Place-Based Metrics Guiding Southwest Urban Forestry Design

Growing Lungs of the Earth in the Semi-Arid Desert

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Master of Natural Resources Degree
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Executive Summary and Conceptual Framework

This work represents the capstone of my professional experience as an urban forestry designer and business owner in Santa Fe, New Mexico, my volunteerism as co-leader of the Santa Fe Public Spaces Tree Inventory, and my educational research as a student toward a Master of Natural Resource degree, emphasis Urban Forestry, through Oregon State University. This capstone is submitted in partial fulfillment of the requirements for this master's degree.

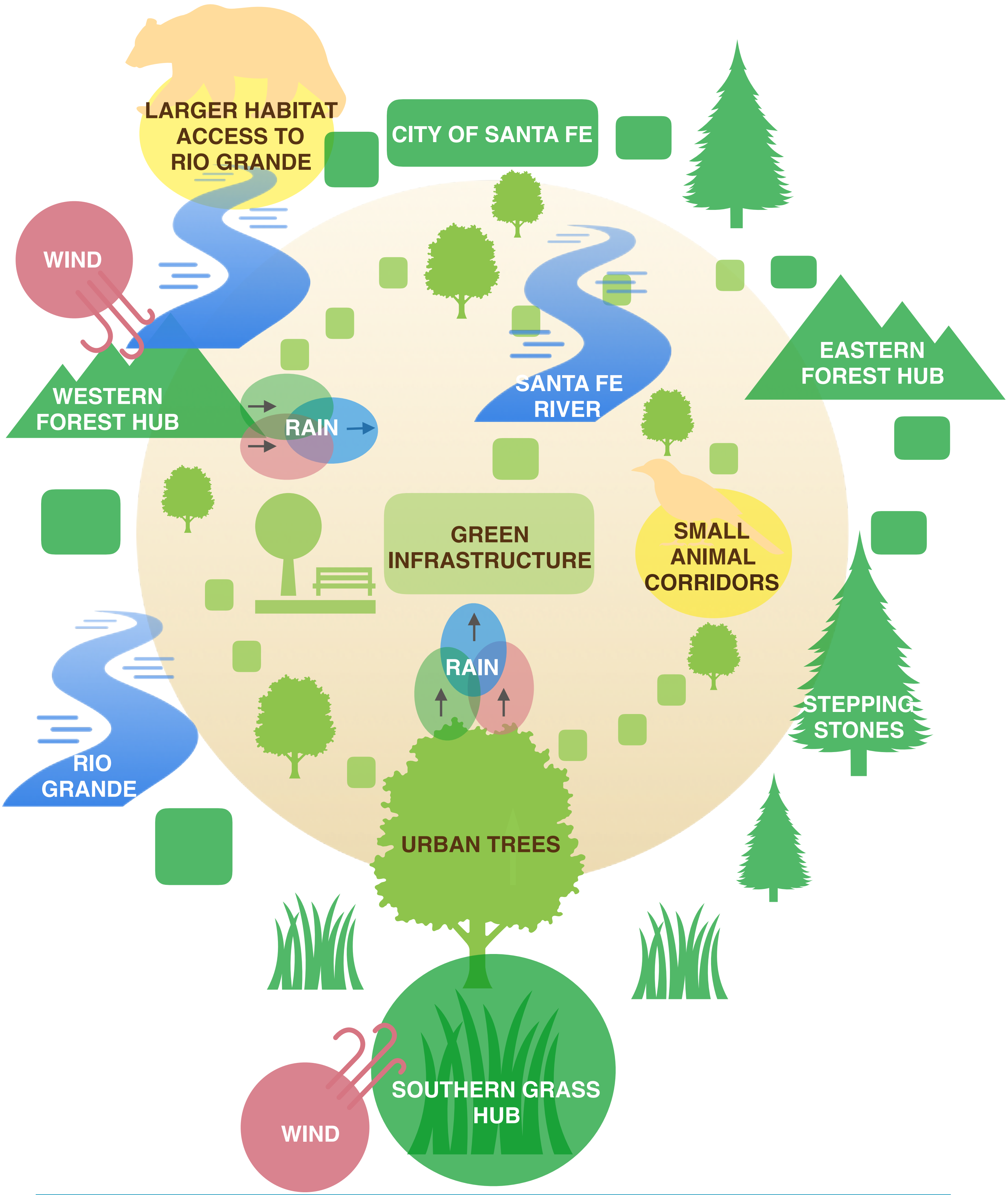
Landscaping in the semi-arid, high mountain desert offers many challenges. These ultimately are opportunities to utilize what we have and develop a solution-based approach to our gardens. Plants fail most often in semi-arid conditions due to lack of water, and the solution *du jour* usually involves potable water through plastic irrigation systems. Through this paper, I hope to highlight the use of stormwater to grow a tree, in a place it has room to grow, and of a species which will thrive for livability and habitat.

Southwestern urban forestry design relates stormwater, road drainage, soil, architecture, construction, wind patterns, ecology, botany, native plants and animals, urbanism, climate change, aesthetics, and most importantly, trees. It brings together my love of people, plants, the place we call 'home', and the animals who share it with us. It welds beauty and science, adaptability and constraint, grey and green infrastructure. It is the study which helps grow the "large oak tree [which] can transpire 40,000 gallons per year" (Perlman 2016), while relishing the shade it provides.

Seeds of Wisdom, LLC, my urban forestry design firm, has designs through the city, including the Stations of the Cross Garden at the Cathedral Basilica of St. Francis of Assisi (2010) and Guadalupe Credit Union, phase one, on Academy (2011). A fire defensible space project we implemented on nineteen acres receives accolades by a home insurance agency and is now showcased to volunteer wildland-urban interface firefighters. In 2018, the *Lagunita* rain garden technology, designed and implemented as part of the City of Santa Fe Alameda Rain Garden Series, received 2nd place Region 6 award by the Environmental Protection Agency (EPA) for a Low-Impact Development / Green Infrastructure Project.

My work focuses on urban forestry design and creating beauty by directing stormwater to trees. My goal for this capstone is to encourage our urban landscapes to mend the patchwork of plant and animal habitat and create cohesion with our outlining forest hubs. I believe that we can retain resiliency in a growing livable city, with more access to clean water. By making a shared commitment to foster healthy soil, open grasslands, shrub structure and tree canopy, our citizens will be healthier, our air moister, and our water sources safer.

Conceptual Design Framework for Southwest Urban Forestry in Santa Fe, NM



Abstract

Through well designed tree placement, redundant use of simple technologies, and stewardship, trees grow. Over time, they mitigate stormwater flooding and enhance livability. This paper offers insights into precipitation patterns, and how small scale redundancy can help build the urban tree canopy. It is specifically geared toward issues in the Southwest United States and Santa Fe, NM. Utilizing basic understanding of transpiration, i-Tree analysis tools and predictive modeling, the notion of trees as suppliers of in-land moisture encourages growing the southwestern urban forest under climate uncertainty conditions. Simple green infrastructure technologies, which can be implemented with each tree planting, make use of stormwater as the primary water source. Special consideration for protecting wildlife habitat is made by acknowledging intact habitat cores and recognizing where these become fragmented within city limits and outlining county open space. Supplemental resources, including ArcGIS Story Map, i-Tree analysis report for 2016-2019 Santa Fe Public Spaces Tree Inventory, Lagunita interpretive poster, and other visual aids help illustrate the concepts in this written paper. Semi-arid urban canopy growth is possible by guided use of stormwater as a resource.

Keywords: Southwest Urban Forestry Design, Santa Fe, New Mexico, Trees, Stormwater, Habitat, Urban Hubs, Green Infrastructure, Lagunitas, Scoritos. Semi-arid, Southwest United States, Seeds of Wisdom, LLC.

This paper is intended to be read in conjunction with visual aids provided within the website: http://sowsfe.com, under the Urban Forestry tab. Although some future reorganization may occur in the website, the series of pages intended for this paper will be available through the thread link:

https://sowsfe.com/place-based-metrics/

Place - Based Design

Purple-grey lines streak the summer horizon on a hot day. These mark potential rainfall, although often the land never receives a drop. The molecules of water are not heavy enough to fall in town, and the lines dissipate past Santa Fe; clouds driven eastward into the Sangre de Cristo Mountains. More often, this moisture is seen instead of felt. When these streaks of water become heavy enough, their accumulation has been about 0.22-inches of moisture (CurrentResults 2019). This is the water that helps identify the uniqueness of Santa Fe landscapes.

Photo credit: A. Beshur 2019

A landscape is not set in a void. It encompasses the qualities provided to it by its specific location, such as being situated on a north or south face of a slope, or having sandy, gravely or clay soil. It is also unique in its broader location, being at 7,199 feet above sea level (Wikipedia 2019), having daily temperature "with a range of 23°F" (Kelly 2015, 4) withstanding winter extremes of -20°F, having predominately alkaline soil, and being able to survive on 14-inches of rainfall a year (USClimateData 2019). These are the conditions that landscapes in the southern Rocky Mountains conform to withstand. These conditions make for uniquely adaptive and resilient plants, and these are the plants that make gardens in Santa Fe precious. As George Miller (2007, 11) wrote, "More and more are realizing that indigenous planting is a major feature that contributes to the scenic landscape that makes the Southwest so special." Indeed the plants in the native landscapes are special. These spaces should not attempt to mimic the gardens of Baltimore, New Orleans or even San Antonio. They should instead represent the uniqueness of place, and as such provide for and aid in the survival of habitat on which it relies.

Sustainable landscape practices become ethical considerations for the value that they provide as well as the resources utilized for its creation. As Paul Hellmund (2006) explains, “a place with strong landscape integrity has a good representation of ecological and cultural resources and a strong sense of place.” As technology develops alongside climate uncertainty, the ability to identify these resources becomes more accessible, and the need for their incorporation into smart design becomes even more necessary. For example, the United States Geological Society (2019) has identified migration patterns of over 2,000 species of mammals, birds, amphibians, and reptiles. Over four hundred are represented in Santa Fe County. These are readily available in their online mapping system, which will be described in more detail in the chapter Hubs and Habitats.

Because this geographical information is available, landscape design could, and should, incorporate alternative food and habitat sources for the site’s projected inhabitants. In this way, the inevitable human disturbance on the vast openness of the Southwest high mountain desert becomes instead sanctuary to migration. The world is becoming too small to further isolate wildlife from human interaction, but as we begin to recognize both the uniqueness of our landscape and those who depend upon it, the biodiversity becomes less strange and more welcomed. Yi-Fu Tuan, the “originator of humanistic geography” (Wiki 2019), describes (2001, 6), “If we think of space as that which allows movement, then place is pause; each pause in movement makes it possible for location to be transformed into place”. In a pathway, this evokes the larger bulge of flagstone offering an opportunity to pause. This is often referred to as the mouse-in-a-snake’s-belly. The pause provides a place for reflection. Place based design is invaluable to making a landscape unify with the world surrounding it.

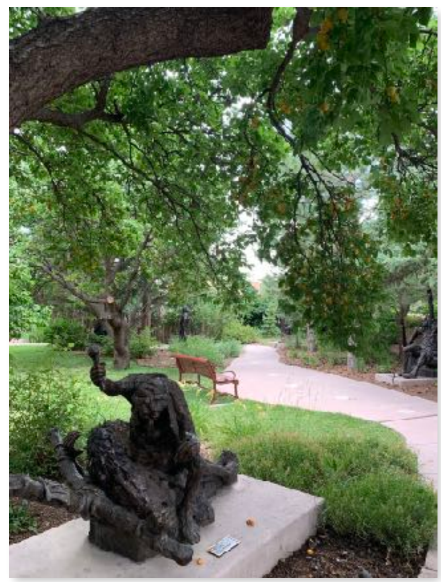


Photo credit: A. Beshur 2019

Landscape ownership has an obligation to create use of space which allows for movement, liberating populations of wildlife from bottlenecking genetics and making available alternative resources during disturbances such as drought and wildfire.

A Sustainable Santa Fe Commission (2018, 31) goal is to “maintain and improve Santa Fe’s urban forest to reduce urban heat-island effects, increase biodiversity, provide wind protection, sequester carbon, and prevent soil erosion.” To make meaningful, this goal incorporates an urban forest that has the integrity to provide shelter and food source for wildlife. Species selection, utilization of stormwater as a primary water resource, and allowing humans and animals to pause in its shade makes this urban canopy place-based.

Climate-smart conservation is "the intentional and deliberate consideration of climate change in natural resource management, realized through adopting forward-looking goals and explicitly linking strategies to key climate impacts and vulnerabilities" (Stein 2014, 3). Southwestern urban forestry design makes use of the technological and science based research available to make informed decisions about 'best plant, best place' as well as best management practices for stormwater infiltration. It incorporates soil science, habitat, and the human influence in its design, for improved pedestrian access to views, cultural features, and the broader landscape.

In addition to offering multiple and exponentially valuable environmental effects, "The (potential) role of city forests in helping to tighten community bonds and enhance place making is without a doubt a key element of city forestry, and of the contributions it can make to better cities. 'Community' can be described as self-defined, formal and informal groups with shared values, knowledge and interests" (Konijnendijk 2018, 179). Where groups of people can gather, culture is retained and created. Where corridors allow for connection to larger hubs, people access different communities, exercise and are generally healthier and happier. In a city that has art as a major industry, the use of art in these spaces helps to reinforce cultural concepts, provides financial backing for local artists, and "helps to re-define the identities and community ties of place, as much as it can help with turning space into place" (Konijnendijk 2018, 107).

Photo credit: A. Beshur 2017

Predictive Modeling

Science based modeling systems allow researchers to gauge possible future conditions. This allows landscape professionals an opportunity to make adaptive design decisions in concurrence with environmental trends instead of reacting to system failures. Predictive modeling also offers teams with collaborative focus to work collectively to discuss how decisions could affect other elements of a whole system. As indicated by the National Wildlife Federation, "Maladaptation is more likely to occur when climate impacts are considered on particular system components in isolation, without assessing the net benefits within and across sectors" (Stein 2014, 53). One example is given of utilizing an arsenic-based pesticide to kill mountain pine beetle (*Dendroctonus ponderosae*) without consideration for woodpeckers or felled trees (53). Another is of the American Beekeeping Federation who is currently petitioning the Environmental Protection Agency of lifted restrictions over sulfoxaflor, which is "'highly toxic to honeybees at all life stages' and harms wild pollinators like bumblebees even at low doses" (Papenfuss 2019).

Using highly toxic chemicals is an example of isolating an issue without considering of the myriad of other environmental impacts that could be affected by this decision. Place-based design incorporates the variety, diversity, and cohesive forces working within it. As Frederick Olmstead (2015, 72), a founder of American landscape architecture wrote, "The union of the deepest sublimity with the deepest beauty of nature, not in one feature or another, not in one part or one scene or another, not in any landscape that can be framed by itself, but all around."

In the case of the sulfoxaflor, it is being used to treat small insects such as aphids, when a much less caustic alternative such as neem oil could be used. By understanding the elements that make a whole system, through collaboration and adaptive management protocol, strategies or goals can become "climate-informed" (Stein 2014, 32), from which long-term healthy options can be considered.

Tree species respond in different ways to stress. The Piñon Pine (*Pinus edulis)* responds to drought by closing its stomata, which are the respiration pores on the plant's leaves or needles. This closing reduces the plant's respiration, and basically causes it to suffocate itself. The lack of moisture also affects resin production, reducing the tree's ability to eject the pests. During the last major drought, the bark beetle (*Ips confusus),* attracted to the carbon dioxide deprived trees, caused "a noteworthy outbreak from 2002 to 2004 [which] killed millions of pinyon pines over an area that included portions of six southwestern states" (USFS 2011b).

Even the mainstays of the broader landscape, One-seed Juniper *(Juniperus monosperma),* as well as other juniper species, are being decimated by pest outbreaks. Although these evergreens continue to respire during drought, leaving their stomata open causes them loose moisture and become stressed. This drought stress has now encouraged outbreaks of the Black-horned Juniper Borer (*Callidium texanum)* as well as the Juniper Borer (*Atimia huachucae),* which often kill the tree "before the insects' exit holes are noticed (USFS 2011a).


Photo credit: A. Beshur 2010

Affectionately referred to as P-J woodland, the two most dominant tree species in this environment are under attack. With a goal of growing the urban forest canopy, the adaptive option is not to leave them to their own demise, nor is it an option to make the environmental impact worse through toxic applications of chemical systemics. The environmental condition by which this predicament has taken hold is drought. By influencing the role of drought in the Southwest, through improvements to the overall condition in which these trees are growing, the effect of drought lessens.

Predictive modeling indicates that under current protocol of stewardship the overall canopy will be reduced due to increase temperature and decreased vapor pressure deficit (VPD). From research at Los Alamos National Laboratory, Nate McDowell (2017) writes, "Current climate change projections predict monotonic increases in air temperature and VPD coupled with continued periodicity of low precipitation…[which] could lead to continued decreases in total ecosystem biomass production and transpiration". There are several indicated factors working against one another, but they all in some way relate to trees. First, air temperature increases, which the shade of a tree helps alleviate. Vapor Pressure Deficit increases, which is related to temperature and the balance between vapor inside and outside the plant. Transpiration, which increases water vapor in the air, is influenced by stress and vapor pressure deficit. Decrease in total biomass will lead to decrease in transpiration, because fewer trees will result in fewer trees transpiring, although the existing ones may transpire more, as evidenced by the *Juniperus monosperma* effect on drought, or less, as evidenced by the *Pinus edulis*.

However, in a subsequent and remarkable five year study, McDowell later encountered that in conjunction with bedrock root access to water, not one tree died when tested for heat and drought. "The resistance of these trees to severe drought and heat treatments appears to originate with their access to water in the bedrock fractures in this area, which provides a water source sufficient to maintain gas exchange even under severe conditions" (McDowell 2019, 7). Because former rainfall, estimated from September 2013, was able to remain in bedrock to 2-feet deep, the native trees in the experiment accessed the water and withstood the drought effects. This indicates not only the importance of reducing use of bedrock water, but also to the resiliency native trees have to climate uncertainty. The natural tree access to water is made more available the less that potable water is used for irrigation and landscape purposes. Linking citizen use of water and trees to underground sources is invaluable to correcting the downward trend of natural space, non-irrigated tree growth, development and propagation. Although *Ips confusus* was not detected during the experiment, researchers suspect that, "There was likely to be high resistance to colonization of these trees by *I. confusus* given the relative minor stress our experimental trees endured" (McDowell 2019, 9).

Access to water is the major discovery of this experiment. It will be this access to water that will help keep trees growing under predicted conditions, and it will be these trees that keep semi-arid conditions from becoming arid ones. "Where extensive deforestation has taken place in upwind areas, one can expect increasingly warm and arid summers to have an increasingly negative impact on regional sustainability and adaptation potential. One can further expect the increasing likelihood of drought events with significant forest and other vegetation die-off in the more downwind regions. These phenomena will most strongly influence interior and downwind continental regions" (Ellison 2012). In other words, as trees die, so do the conditions they are protecting such as cooler temperatures from shaded microclimates and vapor pressure through transpiration, and these effects are evidenced down-wind from the tree die-back.

