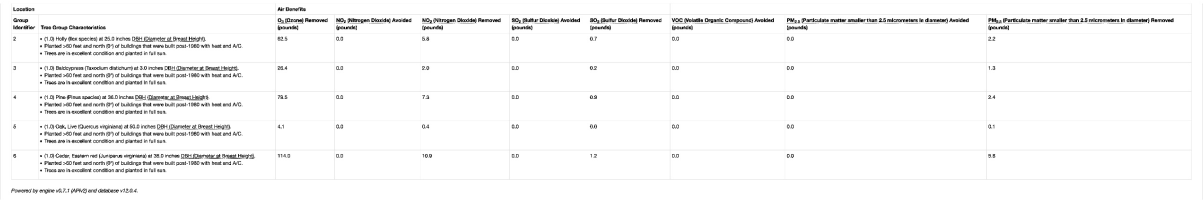
Location: Hutchins, Texas 75141
Electricity Emissions Factor: 818.60 pounds CO2 equivalent/MWh
Fuel Emissions Factor: 53.10 kilograms CO2 equivalent/MMBtu
Lifetime: 50 years
Tree Mortality: 0%

All amounts in the tables are for the full lifetime of the project.

Location		CO_2 (Carbon Dioxide) Benefits			
Group Identifier	Tree Group Characteristics	CO_2 (Carbon Dioxide) Avoided (pounds)	CO_2 Avoided ($)	CO_2 Sequestered (pounds)	CO_2 Sequestered ($)
2	• (1.0) Holly (Ilex species) at 25.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	556.8	$12.95
3	• (1.0) Baldcypress (Taxodium distichum) at 3.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	10,313.6	$239.86
4	• (1.0) Pine (Pinus species) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	26,701.9	$621.00
5	• (1.0) Oak, Live (Quercus virginiana) at 50.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	1,198.3	$27.87
6	• (1.0) Cedar, Eastern red (Juniperus virginiana) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	1,092.6	$25.41

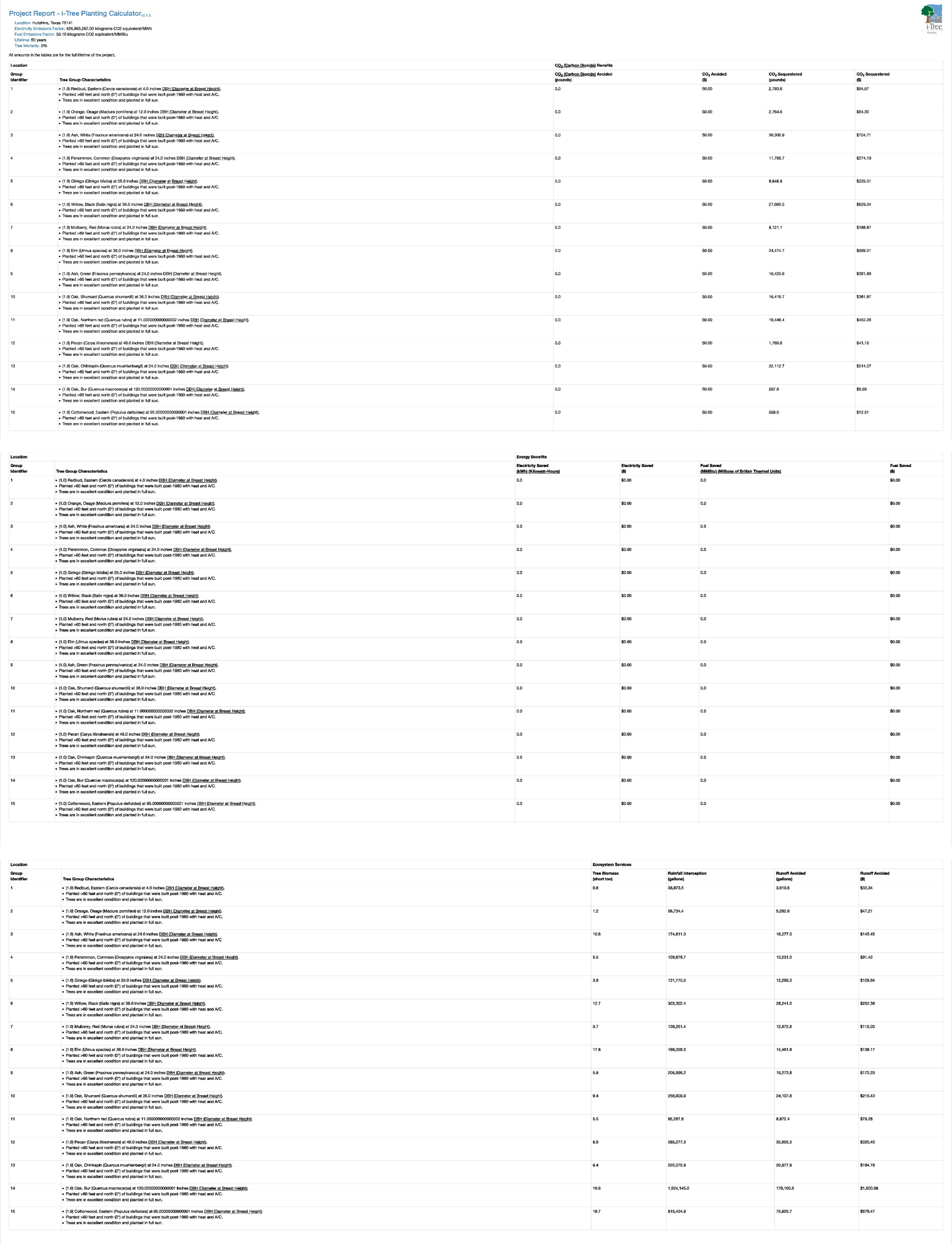
Location		Energy Benefits			
Group Identifier	Tree Group Characteristics	Electricity Saved (kWh) (Kilowatt-Hours)	Electricity Saved ($)	Fuel Saved (MMBtu) (Millions of British Thermal Units)	Fuel Saved ($)
2	• (1.0) Holly (Ilex species) at 25.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
3	• (1.0) Baldcypress (Taxodium distichum) at 3.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
4	• (1.0) Pine (Pinus species) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
5	• (1.0) Oak, Live (Quercus virginiana) at 50.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
6	• (1.0) Cedar, Eastern red (Juniperus virginiana) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00

