LANDSCAPE PERFORMANCE SERIES
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Houston Arboretum and Nature Center, Phase 1
Methods

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This investigation was conducted as part of the Landscape Architecture Foundation's 2022 *Case Study Investigation* (CSI) program. CSI matches faculty-student research teams with design practitioners to document the benefits of exemplary high-performing landscape projects. Teams develop methods to quantify environmental, social, and economic benefits and produce Case Study Briefs for LAF's *Landscape Performance Series*.

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The full case study can be found at: https://landscapeperformance.org/case-study-briefs/houston-arboretum

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Acknowledgements

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Environmental Benefits

- ***Reduces average annual runoff within 1 mile of the site by an estimated 7% (580 acre-ft) as compared to a scenario where the site was instead developed in a similar way to the surrounding area.***

- ***Reduces chemical pollutants by an estimated 13% (498,104 lbs), bacterial pollutants by 16% (553,728 million coliforms), and overall pollutant load by 14% as compared to a scenario where the site was instead developed in a similar way to the surrounding area.***

Background:
The HANC is a major park in Houston and is centrally located within the city. It is composed of approximately 1,423 acres of park/open space land uses across the A, C, and D hydrologic soil groups, as shown in Table 1. A's generally have the smallest runoff potential and D's the greatest. The HANC is valued highly for the environmental and recreational assets that it provides the City of Houston and holds various amenities such as tennis courts, playing fields, a fitness center, and a swimming pool in addition to mountain and recreational bike trails along the bayou. Because of the HANC's presence, the park area is protected from being converted into other land uses and developed upon; this allows for a decrease in volume and depth of runoff along with various chemicals, compounds, and bacterial pollutants.

Table 1: Area of the different hydrological soil groups present within HANC

Soil Groups	Area (Acres)
A (Sand, loamy sand or sandy loam types of soils)	2.10
B (Silt loam or loam)	0.00
C (Sandy clay loam)	304.88
D (Clay loam, silty clay loam, sandy clay, silty clay or clay)	1,116.31
Sum	1,423.29

Method:
The Long-Term Hydrologic Impact Analysis (L-THIA) model, created by Purdue University, was applied to quantify the benefits of Houston Arboretum and Nature Center as well as the impact of its absence (in a hypothetical scenario) to its surrounding context within the City of Houston, TX. To do this, the current land use and soils data within a 1-mile buffer of the continuous of Memorial Park (Houston Arboretum and Nature Center (HANC) and adjacent Memorial Park) were collected and assessed to create a land use change scenario. The city developed the HANC within Memorial Park to provide nature education as well as an urban wildlife sanctuary. Therefore, it is reasonable to include Memorial Park in the analysis of HANC. Surrounding land use patterns/ratios and soils for the area currently occupied by the HANC, although they do not exist in real time, were projected onto the HANC site. A scenario was then developed where the HANC area developed proportionally to the land uses around the 1-mile buffer of the HANC which was compared to the actual existing land uses. To start, the land use and soil group data within the one-mile buffer area of the continuous HANC were collected and assigned categories based on the L-THIA model's necessary input categories of land use.

<u>Land Use Data and Buffer Creation</u>
Land use data at the parcel level was collected from the Houston-Galveston Area Council. From the regional parcel data, the continuous HANC parcels were extracted to form a one-mile buffer of the

surrounding area through ArcGIS Pro 2.9.1's Buffer Analysis Tool. The buffer zone layer was then closed off around the parcels so that areas that did not have parcel polygons, such as the river or major highways, were able to be calculated. On a separate layer, the parcels that comprised the entire HANC area were extracted from the regional parcel data (See Figure 1)