Understanding current trends relating to drought, which is a major environmental factor in the Southwest, can be assessed utilizing the Evaporative Demand Drought Index (EDDI)[1]. This provides current and actual drought severity on a weekly or monthly basis. A twelve month assessment shows most of New Mexico out of drought for 2019, but the one-month review showcases a very dry trend occurring Colorado and the Northeast corner of New Mexico, which begins to dissipate in conjunction with early autumnal cold weather patterns. The value of EDDI is that it "can offer early warning of agricultural drought, hydrologic drought, and fire-weather risk by providing near-real-time

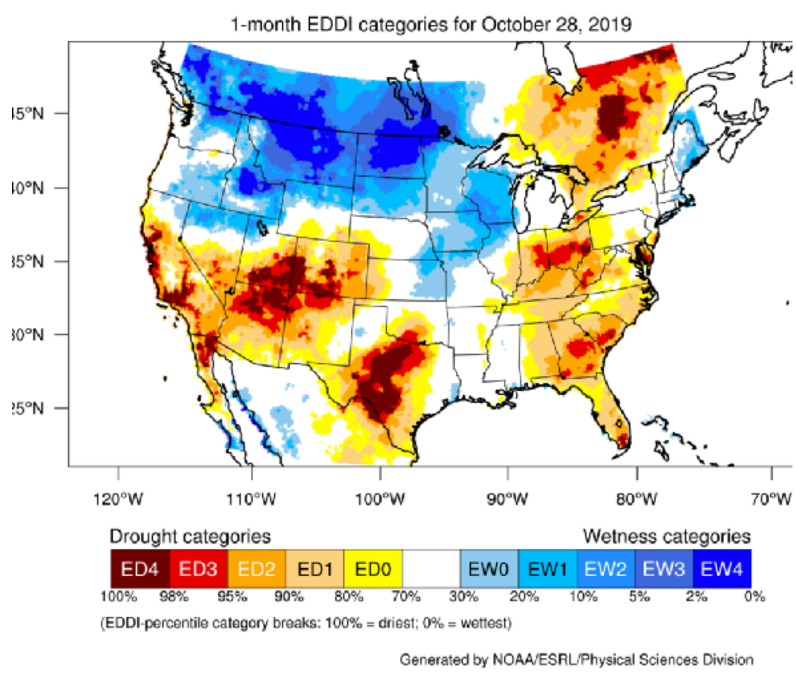


Photo credit: A. Beshur 2019. Data from EDDI (2019)

[1] Available at: https://www.esrl.noaa.gov/psd/eddi/#current_conditions

National Aeronautics and Space Administration (2019) has developed weekly soil and subsurface drought maps including: Groundwater, Root Zone Soil Moisture and Surface Soil Moisture[2].

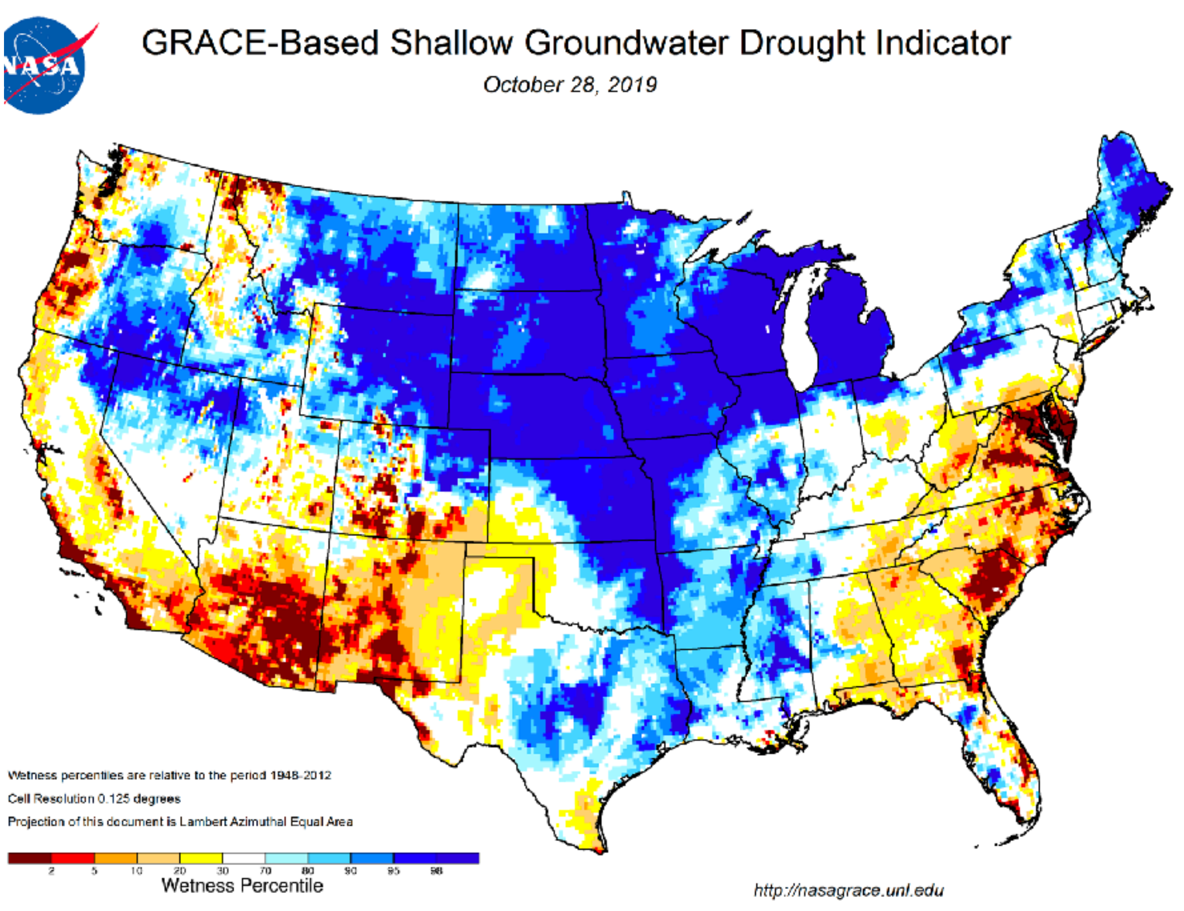


Photo credit: A. Beshur , 2019. Data retrieved from NASA (2019)

The National Integrated Drought Information System also hosts data maps related to drought and the burden lack of moisture places on the landscape[3]. Utilizing national resources such as these will help managers prepare not only for long-term scenarios but also for current trends. This could influence timing of planting programs and watering regimes for plant establishment, as well as predicting fire vulnerability for prescribed burn planning.

[2] Available at: https://nasagrace.unl.edu

[3] Available at: https://www.drought.gov/drought/data-maps-tools

Water Likes Water

The Sangre de Cristo mountains, still dense with evergreens, often receive the moisture that the Southside of town does not. This is not a newly noted phenomena. In 1878, French forester Auguste Matthieu was studying rainfall interception and temperature around the forests of Nancy, FR. His research indicated that not only were temperatures lower within the forest, but that, "A rain-gage located far from the forest received less rainfall than those within the forest and at its edge" (Andreassian 2004). This led him to consider the theory "that forests attract precipitation" (Andreassian 2004). Dr. Kim Coder, urban forestry professor at the University of Georgia, spoke at the Think Trees Conference in Albuquerque in 2019. He breaks down this theory, explaining, "Large groups of water molecules are pulled by surface tension into a round ball to minimize surface area per unit volume. In gravity, tear-drop-shaped droplets are formed as water falls… Water would rather stick to itself than to many surfaces" (Coder 2012).

Photo credit: A.D.Beshur and F.E.Lucci 2019

This theory is also apparent with reference to trees, how water reaches leaves, and transpiration. The power of water molecules to hold onto each other allows them the ability to pull other molecules up through the xylem of the plant. This moisture allows for the turgid pressure in the plant to fill leaves with moisture. As the plant begins to respire in the morning, and the stomata open, the moisture exists the plant, providing the atmosphere with moisture. What is referred to as the 'transpiration stream' or the 'cohesion theory of sap ascent' is that, "The cohesive properties of water (hydrogen bonding between adjacent water molecules) allow the column of water to be 'pulled' up through the plant as water molecules are evaporating at the leaf surface" (Sterling 2004). The "living cells surrounding this xylem pull (tension) system assist with monitoring the transpiration stream" (Coder 2012).

After long periods without moisture, coupled with a warm afternoon of active transpiration, leaves begin to wilt. The monsoon rains provide some relief. They arrive around 5pm, just as tree's stomata are beginning to close. Through the night, roots soak up the moisture and the water molecules, binding to one another, help to reinstate the entire plant with moisture. For this reason, drip irrigation going to trees and shrubs should begin in the evening, allowing the plant all night for rehydration via this cohesion of water molecules.

This mechanism of water supply to the plant can provide insight into the forces of aridity in a changing climate. As long as moisture in the air is less than moisture in the plant, the plant will transpire. As such, "The drier the atmosphere, the larger the driving force for water movement out of the plant, increases rates of transpiration" (Sterling 2004).

The moisture that leaves the plant does not disappear. It becomes vapor in the atmosphere, and the cycle of water molecules connecting to one another and gravity begins again. "The same evapotranspiration (ET) that consumes water at one scale supplies water to the atmosphere, facilitating its cross−continental transport and promoting precipitation at local, regional and global scales" (Ellison 2012). This concept is very clear and obvious within inland tropical forests, such as the Amazonian rainforests of French Guiana. Water is integrated into the atmosphere seamlessly from the Atlantic Ocean. Most afternoons, driven by transpiration, temperature and wind, rain falls throughout the interior forest, across South America and into Ecuador.

Photo credit: A. Beshur, 2018

The lack of precipitation in the Southwest United States however paints a very different picture, but the concept remains the same. Due to the aridity of the atmosphere, the moisture is not immediately felt, but collectively becomes a driver in forest precipitation. i-Tree Eco (i-Tree Tool Suite 2019) analysis of the 2016-2019 tree inventories indicate that 1,791 trees analyzed transpire 336,343 ft^3/yr (i-Tree 2019), with a potential evapotranspiration amounting to 887,912 ft^3/yr (i-Tree 2019). Predictive modeling indicates that increased temperatures may be expected for the Southwest, and "as temperature increases, the water holding capacity of that air increases sharply. The amount of water does not change, just the ability of that air to hold water" (Sterling 2004). Whether this will lead to a decrease in the already scarce precipitation remains to be seen. However, with the help of urban forestry initiatives, perhaps increase tree canopy could compensate for the increase in transpiration needed for gravity to bring rain down onto the parched soil.

Wind connects to precipitation to a place. It it relates to where the water comes from, how it reaches the city and how quickly it arrives, and where it falls.

To view the photo series "Green Water Droplets" and Transpiration Slider, please visit:

https://sowsfe.com/water-likes-water/

Vapor Pressure Deficit

Warm air holds more moisture than cool air. The amount of moisture or vapor in the air therefore would coincide with seasonal temperature fluctuations. In the winter, less vapor would remain suspended in the air. As such, the winter deficit in vapor provides strong indicators as to the lowest amount of vapor under normal conditions. A. Park Williams, meteorological researcher at Columbia and formerly with Los Alamos National Laboratory, has done extensive research on Vapor Pressure Deficit or VPD. This is defined as "a measure of the aridity of the atmosphere, calculated as the difference between the saturation vapor pressure (dictated by temperature) and the actual vapor pressure (dictated by specific humidity)… [and] is negatively related to precipitation (cloud shade and soil moisture)" (Williams 2019). He has found that, "Wind events and delayed onset of winter precipitation are the dominant promoters of wildfire" (Williams 2019). Because VPD is inversely proportional to precipitation, and inland precipitation is prompted by transpiration, it could be inferred that drought stress leading to trees closing their stomata would reduce transpiration, leading to lower precipitation, which then increases VPD. Dr. Williams' research suggests that the increase in forest fires is "mainly due to increased VPD and not concurrent changes in non-climate factors such as forest management, fire suppression practices, or human ignitions" (Williams 2019).

These relationships are both intuitively connected, yet scientifically difficult to measure, especially under desert conditions. With the discovery of isotope indicators, differentiating between atmospheric moisture from large bodies of water and that which came from plants is possible. In the article 'Revisiting the contribution of transpiration to global terrestrial evapotranspiration', Wei Zhongwang, et. al. (2017) "show that transpiration accounts for about 57.2% (with standard deviation $^{+/-}$ 6.8%) of global terrestrial ET [evapotranspiration]". Trees are essential for inland harnessing, utilizing, transpiring and aiding in inland precipitation. Large expanses of trees cumulatively impact this cycle in ways that make the semi-arid desert livable. "With forest loss, the net evaporation over the land declines and may be insufficient to counterbalance that from the ocean: air will flow seaward and the land becomes arid and unable to sustain forests" (Sheil 2009).

In other words, the increase in atmospheric aridity could be in part caused by deforestation. According to Gordon, et al. (2005), "deforestation has decreased global vapor flows from land by 4% (3,000 km^3/yr). For Santa Fe, with most storm events under 1/4" of rainfall, this difference could mean three less rain fall events per year, which would hypothetically lead to a exponential decrease each subsequent year. When the "lack of atmospheric moisture may be the limiting factor for precipitation in the more arid areas" (Tuttle 2016), each deforestation event leads to less predictable precipitation over time.

Green Water: Moisture Supply through Transpiration

The term 'green water' is used to describe water which has gone through the transpiration of plant material and is differentiated from 'blue water' which comes directly from large bodies of water, such as oceans and large lakes. Atmospheric moisture leads to precipitation (Ellison 2017), and as such trees are instruments of downwind precipitation. Although trees require water to grow, and the Southwest has an average of 14.2 inches of rainfall per year (CurrentResults 2019), trees are also suppliers of vapor and rainfall. Dr. David Ellison, research consultant for the Swedish University of Agricultural Sciences and Forest & Water technical report co-author for the International Union of Forest Research Organizations (IUFRO), explains how the "*supply-side school* ... suggests that the overall impact of forests is one of improving water availability at the regional and/ or global scale" (Ellison 2012).

Scientists have been able to quantify this supply of moisture through transpiration. Rockstrom and Gordon (2001) "have estimated the total water vapour [*sic*] flow from continental ecosystems to 71,300cm^3/yr, based on generalized field data. The results suggest that by far the largest proportion of the available water vapour flow generated from land surfaces (63,200 cm^3/yr or 90% of annual return flow of water vapour to the atmosphere) is attributed to forests, woodlands, wetlands, grasslands and croplands." A United Nations report indicates that, "Globally, up to 40% of terrestrial rainfall originates from upwind plant transpiration and other land evaporation, with this source accounting for most of the rainfall in some regions"(WWAP, 2018, 4). Of this water recycling, about 90% is used by plants for survival (Rockstrom 2001).

Photo credit:
A. Beshur 2019

Not only are trees the suppliers of inland rainfall, but they shade the ground, which helps hold moisture in it longer. Shade cools the air around the tree, providing respite from high altitude solar radiation. Meanwhile transpiration adds moisture into the microclimate around the tree, which helps the feeling of being cooler and adds to the sense of livability. The high-altitude semi-arid desert of the intermountain west has a combination of dry air and sun that makes anything with moisture particularly prone to evaporative tendency. Samuel Tuttle and Guido Salvucci compare precipitation feedbacks in the United States, indicating that, "Damp soil did predict a higher probability of rain the next day, but only in the arid West" (Moran 2016). With the high solar impact in the West, "Moisture can then evaporate, rise, and condense into clouds and rain" (Moran 2016).

Soil moisture also supports soil microbes, which in turn build the nutrient composition and water holding capacity within the soil. Fungal hyphae extend slowly within this microbe-rich soil and connect with roots, thereby further enhancing the distance of nutrient and water accessibility. This will be further discussed in the subsequent chapter on the Soil Food Web.

Wind

Wind can come from all directions in Santa Fe. A bitter winter wind from the North brings precipitation from the cold mountains of Colorado. Occasionally strong Gulf storms even send wind from Texas. More typically however are the winds that originate off the Pacific Ocean, head west across the deserts of California, Nevada, and Arizona, and then swing between the Jemez and Sangre de Cristo Mountains into Santa Fe. A digitized Wind Map[4] updates throughout the day with wind direction and speeds indicated by line density. Wind carries transpiration inland, and "even small changes in precipitation arising from upwind land-use change could have big impacts to the fragility of urban water supplies" (Keys 2016).

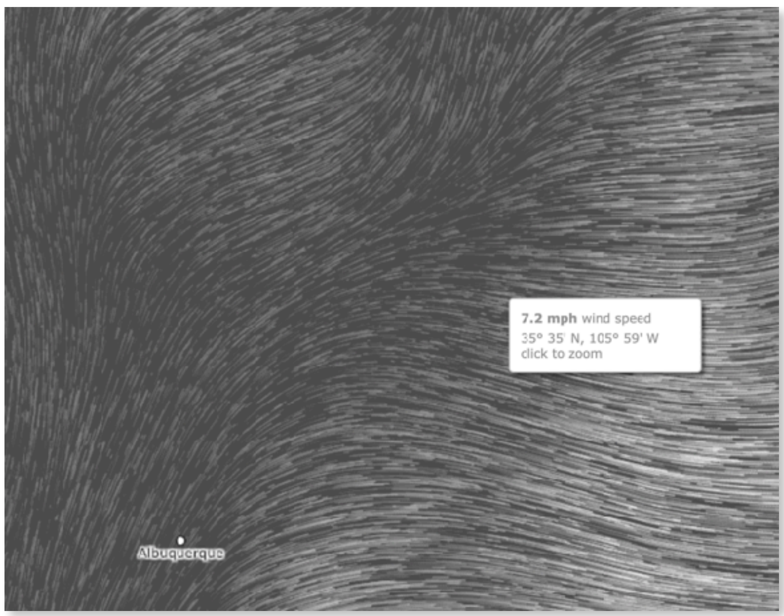


Photo credit: A. Beshur 2019.
Data from hint.fm (2019)

Typical southwest to northeast wind direction for Santa Fe

Taking wind into urban forestry planning could influence the precipitation down-wind. With the rising concern for drought, water consumption, population growth, and climate variability, taking upwind transpiration potential into account could influence major predictions for urban livability. As illustrated by Lan Wang-Erlandsson's (2014) global charts extrapolating connections between vegetation-regulated evaporation, precipitation and wind direction, "Upwind modifications that result in changed transpiration rates (e.g., changes in vegetation species, rainwater harvesting practice, CO^2 concentrations) may play a larger role for downwind regions than changes in interception".

[4] Available at: http://hint.fm/wind/

The southern part of the city is currently undergoing major changes in development. Large parcels of land have become new subdivisions, and urban sprawl into these previously pervious surfaces are taking their toll on extreme storm event flooding. Although Native American pueblo land between Albuquerque and Santa Fe remains grasslands dotted with Piñon and Juniper trees, private parcels are becoming divided, developed, and paved.

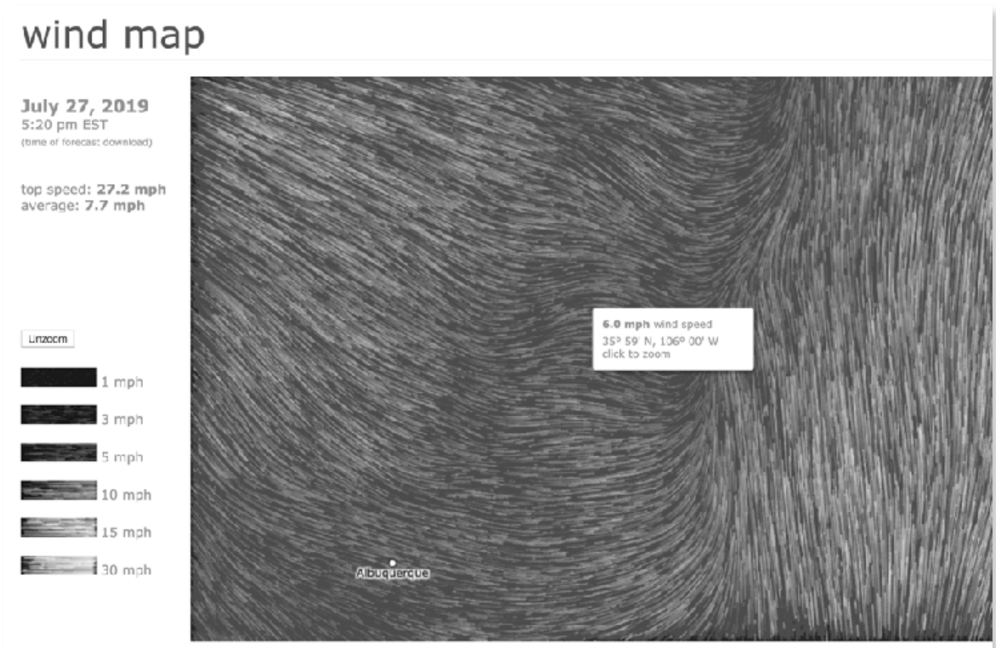


Photo credit: A. Beshur 2019.
Data from hint.fm (2019)

Northwesterly winds through the Jemez Mountains drive moisture

The concepts of transpiration, inland rainfall, and the influence of wind are simple to understand, yet difficult to conceptualize for local decision making. Queries such as 'why is Santa Fe receiving less rainfall than previously recorded?' and 'how is land use affecting urban precipitation?' become mind-boggling, with each step in the query requiring a multi-disciplinary research team. The roles these play, and the myriad of other connections involved, would take decades to understand. However, in conjunction with climate resiliency measures, it seems prudent to acknowledge the possibility of influence than to undermine the hope that it brings. If the possibility that trees could be placed within the wind's path to generate a more livable city, should Planning choose the hopeful option? When water is the primary concern for most citizens, would the relief of an extra inch of rainfall be a welcomed blessing? Invariably it would, and it is for this reason that the relationship between transpiration, precipitation, and wind have become the introduction to this research on southwest urban forestry design.