Location		Ecosystem Services			
Group Identifier	Tree Group Characteristics	Tree Biomass (short ton)	Rainfall Interception (gallons)	Runoff Avoided (gallons)	Runoff Avoided ($)
2	• (1.0) Holly (Ilex species) at 25.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	3.5	104,690.9	9,748.0	$87.11
3	• (1.0) Baldcypress (Taxodium distichum) at 3.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	2.7	34,041.7	3,169.7	$28.32
4	• (1.0) Pine (Pinus species) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	15.0	157,112.4	14,629.0	$130.72
5	• (1.0) Oak, Live (Quercus virginiana) at 50.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	12.7	725,942.7	67,593.9	$604.02
6	• (1.0) Cedar, Eastern red (Juniperus virginiana) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	5.2	138,360.4	12,883.0	$115.12



Location		Air Benefits							
Group Identifier	Tree Group Characteristics	O_3 (Ozone) Removed (pounds)	NO_2 (Nitrogen Dioxide) Avoided (pounds)	NO_2 (Nitrogen Dioxide) Removed (pounds)	SO_2 (Sulfur Dioxide) Avoided (pounds)	SO_2 (Sulfur Dioxide) Removed (pounds)	VOC (Volatile Organic Compound) Avoided (pounds)	$PM_{2.5}$ (Particulate matter smaller than 2.5 micrometers in diameter) Avoided (pounds)	$PM_{2.5}$ (Particulate matter smaller than 2.5 micrometers in diameter) Removed (pounds)
2	• (1.0) Holly (Ilex species) at 25.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	62.5	0.0	5.8	0.0	0.7	0.0	0.0	2.2
3	• (1.0) Baldcypress (Taxodium distichum) at 3.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	26.4	0.0	2.0	0.0	0.2	0.0	0.0	1.3
4	• (1.0) Pine (Pinus species) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	79.5	0.0	7.3	0.0	0.9	0.0	0.0	2.4
5	• (1.0) Oak, Live (Quercus virginiana) at 50.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	4.1	0.0	0.4	0.0	0.0	0.0	0.0	0.1
6	• (1.0) Cedar, Eastern red (Juniperus virginiana) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	114.0	0.0	10.9	0.0	1.2	0.0	0.0	5.8

Powered by engine v0.7.1 (APIv2) and database v12.0.4.



Project Report - i-Tree Planting Calculator v2.1.3

Location: Hutchins, Texas 75141
Electricity Emissions Factor: 426,863,267.00 kilograms CO2 equivalent/MWh
Fuel Emissions Factor: 53.10 kilograms CO2 equivalent/MMBtu
Lifetime: 50 years
Tree Mortality: 0%

All amounts in the tables are for the full lifetime of the project.

Location		CO_2 (Carbon Dioxide) Benefits			
Group Identifier	**Tree Group Characteristics**	**CO_2 (Carbon Dioxide) Avoided (pounds)**	**CO_2 Avoided ($)**	**CO_2 Sequestered (pounds)**	**CO_2 Sequestered ($)**
1	• (1.0) Redbud, Eastern (Cercis canadensis) at 4.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	2,780.8	$64.67
2	• (1.0) Orange, Osage (Maclura pomifera) at 12.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	2,764.6	$64.30
3	• (1.0) Ash, White (Fraxinus americana) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	30,300.9	$704.71
4	• (1.0) Persimmon, Common (Diospyros virginiana) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	11,789.7	$274.19
5	• (1.0) Ginkgo (Ginkgo biloba) at 25.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	9,846.8	$229.01
6	• (1.0) Willow, Black (Salix nigra) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	27,060.5	$629.34
7	• (1.0) Mulberry, Red (Morus rubra) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	8,121.1	$188.87
8	• (1.0) Elm (Ulmus species) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	24,474.7	$569.21
9	• (1.0) Ash, Green (Fraxinus pennsylvanica) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	16,420.6	$381.89
10	• (1.0) Oak, Shumard (Quercus shumardii) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	16,419.7	$381.87
11	• (1.0) Oak, Northern red (Quercus rubra) at 11.000000000000002 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	19,446.4	$452.26
12	• (1.0) Pecan (Carya illinoinensis) at 48.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	1,769.8	$41.16
13	• (1.0) Oak, Chinkapin (Quercus muehlenbergii) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	22,112.7	$514.27
14	• (1.0) Oak, Bur (Quercus macrocarpa) at 120.00000000000001 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	287.8	$6.69
15	• (1.0) Cottonwood, Eastern (Populus deltoides) at 95.00000000000001 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	538.0	$12.51

Location		Energy Benefits			
Group Identifier	**Tree Group Characteristics**	**Electricity Saved (kWh) (Kilowatt-Hours)**	**Electricity Saved ($)**	**Fuel Saved (MMBtu) (Millions of British Thermal Units)**	**Fuel Saved ($)**
1	• (1.0) Redbud, Eastern (Cercis canadensis) at 4.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
2	• (1.0) Orange, Osage (Maclura pomifera) at 12.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
3	• (1.0) Ash, White (Fraxinus americana) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
4	• (1.0) Persimmon, Common (Diospyros virginiana) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
5	• (1.0) Ginkgo (Ginkgo biloba) at 25.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
6	• (1.0) Willow, Black (Salix nigra) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
7	• (1.0) Mulberry, Red (Morus rubra) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
8	• (1.0) Elm (Ulmus species) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
9	• (1.0) Ash, Green (Fraxinus pennsylvanica) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
10	• (1.0) Oak, Shumard (Quercus shumardii) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
11	• (1.0) Oak, Northern red (Quercus rubra) at 11.000000000000002 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
12	• (1.0) Pecan (Carya illinoinensis) at 48.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
13	• (1.0) Oak, Chinkapin (Quercus muehlenbergii) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
14	• (1.0) Oak, Bur (Quercus macrocarpa) at 120.00000000000001 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00
15	• (1.0) Cottonwood, Eastern (Populus deltoides) at 95.00000000000001 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.0	$0.00	0.0	$0.00

Location		Ecosystem Services			
Group Identifier	**Tree Group Characteristics**	**Tree Biomass (short ton)**	**Rainfall Interception (gallons)**	**Runoff Avoided (gallons)**	**Runoff Avoided ($)**
1	• (1.0) Redbud, Eastern (Cercis canadensis) at 4.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	0.8	38,873.5	3,619.6	$32.34
2	• (1.0) Orange, Osage (Maclura pomifera) at 12.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	1.2	56,734.4	5,282.6	$47.21
3	• (1.0) Ash, White (Fraxinus americana) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	10.6	174,811.3	16,277.0	$145.45
4	• (1.0) Persimmon, Common (Diospyros virginiana) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	5.5	109,878.7	10,231.0	$91.42
5	• (1.0) Ginkgo (Ginkgo biloba) at 25.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	3.8	131,770.0	12,269.3	$109.64
6	• (1.0) Willow, Black (Salix nigra) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	12.7	303,302.4	28,241.0	$252.36
7	• (1.0) Mulberry, Red (Morus rubra) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	3.7	138,251.4	12,872.8	$115.03
8	• (1.0) Elm (Ulmus species) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	17.8	166,056.2	15,461.8	$138.17
9	• (1.0) Ash, Green (Fraxinus pennsylvanica) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	5.8	206,996.2	19,273.8	$172.23
10	• (1.0) Oak, Shumard (Quercus shumardii) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	9.4	258,909.9	24,107.6	$215.43
11	• (1.0) Oak, Northern red (Quercus rubra) at 11.000000000000002 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	5.5	95,287.8	8,872.4	$79.28
12	• (1.0) Pecan (Carya illinoinensis) at 48.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	8.9	385,077.3	35,855.3	$320.40
13	• (1.0) Oak, Chinkapin (Quercus muehlenbergii) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	8.4	222,075.9	20,677.9	$184.78
14	• (1.0) Oak, Bur (Quercus macrocarpa) at 120.00000000000001 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	16.6	1,924,145.0	179,160.6	$1,600.98
15	• (1.0) Cottonwood, Eastern (Populus deltoides) at 95.00000000000001 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	16.7	815,424.9	75,925.7	$678.47