The wind direction 2019 screenshot series and transpiration slider is at:

https://sowsfe.com/wind/

Location Prioritization

An urban forestry maxim is 'Right Plant, Right Place'. It unifies many urban forestry concepts into a simple and catchy phrase. It encompasses both the individual plant selection, such as utilizing plants that are adaptive and preferably native, the right diversity in a grouping of plants, the right quantity of plants per acre, and the placement of the plant in a location where it will be more likely to succeed and provide the most benefits. Successful placement in the Southwest will be discussed further in the chapter Green Infrastructure.

In a 2018 bourgeoning development in Las Campanas, each home has a couple Quaking Aspen (*Populus tremuloides)* trees, planted separately in full sun under a field of 3/4" brown gravel. These trees have shallow root systems, making them easy to plant. However, they do not grow well in compacted gravel at 6,500 feet above sea level in the semi-arid desert. This is an obvious, yet continually reenforced example of wasted landscape funds on the wrong plant for the wrong place. Aspens grow at 10,002 feet above sea level (Hiking Project 2019) in a mountainous grove of aspens shading other aspens where the soil is rich with decomposed evergreens, which died from a former fire disturbance, not lack of water. A prime example of them in their splendor is up the road to the Santa Fe Ski Basin, where at Aspen Vista Trail, the autumnal coveted trail, holds snow for months in the winter. Knowing where trees naturally grow provides the framework for tree selection. Engaging a professional to help selection will provide contractors with longevity in their landscapes. There is no longer any time to waste on unconscious decisions. The Southwest is at a critical moment where water can only used to grow the canopy it needs for future livability.

Photo credit: A. Beshur 2019

Photo credit: A. Beshur 2019

Acer grandidentatum "JFS-NuMex3" developed by Rolston St. Hilaire, NMSU

The United States Forest Service has created a suite of tools for urban forestry projects called i-Tree. One tool in the suite, i-Tree Landscape[5] (i-Tree Tool Suite 2019) utilizes planning values for making planting location decisions. Priorities such as poverty, density, and summer temperature can influence where in the city trees are planted. By selecting for transpiration, computer algorithms deduce that the primary locations for planting are in the southern and western portions of the City of Santa Fe and its surrounding Santa Fe County open space.

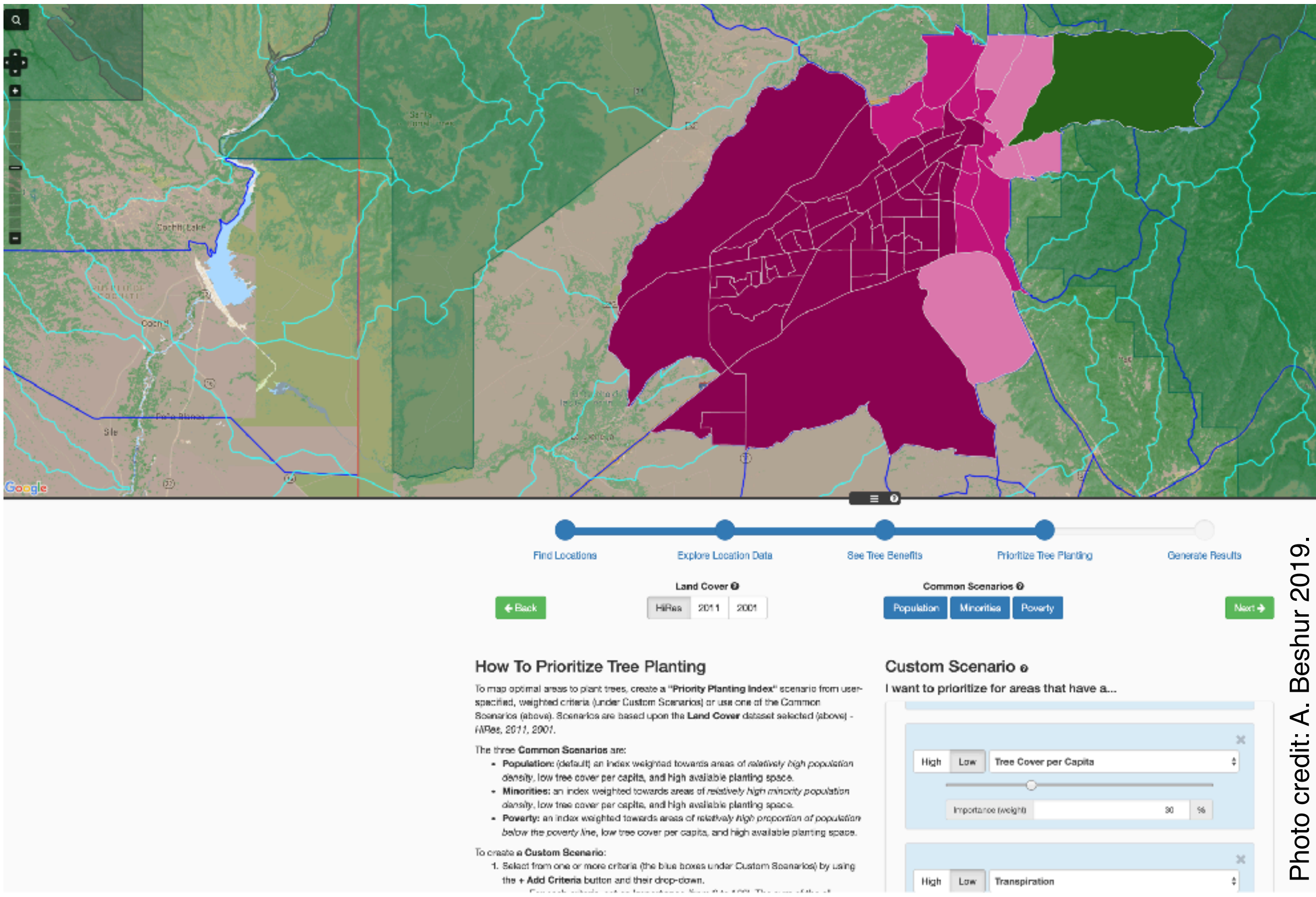


Photo credit: A. Beshur 2019.
Data from i-Tree (2019).

i-Tree Landscape map prioritizing tree cover per capita and transpiration (2019)

This southern region has been additionally identified in ArcGIS by the mapping layer 'Intact Core Habitat'. An ArcGIS StoryMap illustrates how these layers relate to one another. It emphasizes the value of these intact habitat cores. Three main cores surround Santa Fe. The first two are associated with the Sangre de Cristo Mountain range to the East and the Jemez Mountains to the West.

[5] Available at: https://landscape.itreetools.org

surfaces of the urban center. Evergreen trees and undisturbed grasslands have deep root systems and mycorrhizal connections that offer enormous ecosystem services to the city and surrounding areas. In addition to absorbing rainfall, sequestering carbon, and providing temperature stabilization, the open space acreage offers habitat sanctuary as well as transpiration benefits to downwind Santa Fe. Retaining the open space and growing trees in this area may become integral to a stable vegetation-based precipitation for the city. The interactive map integrates several other layers, including watershed drainage, soil types, habitat fragmentation, and the latest city park tree inventory data. This ArcGIS story map is available on the Seeds of Wisdom, LLC website www.sowsfe.com.

Another tool in the suite is i-Tree Design[6] (i-Tree Tool Suite 2019). This tool uses an aerial map to assist in placing a tree in the best place for energy efficiency. It helps gauge especially for summer western shade, but it also provides a guide to distance from a structure, accounting for future growth. It provides a breakdown of existing tree value for electricity and heating savings through an interactive selection tool. This tool, along with all the i-Tree Suite, is electronically available for free to the public, and can be utilized for alternate decision basis, including demographic considerations.

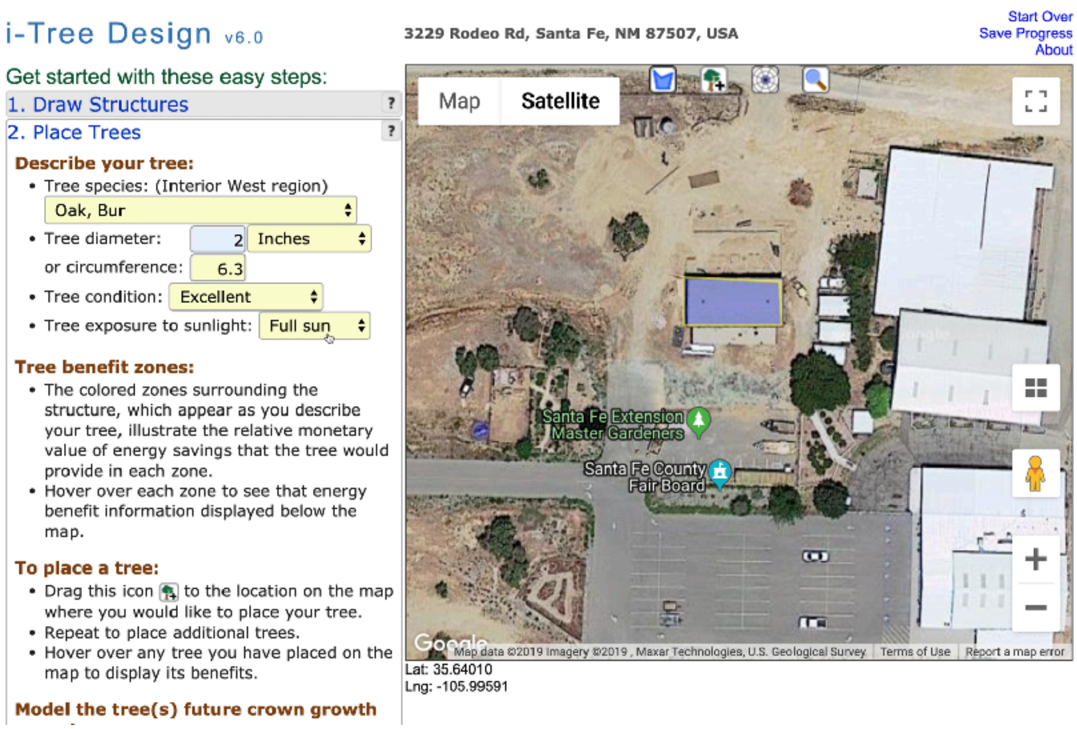


Photo credit: A. Beshur 2019. Data from i-Tree (2019)

To see an example of tree placement using i-Tree Design, please visit:

https://sowsfe.com/trees/

[6] Available at: https://design.itreetools.org

Protect Existing and Grow More

It has become clear that trees offer incredible value and would aid immensely in the livability in the southwestern United States. Although trees are being planted, too many succumb to early mortality due to infrequent, inadequate or misdirected watering regimes early in planting. As identified, "Deforestation in all areas of the world will lead to smaller amounts of recycled *P* [precipitation]…In the more arid regions of the world, this is also likely to mean a higher likelihood of drought as well as an expansion of the total drought-prone area. By the same token, *reafforestation…*in particular outside the tropics- can increase *P* and the overall intensity of the hydrologic cycle, especially during warmer periods of the year and potentially in a warmer future climate" (Ellison 2012).

Ecosystem service value of trees increases exponentially with age. Although this valuation curve is species dependent, the essential message is that stewardship of existing resources and encouraging healthy growth is necessary for future value enhancement. Supporting the existing canopy through maintenance standards should be priority in order to grow what is already established. Tree care is integral to healthy growth, and a trained professional offers invaluable service in early problem assessment. The motto invariably should be to protect and care for existing trees first, and then grow more.

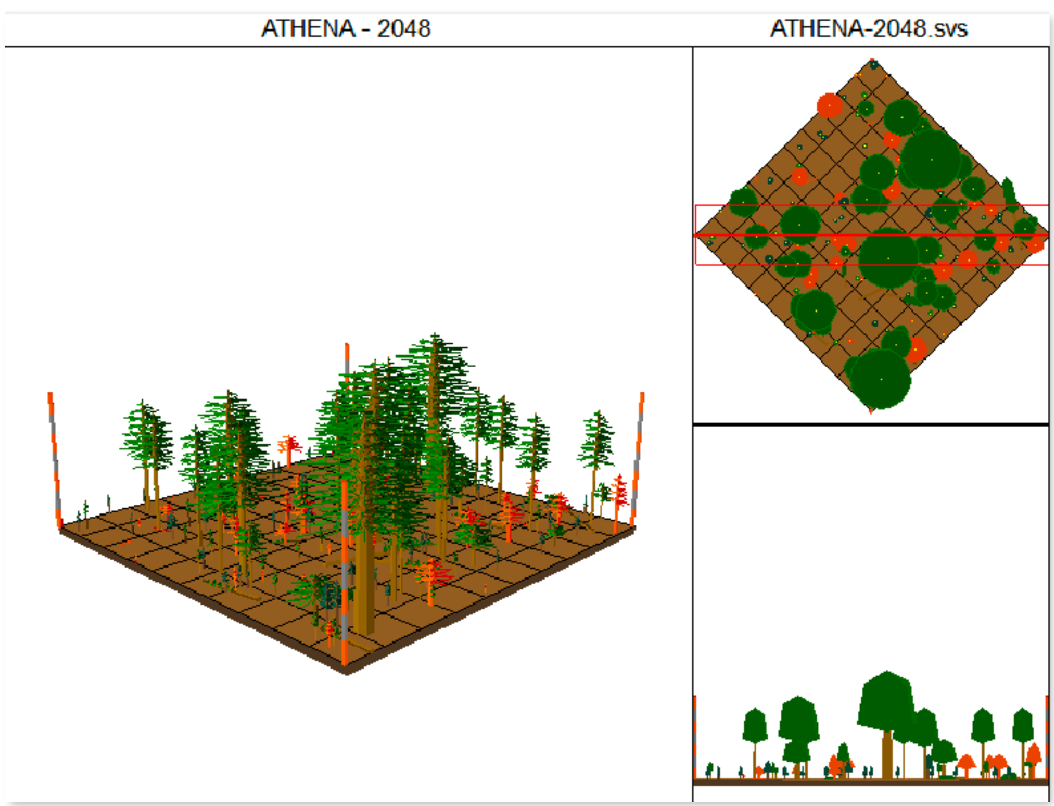


Photo credit: A. Beshur 2018. Data from LMS (2019).

Example of Landscape Management System (2013) model after 30 years of treatment

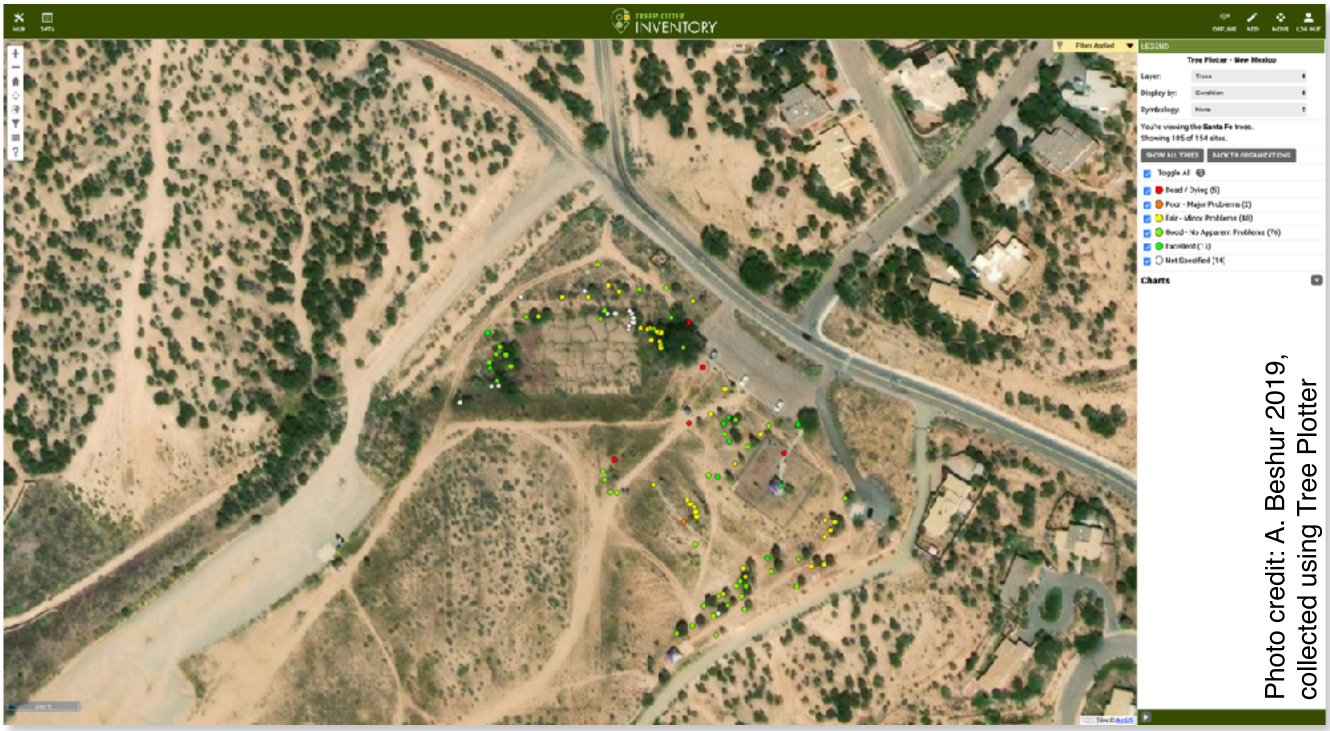
One treatment prediction modeling tool Landscape Management Systems (LMS 2013)[7] offers the opportunity to review how planting practices will be supported by the environment. Importing a CSV file (comma-separated file) into the program, and creating different scenarios of care allows the predictive tool to assess how each scenario will affect future canopy growth. This can be used to create a maintenance plan that reaches management goals, such as retaining canopy particular to threatened species.

Planting too many trees per acre has been shown to diminish the quality of tree canopy, induce more tree stress, and lessen long term diversity. Considering that tree mortality is an unfortunate factor in municipal efforts, planting multiple smaller-caliper trees with density may prove useful for future stability of a site. This can be incorporated first through hypothetical assessments utilizing this predictive tool. LMS may show improved canopy and habitat success through a process of planting, thinning a parcel later, replanting additional smaller specimens, adding diversity, and then thinning again as needed. Although this software was originally designed for large parcel logging treatments, urban models could utilize it in order to estimate needs based on species presented, specific location constraints, and parcel size. Additional funding through small tree sales may provide an added benefit of supplementing stewardship regimes while providing the community with low cost alternatives for the private sector. Trees that are planted too closely together cause canopy conflicts at maturity, so giving several a chance to establish and then selecting for maturity would be a way to assure a larger area will reach the canopy cover goal.

The subsequent chapter offers a collection of simple technologies to support tree growth in the semi-arid southwest. Some of these are possible to utilize for existing trees, and financially backed efforts to assist in retrofitting existing plantings require prioritization. Establishment of a tree takes a lot of effort in this climate, and plants that have withstood dry winters or warm summers are already offering ecosystem services to the community but need care.