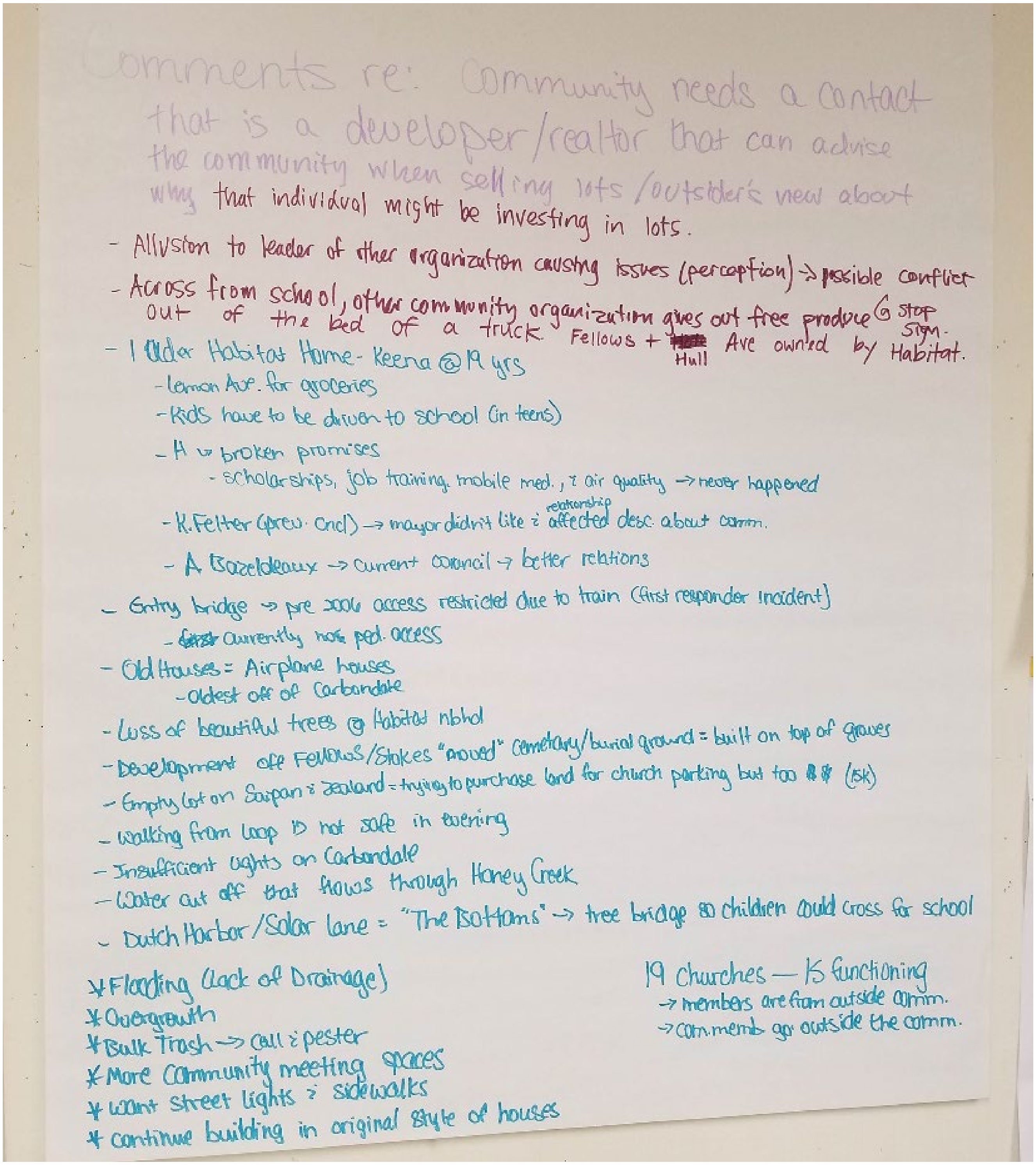
Location		Air Benefits							
Group Identifier	Tree Group Characteristics	O_3 (Ozone) Removed (pounds)	NO_2 (Nitrogen Dioxide) Avoided (pounds)	NO_2 (Nitrogen Dioxide) Removed (pounds)	SO_2 (Sulfur Dioxide) Avoided (pounds)	SO_2 (Sulfur Dioxide) Removed (pounds)	VOC (Volatile Organic Compound) Avoided (pounds)	$PM_{2.5}$ (Particulate matter smaller than 2.5 micrometers in diameter) Avoided (pounds)	$PM_{2.5}$ (Particulate matter smaller than 2.5 micrometers in diameter) Removed (pounds)
1	• (1.0) Redbud, Eastern (Cercis canadensis) at 4.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	24.5	0.0	1.8	0.0	0.2	0.0	0.0	1.0
2	• (1.0) Orange, Osage (Maclura pomifera) at 12.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	38.7	0.0	2.8	0.0	0.4	0.0	0.0	1.7
3	• (1.0) Ash, White (Fraxinus americana) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	68.1	0.0	4.8	0.0	0.7	0.0	0.0	1.9
4	• (1.0) Persimmon, Common (Diospyros virginiana) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	57.4	0.0	4.1	0.0	0.6	0.0	0.0	1.9
5	• (1.0) Ginkgo (Ginkgo biloba) at 25.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	79.9	0.0	5.8	0.0	0.8	0.0	0.0	3.1
6	• (1.0) Willow, Black (Salix nigra) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	47.6	0.0	3.2	0.0	0.5	0.0	0.0	0.9
7	• (1.0) Mulberry, Red (Morus rubra) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	69.1	0.0	4.9	0.0	0.7	0.0	0.0	2.2
8	• (1.0) Elm (Ulmus species) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	72.2	0.0	5.1	0.0	0.7	0.0	0.0	2.0
9	• (1.0) Ash, Green (Fraxinus pennsylvanica) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	127.9	0.0	9.3	0.0	1.2	0.0	0.0	5.1
10	• (1.0) Oak, Shumard (Quercus shumardii) at 36.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	118.0	0.0	8.3	0.0	1.2	0.0	0.0	3.4
11	• (1.0) Oak, Northern red (Quercus rubra) at 11.000000000000002 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	61.9	0.0	4.5	0.0	0.6	0.0	0.0	2.6
12	• (1.0) Pecan (Carya illinoinensis) at 48.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	6.8	0.0	0.5	0.0	0.1	0.0	0.0	0.1
13	• (1.0) Oak, Chinkapin (Quercus muehlenbergii) at 24.0 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	108.5	0.0	7.7	0.0	1.1	0.0	0.0	3.5
14	• (1.0) Oak, Bur (Quercus macrocarpa) at 120.00000000000001 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	11.8	0.0	0.8	0.0	0.1	0.0	0.0	0.2
15	• (1.0) Cottonwood, Eastern (Populus deltoides) at 95.00000000000001 inches DBH (Diameter at Breast Height). • Planted >60 feet and north (0°) of buildings that were built post-1980 with heat and A/C. • Trees are in excellent condition and planted in full sun.	5.0	0.0	0.3	0.0	0.1	0.0	0.0	0.1

Powered by engine v0.7.1 (APIv2) and database v12.0.4.

www.fs.fed.us
www.davey.com
www.arborday.org
www.urban-forestry.com
www.isa-arbor.com
www.caseytrees.org
www.esf.edu
www.northeasternforests.org

Appendix C

Joppa Community Engagement ,2020

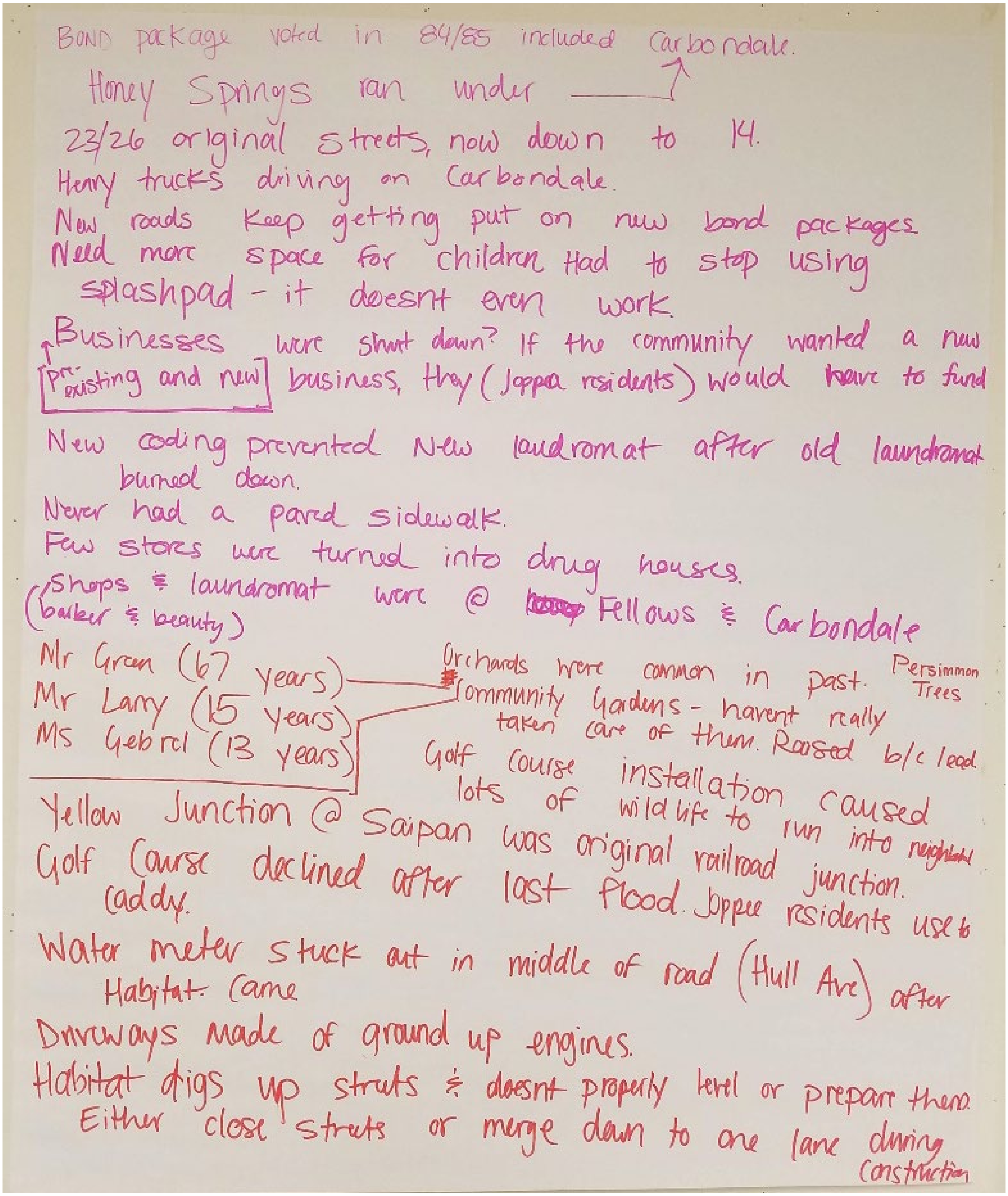


Comments re: Community needs a contact that is a developer/realtor that can advise the community when selling lots/outsider's view about why that individual might be investing in lots.

- Allusion to leader of other organization causing issues (perception) → possible conflict
- Across from school, other community organization gives out free produce @ stop sign. out of the bed of a truck. Fellows + Hull Ave owned by Habitat.
- 1 Older Habitat Home - Keena @ 19 yrs
    - Lemon Ave. for groceries
    - Kids have to be driven to school (in teens)
    - H → broken promises
        - scholarships, job training, mobile med., & air quality → never happened
    - K. Felter (prev. Cncl) → mayor didn't like & relationship affected desc. about comm.
    - A. Bazeldeaux → current council → better relations
- Entry bridge → pre 2006 access restricted due to train (first responder incident)
    - currently no ped. access
- Old Houses = Airplane houses