Planting more trees in Santa Fe is absolutely essential to the continuing canopy. As example, a Forecast (i-Tree 2019c) model was developed with an estimated planting plan adding 80 trees for every existing 1800 per year for 30 years. Current tree inventory conditions include a projected mortality rate of 3% of healthy trees (excellent, good or fair condition), 13.1% of sick trees (poor condition), and 50% of dying trees (dying condition). With current tree conditions as a factor, after 30 years projection, there will be 1,721 trees left (i-Tree 2019c), which includes planting of 2,400 trees! This projection accounts for growth of existing trees. The estimated carbon sequestration would increase by 77% (i-Tree 2019c). It becomes clear through this scenario that protecting existing trees as well as growing more is integral to future livability.

[7] Available at: https://www.landscapemanagementsystem.org/



Tree Plotter software (2019) indicating tree condition for Frank Ortiz Park

Although cost is involved to plant new trees and grow more, the forest can contribute to its own growth. Making the city forest more financially stable and citizens healthy through local produce is not a novel concept. Mulch supplies a "biofuel plant in Yorkshire, England, that runs on 75% wood chips" (Konijnendijk 2018, 64). Fruit and berry picking helps offset citizen food costs and falls in line with the United Nations goal of improving local food for the growing urban communities, a practice that is quickly gaining acclaim. With the realization that urban communities are growing, and worldwide 805 million people are undernourished, the "United Nations post-2015 development agenda and the Sustainable Development Goals…seek to establish a more holistic approach to poverty reduction, the contribution of forests to food security and nutrition, and the integration of food production across forests and landscapes are of particular relevance (Vira 2015, 6-7). Options exist for urban forests to be financially stable investments. Fruit collection and the potential to sell trees to the private sector as they grow beyond carrying capacity are just a couple creative options for increasing the supply of funds to support the growing canopy.

Tree Inventory

The Santa Fe Public Spaces Tree Inventory project's first tree in 2016 was a 19.5-inch diameter[8] Colorado Blue Spruce (*Picea pungens)*. It was a tall beautiful specimen at the front entrance to the Water History Park on the corner of Alameda and Upper Canyon Road. Indicated with a condition of 'good with gopher activity' in March 2016, by the end of the year, it had died, was removed and most likely used as mulch. It does not take much to kill a tree in this changing climate! Without maintenance systems in place, stewardship becomes an afterthought to the myriad of other activities expected of the parks, most notably lawn mowing and trash removal. Trees need care, protection and stewardship to grow these original 'direct carbon capture machines'.

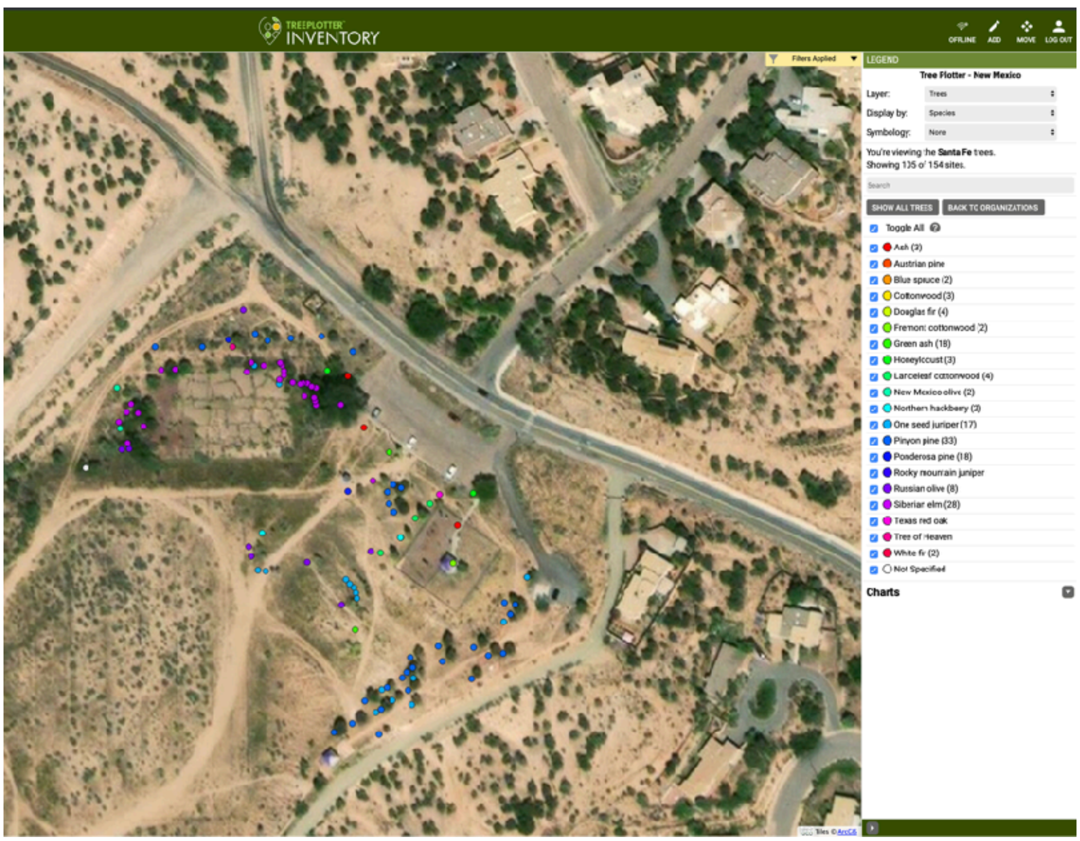


Photo credit: A. Beshur 2019, collected using Tree Plotter (2019)

Example of tree species collection through Tree Plotter (2019)

The volunteer citizen-driven inventory has collected species, condition, size, location, and risk, as well as comments such as co-dominancy on trees since 2016. i-Tree Eco is an i-Tree Suite tool (2019)[9] which offers a report of ecosystem services for an inventory. As the Santa Fe

[8] DBH or diameter at breast height, indicated at 4.5-feet above grade

[9] Available at: https://www.itreetools.org/tools

Public Spaces Tree Inventory data grow, the asset value to the city becomes even more impressive. Parks inventoried and included in the 2019 analysis include: Franklin Miles, Amelia White, Frenchy's Field, Harvey Cornell Rose Park, Santa Fe City Hall, Santa Fe Plaza, Cathedral Park, Tommy Maccione, Ragle Park, Las Acequias Park, Water History Museum Park, Candelario, Ashbaugh Park, Frank Ortiz Park, Torreon, and Bicentennial/ Alto Park. The 16 parks inventoried span 148.58 acres of park space (Parks 2015) and count for 1,836 trees (TreePlotter 2019) in the Santa Fe Urban Forest. TreePlotter[10] software used for the data collection now includes all pre-software data from earlier inventory sessions, beginning with 2016. Both the TreePlotter and the i-Tree Eco Summary analysis reports have been distributed to the Municipal Tree Board and the Parks Division, and they are available as pdfs on the Seeds of Wisdom, LLC website. Tree plotter allows for simple and clear collection, which is paramount for a volunteer driven inventory.

Although i-Tree Eco values are based on national tree data, Santa Fe Weather Station 723656-23049 and Weather and Pollution Year 2016 provide influence on the tool's algorithm, especially related to pest potential, growth rates, and stormwater mitigation. Per i-Tree Report Summary (2019b), "The total annual precipitation in 2016 was 8.4-inches". Some values are based on potential. Values for air pollution removal are potentially based, as it can only be removed if it exists. Inches of stormwater mitigation are only as accurate as landscape design guides water to the tree. If a tree is surrounded by compacted soil with slope draining away from it, then the tree will more likely neither mitigate the stormwater nor grow to the ecosystem benefit of i-Tree Forecast (i-Tree Tool Suite 2019) value. Larger trees offer more ecosystem benefits, and in order to reach optimal value, the community needs to care for existing trees and plant more every year.

Analysis of 1,791 trees from the inventory indicate an overall structural value of $3.47 million, with 11,600 ft^3/yr of avoided runoff, 21.13 tons/yr of oxygen production, and 572.4 pounds/yr of pollution removal. These trees sequester 7.925 tons of carbon and store 482.6 tons. Carbon storage is valued at $82,300. The total amount of carbon storage, carbon monoxide removal, nitrogen dioxide removal, and sulfur dioxide removal is "equivalent to annual emissions from" 420 cars or 142 homes (all from i-Tree 2019b), and this coming from only 16% of the total park system acreage (Parks 2015). The public park trees also only represent a small fraction of the total urban forest as most trees are growing on private property.

Included in the chart is information on diversity by species and genus. A standard guideline in urban forestry is the 30-20-10 rule. This means that ideally "no more than 30% family, 20% genus, and 10% species" (Bethke 2016) are representative in the distribution of canopy diversity. This protects the landscape from pest infestations and other family, genus, or species specific setbacks, as well as offers improved wildlife symbiosis. As the Santa Fe

[10] Available at: planitgeo.com

inventory data grows, evidence of this healthy balance of diversity is becoming apparent. Detailed tree species data and hydrological services are available in Appendix A: Tree Inventory by Species.

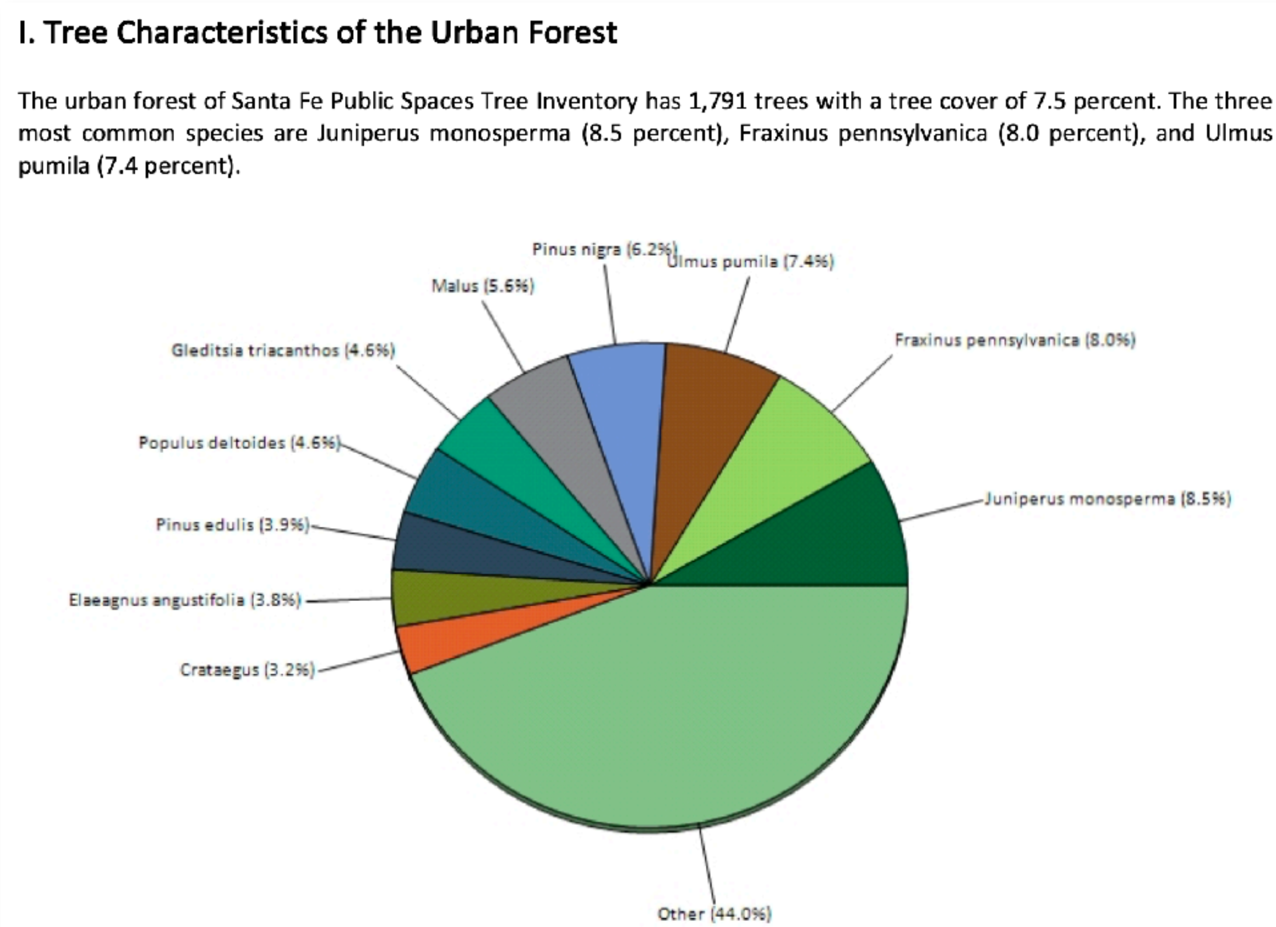


Photo credit: A. Beshur 2019, collected using i-Tree Eco (2019)

In addition to providing the information for Parks Division decision-making, the Tree Inventory offers citizens an opportunity to learn about what trees are doing well, how to assess issues, and what environmental conditions reduce tree stress. This citizen driven project offers a "true means of two-way communication amongst experts and between experts and the public" (Konijnendijk 2018, 152). Although pilot years focused on Master Gardener Association volunteers, these have become experts in the data collection protocol, making possible the expansion of the project to public and other organizations, especially those who have Adopt-A-Park affiliation with a site. In this way, the adoptees connect with the trees in the park they have adopted, feel more connected, and can more readily recognize changes in tree health.

Offering supplemental irrigation is necessary for establishment and should never be overlooked, especially for the first three years after planting. If automated, nighttime watering provides enhanced benefit for trees. As Dr. Coder (2012) indicates, "Night uptake by roots can amount to 20-40% of tree water needs if water is available”. Designing with soil microbes, with mulch, compost and mycorrhizal inoculates, and stormwater as a primary resource allows trees to gain a foothold through lessened drought stress. It has been contended that, “Of particular relevance for plants in water-limited environments…increased solar radiation does not always translate to increased water stress despite its positive effect on potential evaporation. Since solar radiation supplies the energy for photosynthesis and CO_2 assimilation, greater radiation levels enable greater rates of photosynthesis” (Schymanski 2015). Increased energy production due to larger leaf area resulting from photosynthesis will help a plant survive a period of drought.

Summary

Understanding an urban forest's structure, function and value can promote management decisions that will improve human health and environmental quality. An assessment of the vegetation structure, function, and value of the Santa Fe Public Spaces Tree Inventory urban forest was conducted during 2019. Data from 1791 trees located throughout Santa Fe Public Spaces Tree Inventory were analyzed using the i-Tree Eco model developed by the U.S. Forest Service, Northern Research Station.

- Number of trees: 1,791
- Tree Cover: 7.5 %
- Most common species of trees: Juniperus monosperma, Fraxinus pennsylvanica, Ulmus pumila
- Percentage of trees less than 6" (15.2 cm) diameter: 44.8%
- Pollution Removal: 572.4 pounds/year ($443/year)
- Carbon Storage: 482.6 tons ($82.3 thousand)
- Carbon Sequestration: 7.925 tons ($1.35 thousand/year)
- Oxygen Production: 21.13 tons/year
- Avoided Runoff: 11.6 thousand cubic feet/year ($776/year)
- Building energy savings: N/A – data not collected
- Avoided carbon emissions: N/A – data not collected
- Structural values: $3.47 million

Ton: short ton (U.S.) (2,000 lbs)
Monetary values $ are reported in US Dollars throughout the report except where noted.
Ecosystem service estimates are reported for trees.

Photo credit: A. Beshur 2019, collected using i-Tree Eco (2019)

To receive a copy of the 2019 Santa Fe Tree Inventory List, please visit:

https://sowsfe.com/product/2019-santa-fe-tree-inventory-list/

Green Infrastructure

The grey infrastructure of an urban center, its streets, roofs, and hardscape cause water to run off, gaining momentum with each foot of downward movement. The curse becomes a blessing when these guided raindrops are used to grow the urban forest. As the United Nations Report explains "Green infrastructure solutions involve a deliberate and conscious effort to utilize ecosystem services to provide primary water management benefits as well as a wide range of secondary co-benefits, using a more holistic approach" (WWAP 2018). Best Management Practices or BMPs are continually being developed and improved to help professionals design infrastructure that incorporates this environmentally essential component. However, they are not being utilized enough, correctly, or with urban forest intentions.

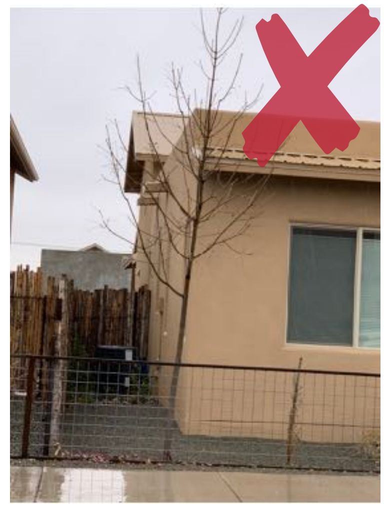


Photo credit: A. Beshur 2019

Just recently, a new multi-home development was built off Agua Fria Street and Harrison Road. Each small yard has a tree next to the house in gravel, with no room to grow beyond 3 feet toward the house. Rain gutters or *canales* are placed to the side, or downhill from the tree. Many of these are directly uphill from the next house, which may cause problems to the neighbor's home. The tree selection offers little diversity. Most are Green Ash (*Fraxinus pennsylvanica)*, a species that could be wiped out if Emerald Ash Borer (*Agrilus planipennis*) reaches New Mexico. This pest is currently being quarantined in Boulder, CO but is responsible for the demise of over 100 million *Fraxinus sp.* trees in the continental United States (Donavan 2013). If these do reach sufficient age to provide any ecosystem services, they will be done primarily with potable water and will be needed to be pruned constantly to avoid property damage. Planting placements do not offer the homes optimal energy savings. It is obvious from this frequently observed scenario that an urban forestry professional was not consulted during the project or during its numerous hearings at municipal review boards.

A better scenario would have been that an urban forestry designer was included on the team of specialists, along with the architects early in the design process and contractors during construction. Plans place canales to direct valuable rain water toward trees. These are given the space they need to reach 'Excellent' future condition without building conflicts. They are located where soil would not be compacted by mounds of ¾-inch gravel. Roots grow, homes are shaded, and trees protect the community and enhance its livability. Some trees create a community area where residents can relax and get to know their neighbors under a shaded canopy. This pocket park adds continuity to a corridor that connects larger hubs for improved habitat value. This scenario is not an esoteric Milton's *Utopia* ideal. It is a brief summary of the requirement needed to make southwest urban forestry possible and should be treated as standard practice in modern construction.

Below are a collection of a few simple BMPs that have proven to utilize stormwater as a valuable resource for tree growth while reducing erosion in and around Santa Fe, NM. These technologies expand the principle 'Guided Raindrops Grow Trees'. They sometimes can be installed together to work in conjunction with one another and are specifically designed to be simple, easy to install, and cost effective. Their cumulative implementation goal is that they can be used to help grow trees in the semi-arid southwest, where average rainfall is 14-inches per year. Alternatives may be mentioned, and are certainly available by many colleagues and water engineering professionals. This is not an extensive BMP list. Designers should continue to study other work, observe the environment, and develop new technologies which support the particulars of the site. The primary focus of these is in value for tree growth in drought regions.

Each location affords an opportunity for creative design. Although BMPs offer standards, the designer should consider the site, who is around it, how quickly water is entering, where erosion exists, and maintenance when developing the green infrastructure design. All of these culminate in place-based design that are beautiful, safe, healthy and functional. By instilling a protocol of redundancy into the design, water is guided from one tree to the next in a smooth way, and large storms can be handled safely by having support through the landscape to control stormwater usefully.