    - Oldest off of Carbondale
- Loss of beautiful trees @ Habitat nbhd
- Development off Fellows/Stokes "moved" cemetary/burial ground = built on top of graves
- Empty lot on Saipan & Zealand = trying to purchase land for church parking but too $$ (15K)
- walking from loop is not safe in evening
- Insufficient lights on Carbondale
- Water cut off that flows through Honey Creek
- Dutch Harbor/Solar lane = "The Bottoms" → tree bridge so children could cross for school

* Flooding (Lack of Drainage)
* Overgrowth
* Bulk Trash → call & pester
* More Community meeting spaces
* want street lights & sidewalks
* continue building in original style of houses

19 churches — 15 functioning
→ members are from outside comm.
→ com. memb. go outside the comm.



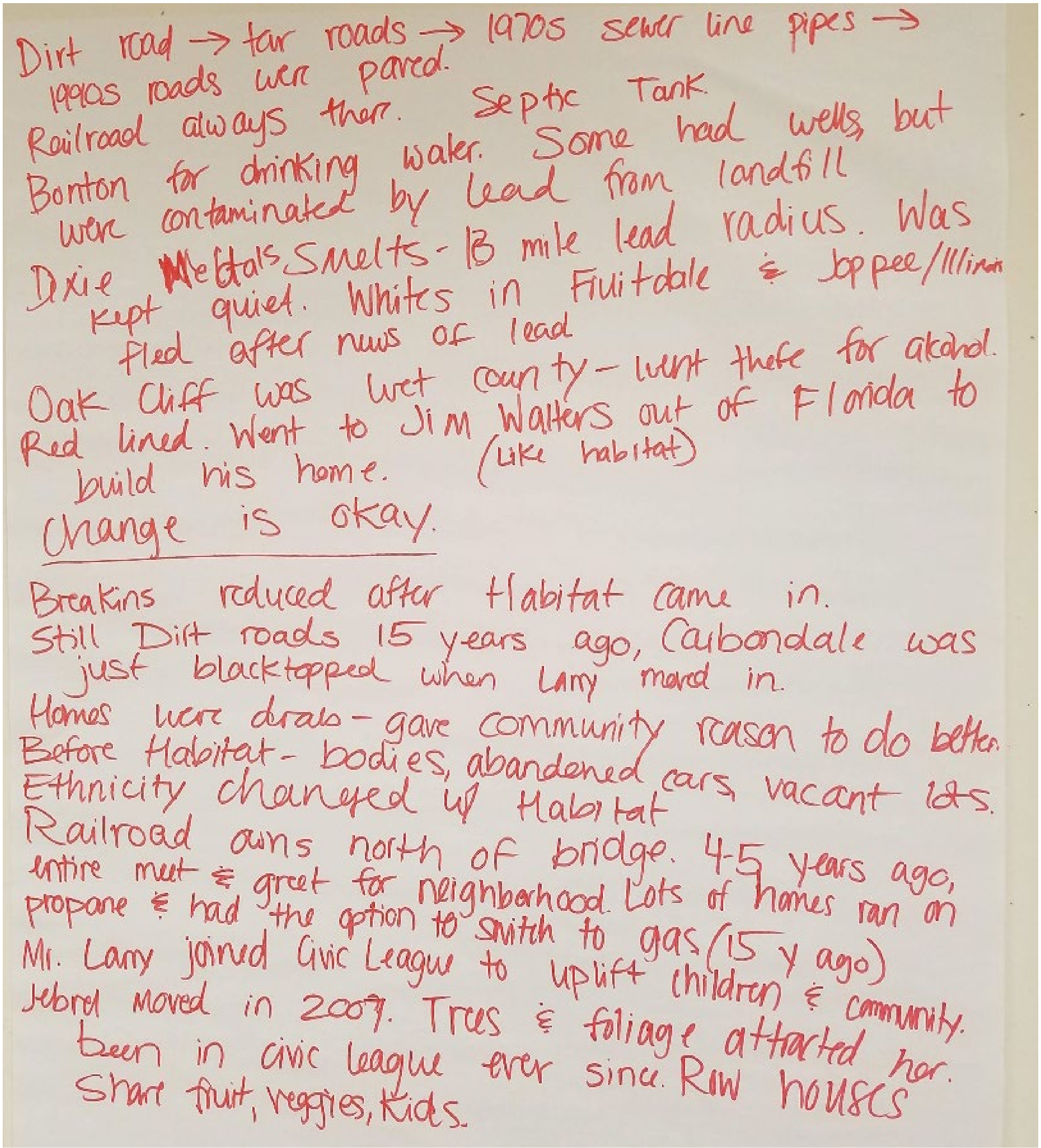
BOND package voted in 84/85 included Carbondale.
Honey Springs ran under ⟶ ↑
23/26 original streets, now down to 14.
Heavy trucks driving on Carbondale.
New roads keep getting put on new bond packages
Need more space for children Had to stop using
splashpad - it doesnt even work.
↑Businesses were shut down? If the community wanted a new
[pre-existing and new] business, they (Joppa residents) would have to fund