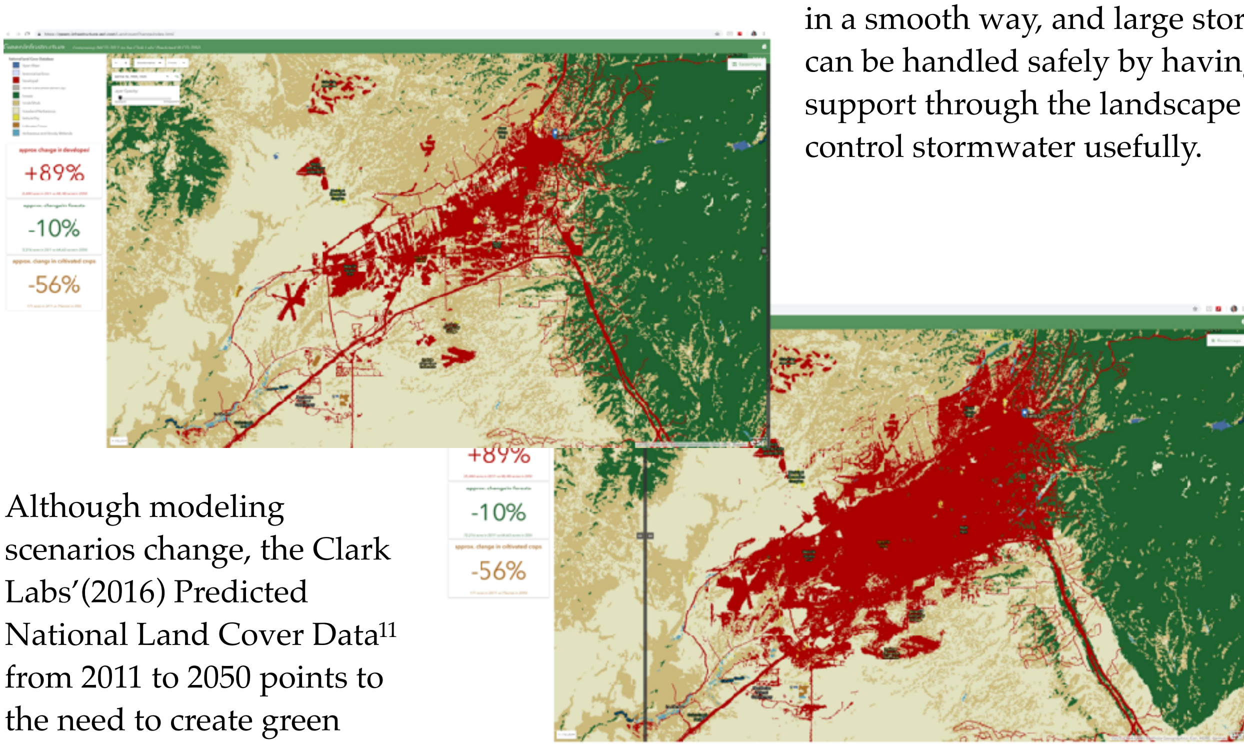


Photo credit: A. Beshur, 2019.
Data from Clark Labs (2016).

Although modeling scenarios change, the Clark Labs'(2016) Predicted National Land Cover Data[11] from 2011 to 2050 points to the need to create green infrastructure protocols while space is available within the city limits to accomplish these initiatives.

[11] Available at: https://green-infrastructure.esri.com/LandcoverChange/index.html

Rain Gardens

When the torrential monsoon rains pound pavement, road engineering removes water off the street to avoid hazardous situations. Traditionally this is done with storm drains and culverts that direct the water away from the street and into the Santa Fe River channel. Directed water moves efficiently, and just as quickly as from the road, it washes down the river, carrying with it a multitude of debris, gallons of car oil, winter de-icing pulverized rock, and soil. Orange-brown water carries remnants of uphill fragile slopes.

Although this stormwater needs to go somewhere, in drought stricken regions it ought to be harvested for urban tree canopy support. The single minded focus of removal not only forgets the guiding precedent 'Water is a Resource,' it causes uphill and downhill issues, such as soil erosion and deposition, property flooding, and waterway pollution, and hazards. Rain gardens are gardens which use water to support the ecosystem, remove pollutants, slow stormwater, recharge aquifers, create beauty for the city, and restore pedestrian culture.

Rain gardens should be built with the capacity to infiltrate substantial rainfall. However, it is not a contest of most water, but rather best use of water to support the trees planted in the garden. For shade and livability purposes, redundancy of smaller scale gardens may have a larger ecosystem and environmental impact than enormous, unsafe pits.

Photo credit: A. Beshur 2019

Seeds of Wisdom, LLC has installed several rain gardens throughout town. Perhaps the more widely known one is on the corner of Alameda and Cathedral Place. Part of the City *Alameda Rain Garden Series*, installation was completed in 2017. It is a pass-through rain garden which directs ran water from approximately 32,000 square feet of impermeable road into what had been a weed filled 810-square foot corner parcel, which was an eyesore in the center of downtown. Due to the size restriction of the parcel, and its close proximity to pedestrian traffic, retaining a safe space is an essential component of the site. For this reason, infiltration designs become hidden within a small visible indentation of the top surface.

The water enters into the garden through a four-foot curb cut, is cleansed of road impurities and slowly meanders down a curving rock riverbed. Within the riverbed are the lagunitas, which are held down by river rocks. This rain garden is estimated to mitigate 22,000 gallons of stormwater per year. As the trees and fungal hyphae grow, gallons absorbed is projected to increase over time. In addition to growing 5 trees, two Frontier Elms (*Ulmus carpinifolia x parvifolia)* and three Burr Oaks (*Quercus macrocarpa)*, which were selected in part for their positive relationship with ectomycorryzal fungal spores used in the lagunitas. In addition to healthy growth, now with no supplemental irrigation, the corner lot offered the opportunity to redirect water down Cathedral Place, which seeps into the road cracks and has offered improved health to at least one Ponderosa *(Pinus ponderosa*) and a Rio Grande Cottonwood *(Populus deltoides var. wislizeni).*

To view rain gardens in action, please visit:

https://sowsfe.com/portfolio/rain-gardens/

Curb Cuts

Rain water harvesting can be initiated along these impervious surfaces by cutting curbs to allow water to enter into sunken gardens. In order for this to even be possible, road engineering needs to design the road itself to slope into areas where infiltration can exist. By working with road engineer contractors at the beginning of a project, during a repair or a retrofit, and communicating in writing the goals of drainage, it becomes possible to have water directed into the basin. Unfortunately, this is still a relatively new concept, even with the mountains of literature available from state and federal agencies. More often a road or parking lot is scraped and asphalt reapplied with as much efficiency as possible. After all, any construction involving vehicular movement becomes a traffic jam. Trees are still planted in narrow strips with water leading away from their roots, even in new construction.

Photo credit: A. Beshur 2019

Many roads already have stormwater gutters along their sides, so these will inevitably become the first to offer opportunity for green infrastructure design. Curb cuts design is invariably influence by slope, style and budget of the project. A simple style is to make the entrance 4-feet wide with a 45^{o} sloped cut angling toward the opening. This wide opening allows the garden to accept debris from the street, which then will get deposited into a sediment trap at the beginning of the garden. Sometimes this width does not visually work with the design. If, as example, cars are parked along the edge of the street, then creating access for passengers would be essential. In this case, each tree could have its own smaller cut, with the downhill portion of the basin higher than the tree. Stormwater will enter and exit the same curb cut in boomerang style, with the cut on the "upslope side of the basin to increase water storage capacity (Landcaster 2008, 199).

Some gardens are 'pass-through,' such as the Cathedral Place Rain Garden, meaning that the water enters one side, infiltrates as it weaves within the garden, and any surplus comes out a second and downhill curb cut. A second sediment trap is recommended to collect any debris, including mulch, from exiting. A corner pass-through style can have the added benefit of redirecting water onto a side street to divert flow and support cross-street vegetation.

Overflows are required so that the water continues downhill after ideal level is reached. Overflows can be the exit curb of a pass-through rain garden. It can also be made into an additional element in the design, for example to prevent too much water from being suspended above the rootline of a tree. Tree trunks in a rain garden should not be inundated with standing water for long periods of time. If they are planted low in the basin, an overflow pipe helps to relieve residual ponding. In the El Alamo Rain Garden, a small one-tree installation also along Alameda Road, an overflow piping allows diversion of a portion of the water inflow to support vegetation outside the garden. It crosses below the sidewalk and is sent to a Black Locust (*Robinia pseudoacacia).* This has a tamped swale below it to retain moisture entering into the basin. As Brad Landcaster recommends, "Overflow…should be directed to adjacent water-harvesting earthworks such as infiltration berms, berm 'n basins, or diversion swales" (Landcaster 2008, 188). This is consistent with recommendations in the City Landscape Code (2011), which indicates that, "Street trees should be planted to the greatest extent possible in swales or basins that collect run-off and precipitation".

Curbs are of course City property. In order to cut, a curb cut bond, cut design and traffic plan approval are required by Public Works Department.

Sediment Trap

The initial collection of debris entering the curb cut is done through a sediment trap. To be clear, the sediment traps described here are for tree growing rain gardens. These guidelines are not intended for use on large scale engineering projects.

The traps should be designed for ease of maintenance, as they regularly require clean-out. Although ideally they are cleaned out after every major storm, realistic expectation should instead be after the first major storm post-winter de-icing, as well as at least one other time in the season especially during or after monsoon season. The trap is indented "minimum 4-inches below gutter inlet elevation" (LANL 2017), which allows water to naturally flow from the curb cut into it. As the oil, sand, sediment, branches, winter de-icing rock, and other street debris enter into this trap, they will be forced down into the trap. Suspended water glides out of the trap, over the crested edge, and continues into the rain garden.

The trap is at least as wide as the curb cut, with 4-feet considered optimal for trapping debris. Depth is based on several factors, including entering water velocity, distance of impermeable collection, and basin length (IDEQ 2005), and 18-inches is a good minimum for many small applications. Oxbow style, meaning water enters and exits through the same opening, standard dictates the sediment trap be "sized to contain 5% of the total" (LANL 2017) water volume capacity for the garden. The bottom of the trap should be flat. Some designers use 4-inch to 12-inch rough-edge rock within the trap; although a simple solution, it requires more frequent clean-out due to low sediment volume potential but is effective in low-debris situations. This is the simple design which was used for the Cathedral Place Rain Garden. It does work. In the spring 2019 clean-out, over 50 gallons of winter de-icing scoria, glass, branches and sediment were collected. However, there are some benefits and flaws to the design, discovered in retrospect after a three year observational period.

Photo credit: A. Beshur 2019

One benefit is that little water remains in the sediment trap, and with small storms, this means that more water reaches the downhill trees. A good portion of the decomposable material is consumed by soil microbes, which have access to material through the base and sides of the trap. It economical to construct, is relatively easy to build and clean, and can often be made with on-site materials. It is a good option for small spaces, especially where budget is a factor and the impervious surface draining into it is relatively clean.

However, this method does take a while to clean out, as all the rocks are removed and washed, debris is scooped out the hole, rocks returned, and grade reestablished. The trap does not hold as much debris as an open-trap system, which means that it needs more frequent clean-out. It is not practical for a multiple project system, and could lead to lessened collection. In the case of the Cathedral Rain Garden, once filled, smaller material, especially vehicle oils, began to infiltrate into the garden. Observation shows the dry river rock becomes oil stained its first 3-feet.

An improved method is to use a stainless steel grate to allow the void to be completely available for debris collection. If this is used, it should be suspended safely with edge support to avoid collapse. Suspension can be held by edges built with block stone and stainless steel crossbeams to hold up the center of the grate. Rocks can then be placed on top of the grate for aesthetic purposes and safety concerns. The final grade should be a few inches below final grade, with measurement approximated here for the purposes of understanding. Having a difference between grade of the sediment trap and entry into the rain garden forces debris into the trap. During strong currants, the lipped edge will force collection even though force is driving sediment forward.

There is contention among designers about lining sediment traps. Some prefer to concrete line the bottom and sides of the trap, which makes for easiest clean-out and reduces water infiltration before the garden. However, tree roots will grow in response to water being delivered through the bottom of the trap, and soil microbial activity below the trap could aid in the decomposition of trapped organic material. A bottom layer of rock prevents velocity from force cutting into the bottom.

“Because finer silts may not settle out completely, additional erosion control measures should be used to minimize release of the fine silt” (IDEQ 2005). Oil especially remains suspended longer than rocks. Continuing the rock into a rock mattress or the beginning of a dry river bed channel after the sediment trap, as example, allows final oil and fine sand to become trapped within the gaps of rocks, and allows the water to continue through the course in a much cleaner state. This has been observed in both the Cathedral Place and the El Alamo Rain Gardens along Alameda.

Mycorrhizae

A major component of growing a healthy tree is the presence of microorganisms in the soil. Microorganisms exist where organic matter exists, and in the Southwest, if soil is lacking in structure, then more water input is required to support a plant. In other words, building soil saves water because healthy loam soil has the capacity to hold water longer, and moist soil supports the growth of microorganisms. As soil biologist Dr. Elaine Ingham (2000) explains, "Many organisms enhance soil aggregation and porosity, thus increasing infiltration and reducing runoff". Through the process of improving the soil structure, the *soil food web* becomes more developed, and with it encompasses the multitude of bacteria, amoebas, flagellates, ciliates, nematodes and fungi that help grow plants. Different plants prefer the presence of a different balance of microbes, and this influences the role of succession of plant communities in a natural system.

When soil becomes disturbed, the first plants to germinate are typically weeds, which are low-nutritionally valuable plants which colonize an area with large seed quantities, such as the infamous desert tumbleweeds (*Salsola tragus)*. As aerobic bacteria populations develop and break down plant matter, the soil becomes less conducive to weeds, and more conducive to grasslands. Through succession, and as the balance of bacterially dominant to fungal dominant, trees are able to grow. When Dr. Ingham visited Santa Fe in 2014, she noted that soil tested from the Santa Fe National Forest was low in fungal hyphae (Ingham 2014). This could impact the growth of the forests, as well as the soil's ability to hold moisture and suppress disease.

Indeed soil microbes act as *biological control agents,* reducing incidence of disease and pest populations. One Seeds of Wisdom, LLC project treated powdery mildew on Rocky Mountain Penstemons (*Penstemon strictus)* on July 3, 2014, May 31, 2015, and September 14, 2015 using spray composed of freshly made aerobic compost tea from a local compost pile, along with supplemental liquid seaweed/ kelp and Age Old Organics Soluble Mycorrhyzae Inoculate. The treatment removed all incidence of the mildew. The mildew had a mild resurgence the following year, but upon reapplication of compost tea on September 23, 2016, the powdery mildew again was removed. This centrally located garden had received neem sprays at least twice a year for minor insect pests, including aphids, mites and whiteflies and the powdery mildew. This practice was stopped as part of the compost tea use in order to not affect the microbes. It has only received one application since this trial began, on June 18, 2015. It no longer has an imbalance of pests or mildew warrantying chemical treatment.

Specific recipes treat specific issues, such as "composted pine bark suppressed root rot caused by *Phytophthora* spp." (Quarles 2001) and maturity of the material influences value. The compost for optimal pest and pathogen use should be active with microbes. After 18 to 24 hours of brewing, the very microbial active tea is applied.

Mutualist fungi are of particular importance for tree growth. Two main types of these are ecto- and endo-mycorrhizal fungi. Mycorrhizae means the "symbiotic association between a green plant and a fungus" (Wikipedia 2019) This relationship can either be via an external connection, such as with ecto-mycorrhizae species, whose hyphae strands form webs around roots, protect roots and are preferred by evergreens. If the connecting link between fungus and root is internal, it relates to endo-mycorrhizal fungi, whose hyphae grow into roots and are of special significance for vegetables, perennials and shrubs. These also provide protection from harmful bacteria and have a component call glomulin which acts as a soil aggregate. Fungi "convert hard-to-digest organic material into forms that other organisms can use. Fungal hyphae physically bind soil particles together, creating stable aggregates that help increase water infiltration and soil water holding capacity"(Ingham 2000). Fungal hyphae extend past where roots can reach, and through the mycorrhizal association, aid in the tree's access to water and nutrients. As such, "The presence of mycorrhizae (fungal modified tree roots) can act to moderate early drought stress in trees" (Coder 2012).

Weeds grow in poor soil. As the composition of the soil improves, bacterial dominance allows for the growth of vegetables, shrubs, and deciduous trees. Fungal hyphae grows much slower. As soil becomes more fungal-rich, it supports the evergreen forests. By introducing microbial populations into the soil, the soil food web helps enhance the growth and succession of plants over time.

Disturbance is integral to the majority of urban environmental conditions, and "reclamation studies have provided some of the strongest evidence of the critical roles of mycorrhizal associations for the establishment of plants" (Ehleringer, 2006, 49). In addition to providing substantial value for plant growth, mycorrhizae "grow into the compost and form a mat of mycelium, or mushroom roots, that hold [soil] together and keep it from floating" (Cahill 2018). This makes it an ideal amendment for rain gardens, which often receive extensive flow velocities.

The City offers low cost mulch at the Buckman Road Recycling and Transfer Station (BuRRT) as well as compost from the City Waste Water Treatment Plant (SFSWMA 2019). By adding these components to the landscape at small and large scale, microbes are able to decompose decaying plant matter, make nutrients more bio-available for plant roots, consume pollutants, and regain balance with pests and pathogens. Through no-till practices, existing hyphae remains intact and supports a wider community of plants with compounding ecosystem benefits.

Lagunita Technology

The lagunita technology was developed by Seeds of Wisdom, LLC as a simple and effective method to absorb more water and hold it in an aerobic manner to support soil development and foster tree growth. Implementing it in the rain garden at Cathedral Place allowed it to be tested under a no irrigation system, where trees rely on the lagunita next to each of them in order to have moisture longer after a rain storm event. Inspiration for the concept comes from the spongy feel of a forest floor, which has the decomposing trees adding to the absorptive power of the soil.

The methodology is easy to install. Dig a hole and side veins branching from the hole. Cathedral Place lagunitas are 2-feet wide by 2-feet deep, with veins extending 2 to 3-feet in perpendicular directions. For slope application, position the veins along the contour to the slope. Add mulch or small woody debris into the hole and veins and compact slightly for safety. Inoculate with mycorrhizal fungal spores, assuring that the mixture has some ecto-mychorrizae, which is particularly important for trees. Place 2-inch or larger rocks on top of the lagunita to keep the mulch from getting washed out in a storm. This technique, as exemplified in the Cathedral Place Rain Garden, won 2nd place at the 2018 Region 6 Environmental Protection Agency Conference for Low-Impact Development/Green Infrastructure Project.

Environmental Interpretation poster by Seeds of Wisdom, LLC 2018

Originally, four lagunitas were installed in conjunction with the first four trees along the rain garden, as well as one next to the tree on the west side of the street in Spring 2017. Observation indicated that the fifth tree was undergoing stress, and several limbs had died. On November 1, 2018, this tree received a lagunita and dead limbs were removed. As of October 2019, no more limbs have died, leaf color through the season is consistent with the other trees, and it has begun to grow. The Frontier Elms were 1.75-inch caliper trees, which is measured at 6-inches from grade, when selected and procured on March 17, 2017. On October 13, 2019, all three measured 3.75-inch caliper. The Burr Oaks were 2-inch caliper trees when procured also on March 17, 2017. These now measure 3.25-inch, 3-inch and 2.75-inch. Caliper is measured at 6-inches above soil grade. Interestingly, the variability in size is corresponding with distance from entry curb cut, indicative that even small rain events influence growth.

The tree across the street, on the corner with the Inn at Loretto parking lot, is not in a rain garden. This Frontier Elm (*Ulmus carpinifolia x parvifolia*) has thrived, even without a curb cut, due to the lagunita and sidewalk drainage of rainwater. Although visually it looks as though it is the low part of the garden, the lagunita actually rests at the low point of the space, leading water away from the trunk of the tree to protect it from wood rot, and into the mulch sponge.