New coding prevented New laundromat after old laundromat
burned down.
Never had a paved sidewalk.
Few stores were turned into drug houses.
Shops & laundromat were @ Fellows & Carbondale
(barber & beauty)

Mr Green (67 years)
Mr Larry (15 years)
Ms Gebrel (13 years)

Orchards were common in past. Persimmon Trees
Community Gardens - havent really taken care of them. Raised b/c lead
Golf Course installation caused lots of wildlife to run into neighborhood

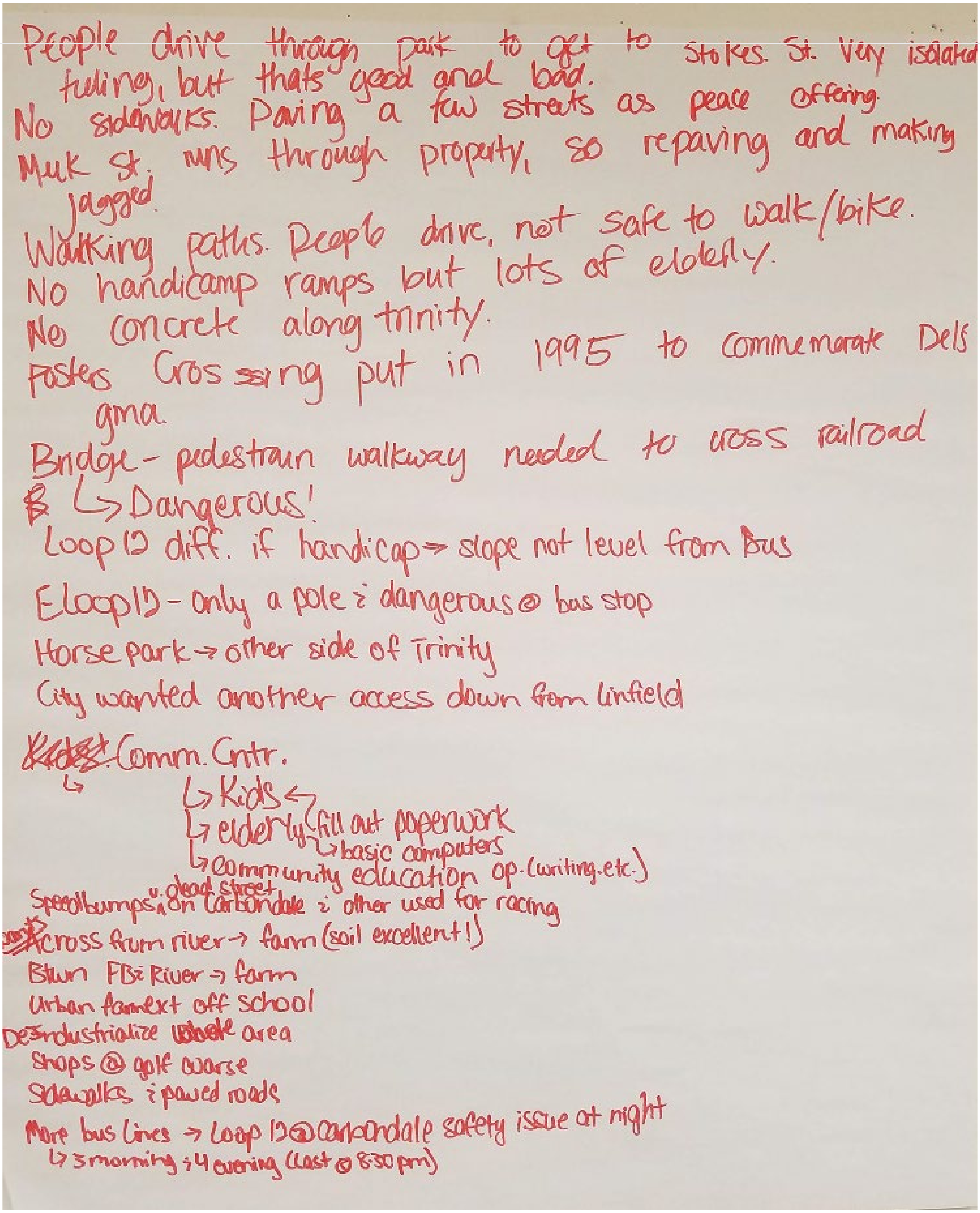
Yellow Junction @ Saipan was original railroad junction.
Golf Course declined after last flood. Joppa residents use to caddy.
Water meter stuck out in middle of road (Hull Ave) after Habitat came
Driveways made of ground up engines.
Habitat digs up streets & doesnt properly level or prepare them.
Either close streets or merge down to one lane during construction