At the El Alamo Rain Garden, where one Chinese Pistache (*Pistacia chinensis*), several shrubs and grasses grow, the main lagunita is 3-feet wide by 3-feet deep. This again is lower in elevation to the tree along the pass-through rain garden. Average pre-treatment percolation rate was 16 minutes/inch, taken on June 7, 2017. In a water trial done on June 1, 2018 over the course of 9 hours, a water tank was filled seven times with 210 gallons of water and hauled to the rain garden; a hose positioned at the entry curb cut simulated drainage into the garden. The length of the rain garden was divided into seven parts. Although some soaking into the soil occurred between the time after emptying one tank and its refill, the 1,470 gallons used never reached past the main lagunita at the tree (flag 4 of 7). Extrapolating each subsequent flag, an estimate capacity of this rain garden is 4,583 gallons of water. If this amount were to drain into the garden for each of the average 36.5 rainfall events in a year, the total yearly water capacity would be 167,279.5 gallons. The exit curb cut is positioned to allow any exiting water into the subsequent rain garden. Although these numbers are hypothetical, they illustrate the enormous potential to divert water off grey infrastructure and into green infrastructure to clean drainage, keep roads safe, as well as grow the urban canopy.

Although it receives accolades from a variety of sources for drought tolerance and has been listed as a *Texas Superstar* (Pemberton 2019), Seeds of Wisdom, LLC no longer recommends *P. chinensis* due to "a 60 percent probability of [*P. chinensis*] being a minor invader" (USDA 2012). Being listed on the Ladybird Johnson's Invasive Database list (TexasInvasives 2019) further emphasizes the need to research species prior to wide adoption in tree planting projects. The tree continues to look very beautiful in the El Alamo garden.

Photo credit: A. Beshur 2017

To see a presentation on the Lagunita technology, please visit:

https://sowsfe.com/lagunitas/

Scoria, Pumice, and GrowStone

Although mulch is a preferred medium for absorbing water, as it also feeds the soil microorganisms and builds the soil food web, an alternative for some applications is the use of water holding rock, either volcanic scoria, pumice or engineered GrowStone, which is made from recycled glass. Although these products each hold their own properties, they all are good options for holding moisture, reducing compaction and reducing erosion.

One simple application is to use it in a drainage site to disperse water. In one instance, where a well expels close to 30 gallons of water per week causing anaerobic conditions in the garden bed, ¾-inch scoria rock was wrapped in a pervious fabric, and graded away from the well pipe to spread the water behind four Russian Hawthornes (*Craetagus ambigua*). Termed a *scorito*, because it looks like a scoria burrito, the well water now seeps slowly around the four trees, following the ¼-inch-per-foot elevation downgrade, and helps them grow well in full sun.

On a couple other occasions either ¾-inch scoria rock or ⅜-inch pumice have been used without liner placed in trenches which follow elevation contour lines. These help absorb runoff on a slope and allow water to permeate into the soil. With both uphill and downhill from a tree, these rock filled trenches have helped improve conditions and moisture content in the soil. Nate Downey (2014), of Santa Fe Permaculture, has used similar technology by using "GrowStone for water retention in conjunction with swales" as well as on-contour straw-pack swales (Downey 2014). Straw-pack swales utilize the packs from a straw bale. These are placed perpendicular to a slope in an on-contour trench, with about ½ of the pack in the trench. Surrounding soil stabilizes the pack and seed, especially native grass seed, is sown uphill from the pack. This simple technology designed by Downey has proven very useful in sites with a gentle decline and aid in grass germination. It also acts as a "sloped dissipater," (LANL 2017) although on slopes 3:1 or greater these should be constructed of "stone, concrete or metal" (LANL 2017).

There is some controversy regarding the use of mined materials such as pumice or scoria. Unfortunately large quantities of GrowStone are not readily available locally for landscape scale applications. All three have been used in Seeds of Wisdom, LLC construction of water wicks, where water is directed from gutters into perforated pipe surrounded by the material and woven through a garden along a ¼-inch-per-foot elevation change. Wicks are impressively functional and somewhat simple to construct, and in every single garden in which Seeds of Wisdom, LLC has designed these into the landscape, plants grow larger with less potable water irrigation. The rock trenches, scoritos, and straw-pack swales provide a couple more alternatives for simple constructed technologies that aid in the control, direction, and absorption of stormwater. Design dictates usefulness.

Trees

Climate uncertainty requires solution-based design. As a recent video featuring journalist George Monbiot and Greta Thunberg describes “There is a magic machine that sucks carbon out of the air, costs very little, and builds itself. It is called a tree. A tree is an example of a natural climate solution. Mangroves, peat bogs, jungles, marshes, sea beds, kelp forests, swamps, coral reefs, they take carbon out of the air and lock it away. Nature is a tool we can use to repair our broken climate. These natural climate solutions could make a massive difference“ (Mustill 2019). Indeed trees are climate champions, exemplified by the *Saturday Night Live* skit “Trees” by rappers Pete Davidson and Chris Redd (2018) receiving 2.2 million views and over 46,000 ‘likes’ on YouTube, up 100,000 views and 2,000 likes in the past month alone.

Planting “more trees isn’t a bad thing” (Chris Redd in Davidson 2018), although the selection process dictates planting the right species of trees in locations where they can grow to maturity. Since Autumn 2015, the Municipal Tree Board and the Santa Fe Extension Master Gardeners have been collecting tree inventory data throughout the Parks system. This data offers real information about what trees do well in Santa Fe. Potable water irrigation supports these trees, and inevitably the trees without it are stressed. Managers can utilize this information to maintain and improve conditions for struggling trees, develop plans for planting additional trees, and analyze performance based on yearly environmental conditions. Analysis of the tree inventory to date is highlighted previously in the chapter ‘Protect Existing and Grow More.’

Trees need room for their roots and branches to grow. Urban trees rarely reach their full potential in large part because the environment in which they are placed is not conducive to longevity. This means that when they reach the age to actually provide ecosystem services, they are already failing.

A large part of the demise of urban trees is the non-compacted root area provided for growth. In a trial done by the Kestrel Design Group, when provided 1500 cubic feet of soil, 100% of trees succeeded. However, when provided 100 cubic feet of soil, success rate dropped to 65% (MacDonagh 2016). Simplified, “For a tree to grow to its natural mature size and live a full life, its root zone (at a 24-inch or 61-cm depth) should be at least as large as the area expected under the tree’s canopy at full maturity” (Landcaster 2008, 190).

Santa Fe Street trees are provided with minimum 5-foot by 13-foot strip (City of Santa Fe 2011, G-3b) with the surrounding area compacted for streets, buildings, and sidewalks. Reducing this compaction not only will allow for increase in root development, it will improve soil aggregate formation, which generally takes “10-25 years to form” (Day 2016) as well as increase porosity for stormwater infiltration. To treat soil compaction, one technique is the *Scoop and Dump* method. This "backhoe subsoiling technique [is used] to create veins of compost 2' into the subsoil. Scoop a backhoe bucket of soil and compost, lift, and let drop" (Bassuk 2012, 299). However, in these constricted areas, an addition of SilvaCells (by DeepRoot, Inc) or similar technology would allow the grey infrastructure above ground to remain safe while reducing compaction below ground by suspending the infrastructure.

Other simple technologies were implemented by Historic Tree Care working with City staff on the Santa Fe Plaza on March 22, 2019. First, they exposed the root collar by removing sod and soil in order to protect the trunk from mower damage and decay and to remove girdling roots. The surrounding 6-inches to 12-inches from the trunks were backfilled with scoria to maintain trunk health. Second, they used an iron bar and a Supersonic Air Knife: Model X-HFA iron bar "that sends an air water mixture at supersonic speed to break up the subsoil" (Meilleur 2019). In order to reduce compaction and improve conditions for struggling trees, they applied scoria rock into holes 1-foot to 2-feet deep in circles around the trunks. The scoria reduces compaction while retaining safe level conditions for pedestrians. "By improving the conditions below the surface, more tree root activity will improve the trees health and resistance to pests and drought" (Meilleur 2019). After one season of intensive use, the trees on the plaza look good, and the scoria around the trunks remain largely in place.

Because "High altitude forests have a special ability to intercept fog and cloud droplets" (Ellison 2017), the trees in Santa Fe provide an essential function, not only for the city but also for the region. Existing trees need support and protection. During construction, City Code (2011, F-5d) dictates that, "Existing plant material to be preserved shall be enclosed by a temporary fence at least five (5) feet outside the dripline. In no case shall vehicles be parked or materials or equipment be stored or stockpiled within the enclosed area." Another metric is based on a standard tree protection zone, which measured in feet, is two times the diameter at breast height (OSUES 2009). Diameter-at-breast-height is measured at 4.5-feet above grade. It is the standard measurement for tree inventories. Heritage trees throughout the city need designation and stewardship support, with new technologies implemented to increase soil food webs and absorption rates.

The Lagunita Poster is available at:

https://sowsfe.com/product/lagunita/

Hubs and Connections

The Sustainable Santa Fe Commission (2018, iv) indicates that a City goal is to "Enhance the connectivity of greenbelt and habitat corridors across the community". Connectivity is vital to citizens and animals and requires extensive forethought for the City to plan. As explained, "Connectivity can be managed as either continuity, the physical connectivity of habitat, or connectedness, the functional connectivity of habitat. Corridors represent one type of connection that can be designed for species with poor ability to cross gaps" (McComb 2016, 218).

Bridging the gaps between habitable sites also allows for livability by providing in-city locations where people can enjoy some fresh air or reach another part of the city by walking or biking to it. Corridors provide safety, where pedestrians can travel on an alternate, and usually more beautiful routes, then vehicular traffic. They offer significant landscape place-making value for a community. One can make a pilgrimage to their church, encounter a rabbit, hear the flapping wings of a flight of birds, and make a random encounter with an old friend. For wildlife, corridors provide necessary travel routes to water sources, especially with a minimum of "1,100-foot width… to provide linkages with interior forest conditions of at least 500 feet wide, with an additional 300 feet of transition to edge on either side of the interior forest" (Benedict 2006, 129). As reference, the distance between W. Alameda and the Bicentennial Pool on the opposite side of the river is 200-feet, which is the widest width of the Bicentennial/ Alto Street Park. The distance from the River Trail to Agua Fria stretching across Frenchy's Field is 1,067-feet. An ideal would have this distance extend the entirety of the river corridor. Although feasibility dictates width of existing open spaces, larger parcels of land are currently for sale on either side of the Veteran's Memorial Highway 599 that would provide the optimal habitat girth for a game corridor. Designing this would have the added value of directing Rio Grande bound migratory large animals away from the City. In one thrilling instance, a mountain lion "broke through a glass door of a jewelry store on the Santa Fe Plaza" (Denver Post 2007). The Department of Game and Fish estimate that "around 4,353 cougars live in New Mexico" (Las Cruces Sun News 2019). Through smart planning, it is possible to navigate these large animals around the urban centers.

Photo credit: P. Rvan. 2019

Corridors offer most value when they reach and connect larger sites, including pocket parks, community gardens, and especially intact core areas or hubs. “Green infrastructure hubs include the highest-quality, largest, and least fragmented ecological landscape attributes,” (Benedict 2006, 126), and are necessary for the survival of wildlife. Three main intact forest hubs surround Santa Fe. Two reflect mountainous topography. The Jemez Mountains to the west of Santa Fe is visually identifiable by the volcanic indentation of the Valles Caldera on satellite imagery. The second intact forest hub is to the east, where the Sangre de Cristo Mountains finalize the Rocky Mountain Range. The third hub is to the south, where open grasslands offer enormous value for wildlife, precipitation accumulation, and access to the Rio Grande.

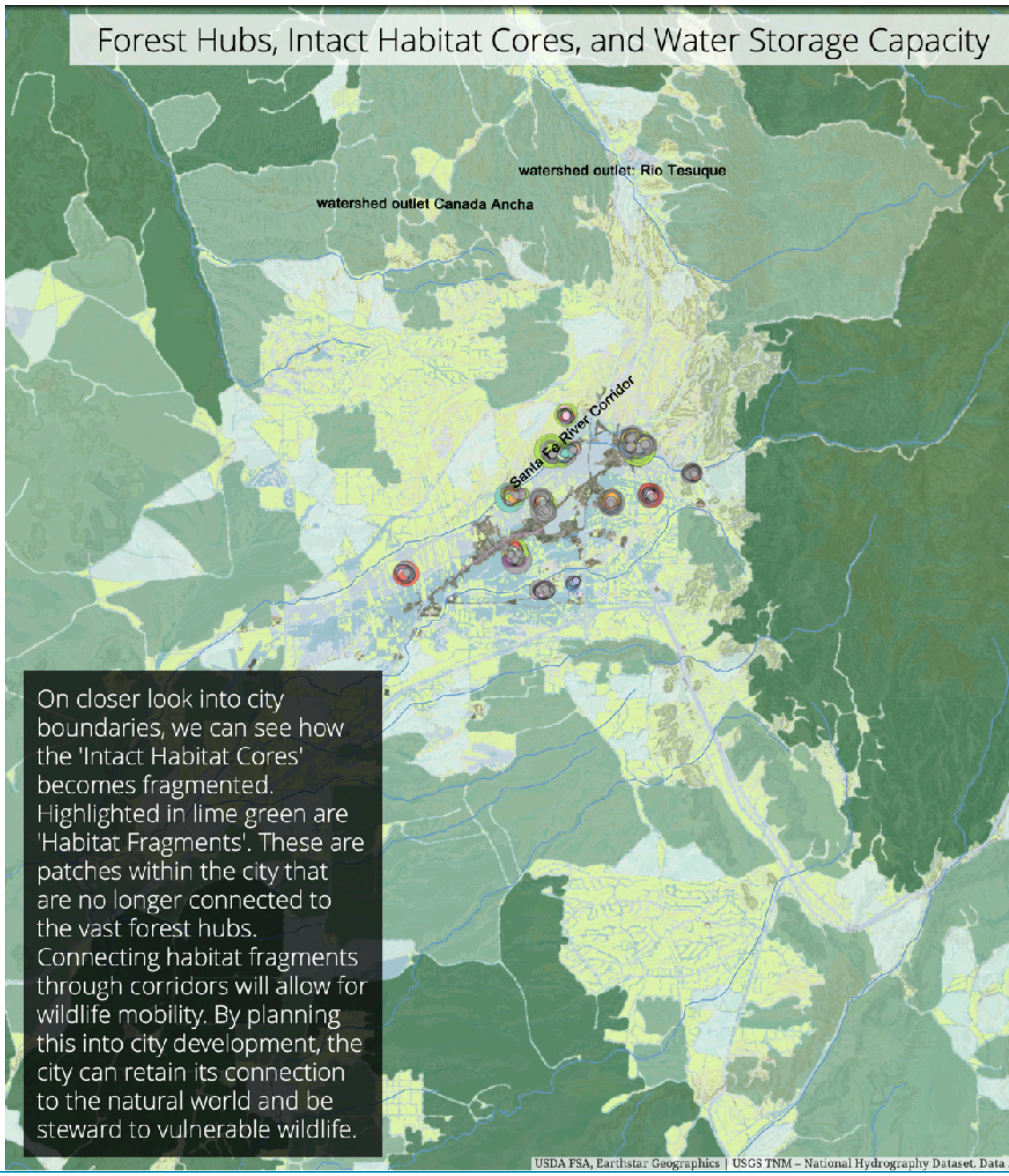


Photo credit: A. Beshur, 2019. Developed through ESRI ArcGIS Online (2019).

This southern *Intact Habitat Core* aids in capturing stormwater coming from impervious urban surfaces, captures and dissipates it across the permeable grasslands. Development quickly encroaches this southern core, as illustrated on the StoryMap[12] "Introduction to Urban Forestry Design Concepts using Tree Inventory Geo-Referencing for Santa Fe, NM," which is available on the Seeds of Wisdom, LLC website, all three of these hubs are fragmenting. Fragmentation occurs as edges to core areas become etched. Forest edges next to development do not support species which would otherwise populate the site. Species which require buffers are forced further into the forest, reducing their resource availability and nesting sites, as well as creating competition for familial territories. Planning is needed to protect hubs from fragmentation for ecosystem benefits, rainfall potential, as well as habitat range.

To view the story map "Introduction to Urban Forestry Design Concepts using Tree Inventory Geo-Referencing for Santa Fe, NM," please visit:

https://sowsfe.com/place-based-geo-referencing/

[12] Available at: https://arcg.is/1uOLHD

Size Matters

Retaining the wholeness of an open space is essential to the ecosystem. Related to wind and precipitation dynamics, large intact parcels of land maintain the water cycle, and "without large forest expanses, the intensity of the water cycle diminishes, reducing water availability" (Ellison 2012). Large intact parcels allow stormwater to infiltrate into the soil, which supports aquifer recharging. Trees grow to their full capacity, provided with the expanse for root development, developed soil food web, and mycorrhizal connectivity between specimens.

Size matters when offering refuge to habitat. Even a small 18-inch Abert's Squirrel (*Sciurus aberti*) requires 5-22 acres habitat range (Marks 2014). Indeed, a multitude of diversity exists within the forests and open spaces surrounding Santa Fe. Bears, mountain lions, elk, fox, deer, coyotes, squirrels, skunks, raccoons, and a plethora of migratory and endemic bird species each needs its own range, and requirements to support wildlife becomes a staggering concept. It is however a necessary one for the integrity of place as well as safety of residents. Developing safe corridors between midsize patches and retaining intact large hubs will allow larger wildlife to access water sources and find safe ground during wildfire. This directional component to the landscape could direct them away from the urban center. Smaller animals begin to have locations for dens, and birds are free to build nests as their species prefers, chirping delightful music at sunset.

Santa Fe exists at a crossroads between western forests, arid lands and grasslands. These have seen decreases in bird populations by 30%, 18% and over 50% respectively, with the latter loosing "717 million birds...decimated by modern agriculture and development" (Zimmer 2019). Grassland populations are indicated in the southern habitat core described previously and visually represented on the ArcGIS StoryMap. Fragmentation influences population decline because it reduces the ability of an individual from reaching food or a nest site. Species which require inner forests for survival are forced out of previously viable sites. Competition of resources reduces diversity of species and compaction influences incidence of malnutrition and disease. Coupled with drought effects, it becomes understandable why more animals are descending into the urban center seeking sources of food or water or simply fulfilling their natural extent of territory. They need room to run, forage, find safety, and populate. As Marc-André Villard and Jean Paul Metzger (2014) direct, "Reducing habitat loss should be a top priority for conservation planners. However, researchers should also investigate the indirect impacts of habitat loss on biodiversity through fragmentation effects" because "One large and continuous habitat will support more species and individuals than an equal area divided into smaller, isolated patches" (Spirn 1984, 218).

For "the closer restored populations are to intact habitats and populations, the greater the opportunity for dispersal leading to colonization and persistence" (Maschinski 2006, 75). The

United States Geological Society (USGS) has mapped migratory and range patterns for over 2,000 species of animals. Of these, 410 species from Santa Fe County are represented. These data, which are available through their National Biogeographic Map[13], could become instruments to improve connectivity and defragmentation efforts for local animals. In a review of bird species with habitat range along Tano Road utilizing the USGS Map System, 87 species showed seasonal or endemic representation, including the Juniper titmouse (*Baeolophus ridgwayi*) which requires large juniper branches for cavity nesting. These birds are consumers of insects, and as such create balance to forest pest infestations. Their habitat has become confined to patches in only 9 southwestern states, most of which are in New Mexico and Utah. Retaining large snags, or dead standing trees, in the landscape will continue to support this species' livability even if the large tree dies. In the urban environment, standing dead trees are often removed, either for aesthetics or for safety concerns. Perception of aesthetics changes as value becomes evident. For safety, Dr. Brenda McComb (2016, 191) offers the option: "If a tree has died and it is within 30 feet of a sidewalk, then topping the tree at 15-feet high would provide a short snag that could then be used by woodpeckers and secondary cavity nesters without significant risk to people or property". Traditionally, Santa Feans welcome wildlife, especially birds, and providing safe snags within the city limits may increase opportunities for cavity nesting.