Dirt road → tar roads → 1970s sewer line pipes →
1990s roads were paved.
Railroad always there. Septic Tank.
Some had wells, but
Bonton for drinking water.
were contaminated by lead from landfill
Dixie Metals Smelts - 13 mile lead radius. Was
kept quiet. Whites in Fruitdale & Joppee/Illinois
fled after news of lead
Oak Cliff was wet county - went there for alcohol.
Red lined. Went to Jim Walters out of Florida to
build his home. (Like habitat)

Change is okay.

Breakins reduced after Habitat came in.
Still Dirt roads 15 years ago, Carbondale was
just blacktopped when Larry moved in.
Homes were drab - gave community reason to do better.
Before Habitat - bodies, abandoned cars, vacant lots.
Ethnicity changed w/ Habitat
Railroad owns north of bridge. 4-5 years ago,
entire meet & greet for neighborhood. Lots of homes ran on
propane & had the option to switch to gas (15 y ago)
Mr. Larry joined Civic League to uplift children & community.
Jebra moved in 2007. Trees & foliage attracted her.
been in civic league ever since. Row houses
Share fruit, veggies, kids.



People drive through park to get to Stokes St. Very isolated feeling, but thats good and bad.

No sidewalks. Paving a few streets as peace offering.

Muk St. runs through property, so repaving and making jagged.

Walking paths. People drive, not safe to walk/bike.

No handicamp ramps but lots of elderly.

No concrete along trinity.

Fosters Crossing put in 1995 to commemorate Dels gma.

Bridge - pedestrain walkway needed to cross railroad
↳ Dangerous!

Loop 12 diff. if handicap → slope not level from Bus

E Loop 12 - only a pole & dangerous @ bus stop

Horse park → other side of Trinity

City wanted another access down from Linfield

~~Kids~~ Comm. Cntr.
↳
↳ Kids ←
↳ elderly ← fill out paperwork
↳ basic computers
↳ community education op. (writing, etc.)

Speedbumps & dead street on Carbondale & other used for racing

Across from river → farm (soil excellent!)

Btwn FB & River → farm

Urban farm ext off school

De-industrialize ~~whole~~ area

Shops @ golf course

Sidewalks & paved roads

More bus lines → Loop 12 @ Carbondale safety issue at night
↳ 3 morning & 4 evening (Last @ 8:30 pm)

Appendix D

UNIVERSITY OF TEXAS ARLINGTON | OFFICE OF RESEARCH ADMINISTRATION REGULATORY SERVICES

3/25/2022

IRB Approval of Minimal Risk (MR) Protocol

PI: Lauren Wardwell

Faculty Advisor: Joowon Im
Department: Planning and Landscape Architecture
IRB Protocol #: 2022-0169
Study Title: *Particulate Matter Air Pollution Mitigation Using Green Infrastructure for Industry-Adjacent Communities: A Study In Joppa, Texas*

Effective Approval: 3/25/2022

The IRB has approved the above referenced submission in accordance with applicable regulations and/or UTA's IRB Standard Operating Procedures.

Principal Investigator and Faculty Advisor Responsibilities

All personnel conducting human subject research must comply with UTA's IRB Standard Operating Procedures and RA-PO4, Statement of Principles and Policies Regarding Human Subjects in Research. Important items for PIs and Faculty Advisors are as follows:

- **Notify Regulatory Services of proposed, new, or changing funding source**
- Fulfill research oversight responsibilities, IV.F and IV.G.
- Obtain approval prior to initiating changes in research or personnel, IX.B.
- Report Serious Adverse Events (SAEs) and Unanticipated Problems (UPs), IX.C.
- Fulfill Continuing Review requirements, if applicable, IX.A.
- Protect human subject data (XV.) and maintain records (XXI.C.).
- Maintain HSP (3 years), GCP (3 years), and RCR (4 years) training as applicable.

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