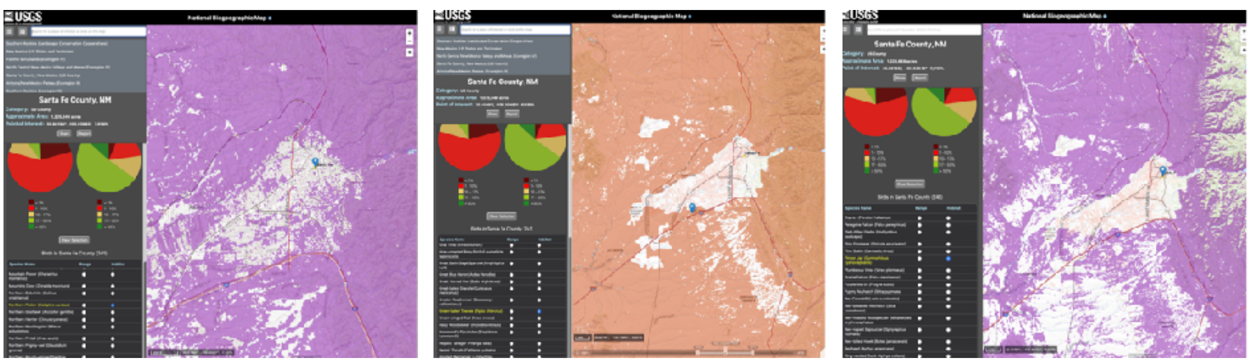


Photo credit: A. Beshur, 2019. Data from USGS (2019).

Examples of predicted bird habitat skirting around the city, from USGS Maps (2019)

Appendix B charts birds predicted to live in and surrounding Santa Fe. Columns represents predicted habitat in the City of Santa Fe, the immediately surrounding county, directional patching, seasons and particular considerations. North, south, east, west, near water all relate to general landscape distinctions, including forest hubs, grasslands, cooler summers, warmer winters, water availability, and size of hub.

The city landscape influences habitat as well. Of 144 bird species, 81 have a negative habitat pattern with the city (USGS 2019). This is equivalent to 56% of types of birds go around the city instead of within it. The urban influence on their environment is evident due to sound

[13] Available at: https://maps.usgs.gov/biogeography

and light pollution. It is also due to the overwhelming fragmentation that occurs, and the edges created, which prevent many species from having access to resources. These resources include food, water, nesting sites and shelter. Each family of birds may require a range of its own, so expanse of habitat becomes multiple in order to avoid bottlenecking genetic traits.

Plant selection, snag retention, and design details help provide *stepping stones* to the larger habitat areas with core centers. Designating wide hubs within the City will provide buffer between the urban disturbance. This is vital "for species that are particularly edge-sensitive" (McComb 2016, 204).

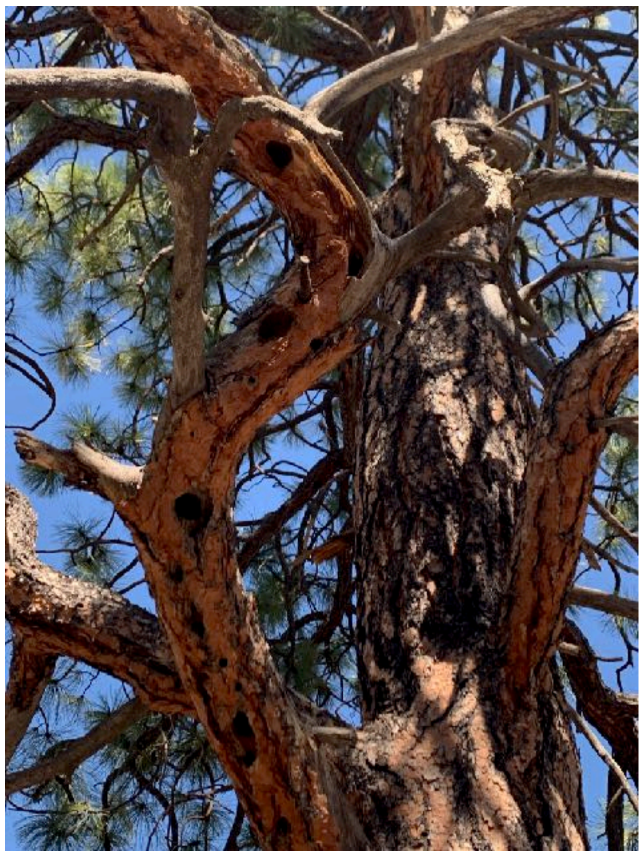


Photo credit: A. Beshur, 2019

Evidence of cavity nesters in large Ponderosa

Hubs and Habitats

Native vegetation plays an important role in habitat, as it offers variability of food sources, shelter, accessibility and visibility specific to species at particular times in their lifecycle. In restoring habitat hubs and retaining integrity within them, managing for native vegetation will provide the most valuable food sources. As Doug Tallamy (2013) explains, "From the perspective of maintaining food webs…we need to add the right plants because all plants are not equal in their ability to support food webs." In his remarkable study comparing diversity of caterpillars on native and invasive trees, he found that native species had "five times more species of caterpillars in the uninvaded hedgerows and twenty-two times more caterpillars themselves." Of the species he researched, the most caterpillar friendly ones which also grow in Santa Fe, in sequential order, include: *Quercus*, *Prunus*, *Salix*, *Populus*, *Malus*, *Acer*, *Ulmus*, *Pinus*, *Crataegus*, *Rubus* and *Picea* (Tallamy 2013).

Where habitats have declined and soils depleted, landscapes become populated with invasive species. These not only interrupt the habitat value, but they begin to affect water dynamics and sometimes prevent natives from repopulating the site by competitive root formation and seed dispersal. This in turn can "change rates of resource turnover, nutrient distribution, food-web structure, and disturbance regimes can shift competitive rankings and affect the dynamics and structure of a degraded system" (Suding 2006, 199). Ultimately, this leads to a reduction in resources for native animals. When "As of 2004, 1,265 species of animals and plants in the United States were listed as threatened or endangered by the U.S. Fish and Wildlife Service" (Hellmund 2006), restorative measures ought to be seen as paramount for improving population dynamics. Where invasives have a widespread foothold on a site, restoration methodology should follow a strategic path of reducing invasive presence, replanting with natives, and then

Photo credit: A. Beshur, 2019

once these have gained prominence, remove the invasives. This method has shown success along the Santa Fe river corridor, where Siberian elms (*Ulmus pumila)* certainly offer a majority of shade for the river, pedestrians, and wildlife. Gradually these have been removed, especially where they were in canopy conflict with Rio Grande Cottonwoods (*Populus deltoides wislizeni).* Over time, more can be reduced, replaced and then removed.

Fragmentation occurs when the city is isolated from its surrounding native landscapes. While gardens exist, they become substituted with plants that do not provide the needed resources that wildlife requires. An enormous quantity of native species are becoming available to local gardeners, as Jack Carter has cohesively outlines in his books *Trees and Shrubs of New Mexico* (2012) and *Common Southwestern Native Plants* (2018). By including succession of native species, especially trees and shrubs, the city can reduce fragmentation, smooth forest edges, and offer habitat within the city boundaries. Selections and placements transform into value, use, and longevity as well as beauty and personal aesthetics.

To see a sample of predicted bird habitat maps, please visit:

https://sowsfe.com/hubs-and-habitat/

Biotic Heterogeneity

Urban gardens are often much smaller than their rural counterparts, and they cannot, and should not, represent a collection of individual species. Not only would it aesthetically feel incongruent, messy and overwhelming, it would not be conducive to providing a viable food source for animals. However, some variation in color, size, shape and species is necessary. The difference between oak species make for a good example for variability of species within a genera. The Southwest is fortunate to have both red oaks (such as *Quercus buckleyi* and *Quercus shumardii*) and white oaks (such as *Quercus macrocarpa, Quercus gambelii,* and *Quercus 'undulata'*). Red Oak "acorns mature in fall after [the] second growing season [and] sprout in [the] following spring" (Sibley 2009, 180), whereas White Oak "acorns mature in fall after one growing season [and] sprout mainly in fall" (Sibley 2009, 180). Because Santa Fe winters can dip to -20° F, springs can be dry and windy, and autumns inconsistent, having two species which aesthetically are consistent that offer habitat variation will provide alternatives should one season not be conducive to sprout growth for foragers or acorn development for gatherers. Gambel Oaks (*Quercus gambelii*) also offer an alternative food source for animals whose primary foods are seeds from the Pine family (*Pinus ponderosa*, *Pinus edulis*, *Pinus flexilis*, and *Pinus strobiformis*), such as the Abert's squirrel (*Sciurus aberti*), who's southern range extent is the Ponderosa pine forest bordering Old Santa Fe Trail near Barbaria Road. Seeds of Wisdom, LLC has treated 14 acres of a 19 acre parcel in these foothills. The project involved fire defensible space with a focus on animal habitat security, soil erosion control and sapling planting. Since the project's first year, sitings of this tassel-eared squirrel have tripled.

Photo credit: A. Beshur 2019

"Forest structure also has an impact on different ecosystem services. Species diversity, diversity within a species, age and size diversity are all necessary for urban ecosystem adaptability - an adaptable ecosystem is resistant and resilient to disturbance" (Konijnendijk 2018, 192). Diversity extends to vertical heterogeneity as well. Providing over story trees combined with mid-story shrubs within a design "is important for many species of birds and mammals that either nest in the shrubs, use shrubs for cover, or eat the fruit, leaves, or twigs of the plants" (McComb 2016, 192). In the sensitive and unpredictable future ahead, having resilience through redundancy and variability will help protect, feed and shelter wildlife.

Photo credit: P. Ryan 2019, taken with a Bushnell wildlife camera

Abert's Squirrel under a Ponderosa tree

Landscape height and width variety also helps hold moisture through shading of water sources, soil, and plant leaves. Utilizing a synergistic approach with multiple heights and densities, the overall effect "is efficient at conserving site water because sunlight energy is spread over a vertically spread, relative large but widely distributed crown surface area which has some self-shading" (Coder 2012).

Pedestrian Movement

The purpose of Alameda Rain Garden at Cathedral Place design is three-fold: stormwater, trees, and people. With widened crosswalks and bus stops, as well as sitting rocks, pedestrians feel comfortable walking, sitting, and waiting to cross the street or for the bus. By creating opportunities for pedestrian and bicycle movement, the pedestrian culture is reawakened. As Frederick Law Olmstead wrote, "It should be a ground which invites, encourages & facilitates movement, its topographical conditions such as make movement a pleasure; such as offer inducements in variety, on one side and the other, for easy movement, first by one promise of pleasure then by another, yet all of a simple character" (Beveridge 2015).

A good example of ease of movement and passing is evidenced by the 10-foot wide pathway along the newer section of the river corridor, where two bicycles can easily and safely pass one another without stopping. Increasing safety for recreation allows for multiple use for ecological corridors. As Paul Hellmund and Daniel Smith explain in their book *Designing Greenways* (2006), "To evaluate landscape integrity is to consider the overall quality or health of the landscape, including ecological and social functions. It includes the health of plants and animals, and other qualities embodied in the term *ecological integrity*, as well as social functions related to economic, recreational, and aesthetic resources, improving the quality of social and civic interactions, and ensuring equitable access to public spaces and the benefits, both economic and intangible, they offer".

Enjoyment of open space translates into feelings of tranquility, " 'freedom and space', 'forest feeling', and peace and quietness'" (Konijnendijk 2018, 93), as well as providing an opportunity to allow the mind to wander. This mind wandering has been shown to increase creativity through attention restoration by "facilitating new associations between previously unconnected ideas" (Williams K. 2018). In a city where the main industry is artistic pursuits, enhancing creativity restoration opportunities will become evidenced in citizen's sense of purpose and self-fulfillment. This could translate into tax benefits for the City as well. Additionally, healthy citizens leads to decreases in disease spending. Specifically, a "10% increase in forest cover leads to $80 decrease in health spending per person" (Browning 2017). With 84,612 city residents (U.S. Census 2018), this amounts to an additional $6.77 million, much of which would be spent at the local level.

Cumulative Design Theory and Recommendations

Landscape design is unique in that it is creative, involves living things, grows and changes over time, and interacts with other things, people and animals who enter into it. Urban Forestry design builds on the principals of landscape design with a focus on ecological principles, trees and shrubs, and wildlife. Southwestern urban forestry design includes concepts such as drought resilience, stormwater use and cultural connectivity. Here is a summation of some essential components necessary in designing in the southwest.

- Connect to surrounding landscapes, corridors, and build hubs,
- "Keep nature near where people live, no matter how urban the area" (Hellmund, 2006),
- Equitable distribution of green space for livability and stepping stones throughout city,
- Connect with natural and cultural resources,
- Grey and green infrastructure designed in unison for mutual benefit,
- Plan for animal habitat,
- Make decisions based on current conditions, future predictions of growth, size, shade, water and use,
- Diversify plants across species, size and distribution for decreased fragmentation,
- Utilize slope to direct water,
- Water trees in the evening,
- Make water holding and soil erosion structures provide redundancy,
- Build soil food webs,
- Give trees room to grow,
- Cut curbs,
- Absorb water,
- Select the right tree for the right place,
- Design for trees to grow,
- Develop place out of open space.

Urban Forestry Recommendations for Santa Fe, NM

Urban forestry initiatives are required within the framework of public planning and private construction. By incorporating an urban forestry designer onto the teams that are molding the future of the city, the urban forester can bring forward the needs of trees and wildlife into design plans as well as architectural standards. The urban forest incorporates all trees within the urban and surrounding space, and large scale construction ought to unify green infrastructure with the grey infrastructure to make best use of both.

Forest hubs need linkages a minimum of 1,100 feet wide to guide large animals safely around the city to access water sources, follow historic and climate driven migration patterns, and find protection during wildfire. Buffering fragmentation of forest edges will improve conditions for inner-forest habitants. Creating stepping stones of pocket parks and corridors throughout the city will improve bird habitat, which in turn will reduce tree pests. Large scale hub designation will offer inner city sanctuary. In this way, smaller animals can live safely within the growing city. These hubs are not manicured parks, but rather open natural spaces that will additionally provide the permeable surface for stormwater infiltration.

Because wind most often comes between the mountain ranges from the southwest, Santa Fe is uniquely positioned to plant trees which will provide moisture up-wind and into the city. This rainfall could then provide soil moisture which will continue this cycle by supporting tree growth down-stream. Growing green space within the southern portion of the city additionally addresses the needs of citizens who would like to create a sense of place along the Airport Road corridor (Lewin 2019). This includes having 10-foot sidewalks for passing pedestrians on trails off of the main road which connect larger open spaces. Utilizing green infrastructure protocol will help grow the urban canopy. This canopy and these corridors will develop a place for community connection and culture creation.

Santa Fe needs to plant hundreds of trees per year, guide stormwater to these and existing trees and provide standards to allow for trees to have 1,500 cubic feet of non-compacted soil for root growth. Mulch and compost need to be utilized to build soil food webs and hold moisture within soil. These are available and are desperately needed in every park that has been inventoried. Curb cuts allow water to enter permeable medians and open spaces.

Visioning for a future livability incorporates the needs of citizens and animal life. New urbanism is one that unifies with the native environment, incorporates local based plant selections and provides refuge for plants and animals under threat from the unpredictable future climate. It is one that safeguards precious water resources and values trees as suppliers of inland moisture.

Conclusion

This paper examines factors essential to southwestern urban forestry design, specifically for Santa Fe, NM. It incorporates transpiration benefit of trees, and the value of retaining and restoring the southern part of the city as it relates to wind patterns and the use of wind to enhance the City's use of transpiration. By analyzing 1,800 trees through the Santa Fe Public Spaces Tree Inventory, effects of climate change are beginning to become more visible in the park system. Simple green infrastructure designs provide trees with greater access to stormwater as a primary resource for tree growth. Value of trees are examined for their importance to wildlife and a shared need for livability. The Southwest landscape offers a unique connection to the surrounding environment and affords residents a sense of place within their community. As Cecil Konijnendijk (2018, 217) expresses, "It is very important for people's well-being and quality of life to have a shared sense of place at the local level."

By focusing on the real value that landscapes provide, they can grow and exceed the expectations of those who planted them. Landscapes create places, build culture, and connect those who rely on them. It is not a connection for a season or for a year. It is a connection that spans generations. By connecting the city to the forest, "City forests are city as well as forest, marketplace, as well as privacy reserve, place as well as space. On the one hand they are 'anti-urban' space (Dings and Munk 2006), yet on the other hand, they are a necessary and integral element of urban life." (Konijnendijk 2018, 222). This is possible in the semi-arid climate utilizing green infrastructure as a component to maximize water efficiency and grow more. It is a misnomer to accept that the lungs of the earth are in a far away continent where conditions make easy tree growth. The lungs of the earth begin here and now, and become what a city makes of them. The new urbanism is one that connects with the landscape around it, in benefit for citizens and wildlife. It recognizes the value that diversity of plants and habitants provide. These make livability beautiful, adaptable, and smart. These create a culture of place.

This paper is available electronically at:

https://sowsfe.com/product/place-based-metrics-guiding-southwest-urban-forestry-design/

Appendix A: Santa Fe City Tree Inventory Species 2019

The below list represents trees analyzed through i-Tree (2019a, 2019b) from data provided by the Santa Fe Public Spaces Tree Inventory project, a volunteer collaboration between the Municipal Tree Board and the Santa Fe Extension Master Gardeners. It includes data from 2016- 2019, with weather station data from 2016. The list is a culmination of several data points provided through analysis relating to tree species diversity and condition, as well as place based metrics: avoided runoff, transpiration, and structural value. The 1,791 trees represent a structural value of $3.47 million with 11,600 feet^3 per year of avoided stormwater runoff. These trees transpire 336,343 feet^3 per year, with a potential evapotranspiration reaching 887,912 feet^3 per year. These data highlight the supply-side of inland precipitation potential.

Santa Fe City Tree Species					A. Beshur (i-Tree 2019a, 2019b)	
Species	Number of Trees	Percentage of Total Species	Average Condition	Avoided Runoff ft^3/yr	Transpiration ft^3/yr	Structural Value
Abies concolor	34	1.9%	81%	373	10,820	102760
Acer	4		86%	16	449	1703
Acer negundo	12		71%	102	2,958	18723
Acer platanoides	7		83%	20	578	2589
Acer pseudoplatanus	1		83%	2	66	197
Acer saccharinum	2		38%	4	110	689
Acer saccharum	1		63%	4	106	547
Aesculus hippocastanum	3		69%	45	1,301	13094
Ailanthus altissima	3		76%	10	292	1364
Catalpa	2		63%	2	67	386
Catalpa speciosa	2		83%	9	228	1838
Celtis occidentalis	54	3.0%	70%	222	6,422	41272
Celtis reticulata	5		79%	23	680	3266
Cercis canadensis	16		78%	37	1,085	7141
Cercis canadensis v. texensis	7		83%	19	556	3694
Chilopsis linearis	1		63%	5	148	971

Santa Fe City Tree Species				A. Beshur (i-Tree 2019a, 2019b)		
Species	Number of Trees	Percentage of Total Species	Average Condition	Avoided Runoff ft³/yr	Transpiration ft³/yr	Structural Value
Cotinus coggygria	1		83%	1	27	669
Crataegus	58	3.2%	74%	66	1,902	39698
Elaeagnus angustifolia	68	3.8%	70%	184	5,341	81144
Forestiera neomexicana	13		75%	52	1,494	10425
Fraxinus	21	1.2%	76%	130	3,773	47912
Fraxinus americana	11		80%	89	2,590	17194
Fraxinus pennsylvanica	144	8.0%	76%	1,221	35,412	279869
Fraxinus velutina	2		83%	39	1,141	17280
Gleditsia triacanthos	83	4.6%	74%	256	7,407	138230
Gymnocladus dioicus	10		79%	14	404	1554
Juniperus	7		83%	12	339	2188
Juniperus monosperma	153	8.5%	68%	1,021	29,594	309204
Juniperus scopulorum	30	1.7%	72%	264	7,665	82789
Koelreuteria paniculata	19	1.2%	83%	87	2,526	47347
Malus	101	5.6%	73%	410	11,898	116488
Malus domestica	2		89%	4	121	776
Picea engelmannii	3		69%	32	917	6975
Picea glauca	1		38%	3	80	1271
Picea mariana	1		95%	8	236	1685
Picea pungens	21	1.2%	73%	175	5,072	62422
Pinus	3		95%	6	180	2446
Pinus edulis	69	3.9%	72%	186	5,379	66227
Pinus flexilis	12		78%	35	1,012	12645
Pinus heldreichii	2		63%	5	132	1717
Pinus mugo	2		83%	13	373	4527
Pinus nigra	111	6.2%	79%	550	15,959	257006
Pinus ponderosa	53	3.0%	77%	416	12,064	180269

Santa Fe City Tree Species				A. Beshur (i-Tree 2019a, 2019b)		
Species	Number of Trees	Percentage of Total Species	Average Condition	Avoided Runoff ft³/yr	Transpiration ft³/yr	Structural Value
Pinus strobiformis	9		85%	22	627	7751
Pinus sylvestris	4		63%	7	212	2752
Pistacia chinensis	1		83%	1	20	218
Platanus x acerifolia	48	2.7%	81%	265	7,686	38206
Populus	7		83%	117	3,393	42861
Populus alba	1		95%	0	7	55
Populus deltoides wislizeni	83	4.6%	73%	1,323	38,354	384613
Populus fremontii	15		79%	169	4,905	56652
Populus nigra	2		38%	6	177	1717
Populus tremuloides	25	1.4%	55%	17	502	17628
Populus x acuminata	9		79%	75	2,175	29464
Prunus	4		73%	12	348	2751
Prunus armeniaca	9		79%	55	1,599	15626
Prunus cerasifera	4		56%	13	376	2919
Prunus virginiana	10		85%	13	380	2469
Pseudtsuga menziesii	17	0.1%	80%	282	8,177	74195
Pyrus	8		70%	22	640	8050
Pyrus calleryana	25	1.4%	85%	94	2,722	31418
Quercus	1		83%	2	69	685
Quercus buckleyi	5		86%	10	284	2564
Quercus gambelii	7		81%	9	253	2016
Quercus macrocarpa	2		83%	3	85	733
Quercus shumardii	1		83%	2	50	442
Robinia	2		60%	2	50	295
Robinia neomexicana	21	1.2%	75%	84	2,434	16430
Robinia pseudoacacia	39	2.2%	62%	109	3,148	19781
Salix matsudana			38%	1	18	200

Santa Fe City Tree Species					A. Beshur (i-Tree 2019a, 2019b)	
Species	Number of Trees	Percentage of Total Species	Average Condition	Avoided Runoff ft³/yr	Transpiration ft³/yr	Structural Value
Sequoiadendron giganteum	1		95%	28	807	23853
Sorbus americana	7		77%	21	595	5294
Thuja	1		38%	1	37	1230
Thuja occidentalis	1		63%	6	163	2656
Tilia americana	3		83%	67	1,939	22325
Tilia cordata	21	1.2%	72%	65	1,870	15854
Ulmus	54	3.0%	80%	185	5,362	29583
Ulmus americana	31	1.7%	59%	613	17,760	144925
Ulmus davidiana	13		75%	65	1,879	10848
Ulmus parvifolia	8		85%	27	785	4946
Ulmus pumila	133	7.4%	62%	1,637	47,450	453853
Zelkova serrata	3		69%	3	99	763
TOTALS (may include rounding deviation)	**1,790**	**0.84**	**0.75**	**11,605**	**336,341**	**3,468,812**

To receive a copy of the 2019 Tree Inventory chart, please visit:

https://sowsfe.com/product/2019-santa-fe-tree-inventory-list/

Appendix B: Santa Fe City Predicted Bird Habitat 2019

The below list represents birds identified through the United States Geological Survey mapping system (2019) as having 'predicted habitat' in or around Santa Fe, NM. Included are predicted habitat patterns deduced from per species map analysis, available from: maps.usgs.gov/biogeography.

Of the 144 species, 81 of these have a negative habitat pattern with the city, which is equivalent to 56% of the species indicated. The table also illustrates the patterns evident in their habitat, which could become pivotal in plant selection, snag retention, and design details which help provide *stepping stones* to the larger habitat areas with core centers. Designating wide spaces within the City will provide buffer between the urban disturbance. This is vital "for species that are particularly edge-sensitive" (McComb 2016, 204).

Santa Fe City Bird Species					A. Beshur (USGS 2019)
Common Name (Genus species)	**City Predicted Habitat**	**City Patch**	**County**	**Season**	**Special consideration**
Acorn Woodpecker (Melanerpes formicivorus)	city	yes	no	all	
American Crow (Corvus brachyrhynchos)	city	no	yes	all	
American Goldfinch (Carduelis tristis)	1/3 patch	yes	yes	winter	
American Kestrel (Falco sparverius)	1/2 patch	south	yes	all	
American Robin (Turdus migratorius)	1/2 surrounding	no	yes	all	
American Tree Sparrow (Spizella arborea)	1/4 patch	yes	yes	Winter	
Aplomado Falcon (Falco femoralis)	1/8 patch	south	patch	All	
Ash-throated Flycatcher (Myiarchus cinerascens)	1/2 patch	yes	yes	summer	

Santa Fe City Bird Species					A. Beshur (USGS 2019)
Common Name (Genus species)	**City Predicted Habitat**	**City Patch**	**County**	**Season**	**Special consideration**
Band-tailed Pigeon (Patagioenas fasciata)	1/2 surrounding	no	yes	Summer	
Bank Swallow (Riparia riparia)	Water only	no	patch	Summer	
Barn Owl (Tyto alba)	yes	no	south	all	
Barn Swallow (Hirundo rustica)	yes	no	yes	summer	
Belted Kingfisher (Megaceryle alcyon)	Water only	no	patch	Winter	
Bewick's Wren (Thryomanes bewickii)	no	no	yes	all	Skirts around city
Black Rosy-finch (Leucosticte atrata)	1/4 patch	yes	yes	winter	Skirts around city
Black-billed Magpie (Pica hudsonia)	yes	no	patch	all	
Black-capped Chickadee (Poecile atricapillus)	no	no	north	All	
Black-chinned Hummingbird (Archilochus alexandri)	1/2 patch	yes	patch	summer	
Black-headed Grosbeak (Pheucticus melanocephalus)	1/4 patch	yes	yes	Summer	
Black-throated Gray Warbler (Dendroica nigrescens)	no	no	north	summer	Skirts around city
Black-throated Sparrow (Amphispiza bilineata)	no	no	yes, all except east	summer	Skirts around city
Blue Grosbeak (Passerina caerulea)	no	no	yes, all except east	summer	Skirts around city
Blue Jay (Cyanocitta cristata)	1/4 patch	yes	north	all	

Santa Fe City Bird Species					A. Beshur (USGS 2019)
Common Name (Genus species)	**City Predicted Habitat**	**City Patch**	**County**	**Season**	**Special consideration**
Blue-gray Gnatcatcher (Polioptila caerulea)	no	no	yes, all except high altitude	summer	
Brewer's Blackbird (Euphagus cyanocephalus)	yes	all	north	Winter	
Brown Creeper (Certhia americana)	no	no	yes, all except south	all	
Brown-capped Rosy-finch (Leucosticte australis)	1/2 patch	yes	patch	Winter	
Brown-headed Cowbird (Molothrus ater)	no	no	yes	summer	Skirts around city
Bullock's Oriole (Icterus bullockii)	1/2 patch	yes	no	summer	
Burrowing Owl (Athene cunicularia)	1/2 patch	yes	South & west	Summer	
Bushtit (Psaltriparus minimus)	no	no	yes, all except patch south	all	Skirts around city
Canada Goose (Branta canadensis)	1/2 patch	yes	Patch south and west	all	
Canyon Towhee (Pipilo fuscus)	1/8 patch	yes	yes	all	Skirts around city
Canyon Wren (Catherpes mexicanus)	no	no	Patch north	all	Skirts around city
Cassin's Finch (Carpodacus cassinii)	no	no	yes, esp. north	winter	Skirts around city
Cassin's Kingbird (Tyrannus vociferans)	no	no	yes, esp. north and east	summer	Skirts around city

Santa Fe City Bird Species					A. Beshur (USGS 2019)
Common Name (Genus species)	**City Predicted Habitat**	**City Patch**	**County**	**Season**	**Special consideration**
Cassin's Sparrow (Aimophila cassinii)	no	no	yes, esp. south and west	summer	Skirts around city
Cedar Waxwing (Bombycilla cedrorum)	1/2 patch	south	yes	Winter	Skirts around St. Francis Drive
Chestnut-collared Longspur (Calcarius ornatus)	no	South corner	Patch south and west	winter	
Chipping Sparrow (Spizella passerina)	1/2 patch	surrou nding	yes, esp. north and east	summer	Skirts around city
Clark's Nutcracker (Nucifraga columbiana)	no	no	yes, esp. north and east	All	Skirts around city
Cliff Swallow (Petrochelidon pyrrhonota)	1/2 patch	southw est	South & west	summer	
Common Grackle (Quiscalus quiscula)	city	no	patch	Summer	
Common Nighthawk (Chordeiles minor)	city	no	yes	Summer	
Common Poorwill (Phalaenoptilus nuttallii)	no	no	Patch esp. north	summer	Skirts around city
Common Raven (Corvus corax)	city	no	yes	all	
Common Yellowthroat (Geothlypis trichas)	no	no	Yes, except south	summer	Skirts around city
Cooper's Hawk (Accipiter cooperii)	yes	no	yes	All	
Dark-eyed Junco (Junco hyemalis)	1/2 patch	yes	yes	All	Somewhat skirts around city

Santa Fe City Bird Species					A. Beshur (USGS 2019)
Common Name (Genus species)	**City Predicted Habitat**	**City Patch**	**County**	**Season**	**Special consideration**
Downy Woodpecker (Picoides pubescens)	1/4 patch	yes	Yes, except south	All	Somewhat skirts St. Francis Drive
Dusky Flycatcher (Empidonax oberholseri)	no	southwest	Yes, except south	summer	Skirts around city
Eurasian Collared-dove (Streptopelia decaocto)	yes	no	Yes, except south	all	
European Starling (Sturnus vulgaris)	yes	no	Patch	All	
Evening Grosbeak (Coccothraustes vespertinus)	no	no	yes, esp. north and east	All	
Ferruginous Hawk (Buteo regalis)	no	no	South & west	all	
Flammulated Owl (Otus flammeolus)	no	no	yes, esp. north and east	Summer	
Golden Eagle (Aquila chrysaetos)	no	no	yes	All south, winter north	Skirts around city
Golden-crowned Kinglet (Regulus satrapa)	1/4 patch	yes	yes, esp. north and east	winter	Skirts around St. Francis Drive
Grace's Warbler (Dendroica graciae)	no	no	yes, esp. north and east	summer	Skirts around city
Gray Flycatcher (Empidonax wrightii)	no	no	yes, esp. north and east	Summer	Skirts around city
Gray Vireo (Vireo vicinior)	no	no	patch	summer	Skirts around city

Santa Fe City Bird Species					A. Beshur (USGS 2019)
Common Name (Genus species)	**City Predicted Habitat**	**City Patch**	**County**	**Season**	**Special consideration**
Gray-crowned Rosy-finch (Leucosticte tephrocotis)	1/3 patch	yes	no	Winter	
Great Blue Heron (Ardea herodias)	1/8 patch	yes	patch	summer	
Great Horned Owl (Bubo virginianus)	1/8 patch	yes	yes	All	Skirts around city
Great-tailed Grackle (Quiscalus mexicanus)	yes	no	yes, esp. north	All	
Green-tailed Towhee (Pipilo chlorurus)	no	no	Yes	Summer	Skirts around city
Hairy Woodpecker (Picoides villosus)	1/2 patch	yes	east	all	
Hepatic Tanager (Piranga flava)	no	no	yes, esp. north and east	Summer	Skirts around city
Hermit Thrush (Catharus guttatus)	no	no	yes, esp. north and east	Summer	Skirts around city
Horned Lark (Eremophila alpestris)	no	no	Patch south and west	all	Skirts around city
House Finch (Carpodacus mexicanus)	yes	yes	yes	all	
House Sparrow (Passer domesticus)	yes	no	no	All	city only
House Wren (Troglodytes aedon)	no	no	yes	summer	Skirts around city
Juniper Titmouse (Baeolophus ridgwayi)	no	no	yes	All	Skirts around city
Ladder-backed Woodpecker (Picoides scalaris)	no	no	yes	all	Skirts around city

Santa Fe City Bird Species					A. Beshur (USGS 2019)
Common Name (Genus species)	**City Predicted Habitat**	**City Patch**	**County**	**Season**	**Special consideration**
Lapland Longspur (Calcarius lapponicus)	1/2 patch	yes	no	Winter	city only
Lark Sparrow (Chondestes grammacus)	no	no	yes	summer	Skirts around city
Lazuli Bunting (Passerina amoena)	no	no	east	summer	Skirts around city
Lesser Goldfinch (Carduelis psaltria)	1/2 patch	yes	yes, esp. north and east	Summer	
Loggerhead Shrike (Lanius ludovicianus)	1/8 patch	yes	yes, except east	all	skirts around city
Long-eared Owl (Asio otus)	no	no	southwes t	all	skirts around city
Merlin (Falco columbarius)	1/3 patch	yes	yes	winter	skirts around city
Mississippi Kite (Ictinia mississippiensis)	1/2 patch	yes	yes	summer	
Mountain Bluebird (Sialia currucoides)	1/4 patch	yes	yes	all	skirts around city
Mountain Chickadee (Poecile gambeli)	no	no	yes, esp. north and east	all	Skirts around city
Mountain Plover (Charadrius montanus)	no	no	Patch south and west	summer	Skirts around city
Mourning Dove (Zenaida macroura)	1/2 patch	yes	yes	all	skirts around city
Northern Flicker (Colaptes auratus)	1/2 patch	yes	yes, esp. north and east	all	skirts around city

Santa Fe City Bird Species					A. Beshur (USGS 2019)
Common Name (Genus species)	**City Predicted Habitat**	**City Patch**	**County**	**Season**	**Special consideration**
Northern Goshawk (Accipiter gentilis)	no	no	yes, esp. north and east	winter	Skirts around city
Northern Harrier (Circus cyaneus)	no	no	Patch south and west	all	skirts around city
Northern Mockingbird (Mimus polyglottos)	no	no	yes, all except high altitude	all	skirts around city
Northern Pintail (Anas acuta)	no	no	Patch south and west	Summer	
Northern Pygmy-owl (Glaucidium gnoma)	no	no	yes, esp. north and east	All	Skirts around city
Northern Rough-winged Swallow (Stelgidopteryx serripennis)	1/3 patch	yes	yes	summer	
Northern Shrike (Lanius excubitor)	1/4 patch	yes	yes	Winter	Skirts around city
Olive-sided Flycatcher (Contopus cooperi)	no	no	yes, esp. north and east	Summer	Skirts around city
Peregrine Falcon (Falco peregrinus)	Yes	yes	yes	all	
Pine Grosbeak (Pinicola enucleator)	no	no	yes	all	skirts around city
Pine Siskin (Carduelis pinus)	1/2 patch	yes	yes	Winter	Skirts around St. Francis Drive
Pinyon Jay (Gymnorhinus cyanocephalus)	no	no	yes	all	Skirts around city

Santa Fe City Bird Species					A. Beshur (USGS 2019)
Common Name (Genus species)	**City Predicted Habitat**	**City Patch**	**County**	**Season**	**Special consideration**
Plumbeous Vireo (Vireo plumbeus)	no	no	yes, esp. north and east	summer	Skirts around city
Prairie Falcon (Falco mexicanus)	no	no	patch	all	Skirts around city
Purple Martin (Progne subis)	1/4 patch	yes	Patch east	summer	
Pygmy Nuthatch (Sitta pygmaea)	no	no	yes, esp. north and east	all	Skirts around city
Red Crossbill (Loxia curvirostra)	1/4 patch	yes	yes, esp. north and east	All	Skirts around St. Francis Drive
Red-breasted Nuthatch (Sitta canadensis)	1/2 patch	winter only	yes, esp. north and east	All	skirts around city
Red-tailed Hawk (Buteo jamaicensis)	yes	no	yes	all	
Rock Pigeon (Columba livia)	yes	no	no	all	city only
Rock Wren (Salpinctes obsoletus)	no	no	yes	all	skirts around city
Ross's Goose (Chen rossii)	no	no	patch south	winter	
Rough-legged Hawk (Buteo lagopus)	no	no	patch south	winter	Skirts around city
Ruby-crowned Kinglet (Regulus calendula)	1/2 patch	yes	yes, esp. north and east	all	Skirts around St. Francis Drive
Sage Thrasher (Oreoscoptes montanus)	no	no	yes, except east	summer	Skirts around city
Say's Phoebe (Sayornis saya)	1/2 patch	yes	yes, except east	summer	patched seasonally

Santa Fe City Bird Species					A. Beshur (USGS 2019)
Common Name (Genus species)	**City Predicted Habitat**	**City Patch**	**County**	**Season**	**Special consideration**
Scaled Quail (Callipepla squamata)	no	no	Patch south and west	all	Skirts around city
Sharp-shinned Hawk (Accipiter striatus)	no	no	yes	all	skirts around city
Short-eared Owl (Asio flammeus)	no	no	Patch south and west	Winter	skirts around city
Snow Bunting (Plectrophenax nivalis)	1/3 patch	yes	Patch south and west	Winter	Skirts around St. Francis Drive
Song Sparrow (Melospiza melodia)	1/2 patch	yes	patch	all	mainly city
Spotted Towhee (Pipilo maculatus)	1/2 patch	yes	Patch esp. north	all	Skirts around St. Francis Drive
Steller's Jay (Cyanocitta stelleri)	no	no	yes, esp. north and east	all	Skirts around city
Swainson's Hawk (Buteo swainsoni)	1/4 patch	yes	yes, except patch east	summer	Skirts around city
Townsend's Solitaire (Myadestes townsendi)	no	no	Seasonal patching	Summer east, winter west	skirts around city
Turkey Vulture (Cathartes aura)	1/3 patch	yes	yes	summer	skirts around city
Violet-green Swallow (Tachycineta thalassina)	1/2 patch	yes	yes	summer	Skirts around St. Francis Drive
Virginia's Warbler (Vermivora virginiae)	no	no	yes, esp. north and east	summer	Skirts around city

Santa Fe City Bird Species					A. Beshur (USGS 2019)
Common Name (Genus species)	**City Predicted Habitat**	**City Patch**	**County**	**Season**	**Special consideration**
Western Bluebird (Sialia mexicana)	no	no	yes	all	skirts around city
Western Kingbird (Tyrannus verticalis)	yes	no	yes, except east	Summer	
Western Meadowlark (Sturnella neglecta)	no	no	Patch south and west	all	skirts around city
Western Screech-owl (Megascops kennicottii)	Water only	yes	Patch	All	
Western Scrub-jay (Aphelocoma californica)	yes	no	yes, all except south	all	
Western Tanager (Piranga ludoviciana)	no	no	Yes east, patch south	Summer	Skirts around city
Western Wood-pewee (Contopus sordidulus)	1/2 patch	yes	yes, all except south	Summer	
White-breasted Nuthatch (Sitta carolinensis)	no	no	yes, esp. north and east	all	Skirts around city
White-crowned Sparrow (Zonotrichia leucophrys)	1/2 patch	yes	yes, esp. north and east	Winter	Skirts around St. Francis Drive
White-throated Swift (Aeronautes saxatalis)	yes	no	Patch	summer	
White-winged Dove (Zenaida asiatica)	1/2 patch	yes	patch	winter	Mainly city
Wild Turkey (Meleagris gallopavo)	no	no	yes, esp. mountain s	all	Skirts around city

Santa Fe City Bird Species					A. Beshur (USGS 2019)
Common Name (Genus species)	**City Predicted Habitat**	**City Patch**	**County**	**Season**	**Special consideration**
Williamson's Sapsucker (Sphyrapicus thyroideus)	no	no	yes	all	Skirts around city
Wilson's Snipe (Gallinago delicata)	no	no	patch in south	winter	Skirts around city
Yellow-breasted Chat (Icteria virens)	no	no	patch south and north	summer	skirts around city

To receive a copy of the Santa Fe City Bird Species chart, please visit:

https://sowsfe.com/product/birds-around-santa-fe-2019/

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