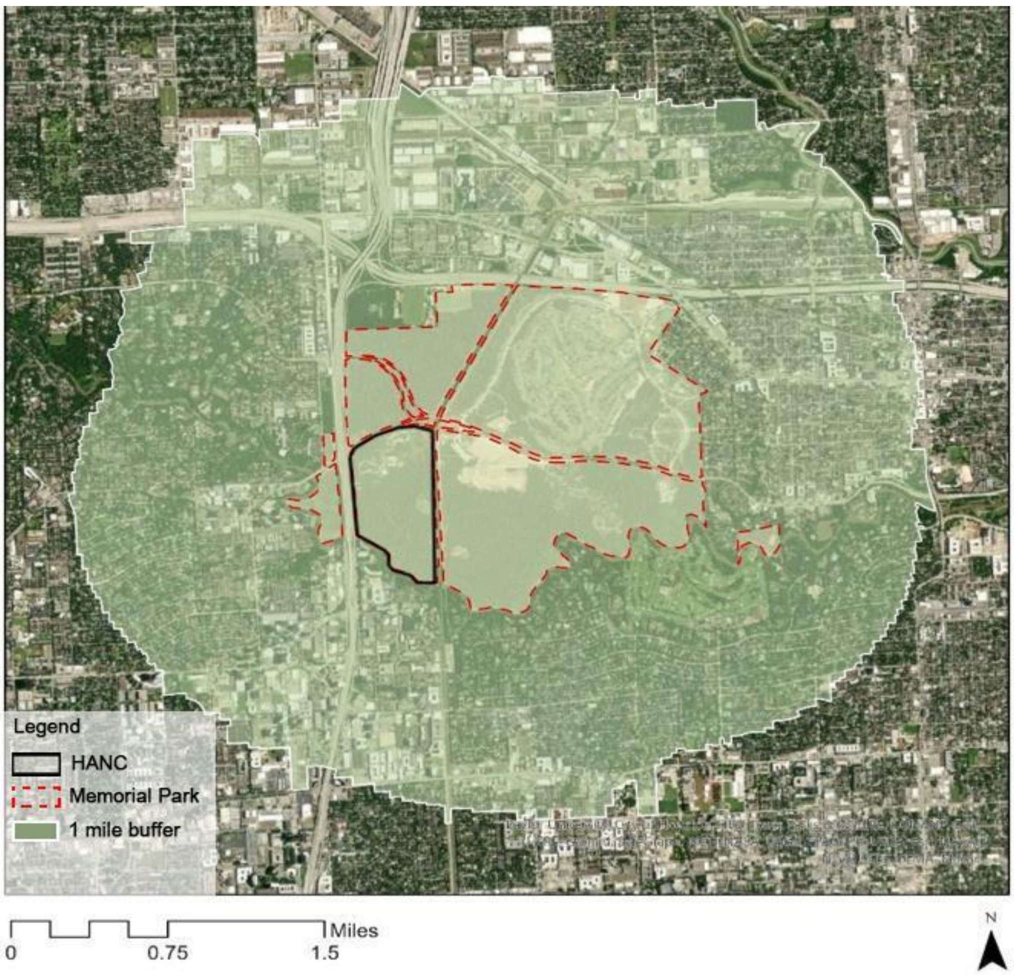

Figure 1: Image of the one-mile buffer zone around continuous the HANC

Some Google Map imagery is not up to date, which can impact the current accuracy of land use designation, especially for the parcels that fall under the "Parcel Dependent" category. Also, not all of the aerial photos or street views were clear, which caused some uncertainty in assigning some of the L-THIA land uses. Because of this, best guesses had to be made based on the surrounding context in some of the land uses. Reclassification of some land uses was necessary due to the limited range of available land uses in the L-THIA tool.

<u>Reclassifications of Parcel Land Uses to L-THIA model Land Use Categories</u>

Parcel land uses collected from the Houston-Galveston Area Council is much more detailed than L-THIA model land use categories. It was necessary to reclassify parcel land uses to match L-THIA model land uses to complete the calculations (see Table 2).

Table 2: Reclassifications of parcel land uses to L-THIA model land use categories

L-THIA Land Use	Parcel Land Use
Commercial	Retail
	Office
	Restaurants
	Hotel
	Recreational
	Government
	Educational
Industrial	Warehouse
	Industrial
High Density Residential	Multi-Family
	Group Quarters
Low Density Residential	Single-Family
	Condo
Grass/Pasture	Parks/Open Space
Water/Wetlands	Water/Wetlands
Parcel Dependent	Other
	Undevelopable
	Unknown
	Vacant Developable (includes Farming)

<u>Soil Survey Data Breakdown</u>

Data for the different hydrologic soil groups were collected from the U.S. Department of Agriculture's Web Soil Survey. For the current land use, the one-mile buffer zone around the HANC was set as the Area of Interest (AOI) for the Web Soil Survey. The area of the land use was divided based on the subdivisions within the map units, soils, and hydrologic soil group. For example, the map unit VauA has two soil types within it, Vamont and Urban Land. Vamont is composed of two different hydrologic soil groups, C and D, while Urban Land only contains one, D. When calculating the acres of each soil group for the Commercial land use which is 76.4 acres of this map unit, the process would proceed as Vamont: ¼ factor of C (19.10 acres) and ¼ factor of D (19.10 acres) while the Urban Land would be ½ of the Commercial land use (38.20 acres). This results in 19.10 acres of Soil Group C and 57.3 acres of Soil Group D. These calculations were performed for each map unit and land use. The area for each soil group was then totaled.

Calculations:

<u>Current and Land Use Change Scenario Calculations</u>

While the current land use scenario is calculated based on real time data, as noted, in the scenario projected without the HANC, it was assumed that the HANC's area and context's land uses would develop proportionality to the surrounding area's land use categories. This entails the proportional distribution of the hydrological soil groups as well. For example, the one-mile buffer area is composed of approximately 2,418 acres or 30.64% of Commercial as its current land use. The scenario assumption would implicate that, if there was no HANC, the park's land would follow commercial development percentage. As HANC makes up roughly 1,423 acres or 18% of the buffer zone with only Grass/Pasture, this would mean that the Commercial land use increased to about 2,854 acres or 36.17% of the area, in the no HANC scenario.

The same assumption pattern for the land use changes was made for the hydrological soil group types: the area for each soil group type (A, B, C, and D) of the HANC is distribution proportionally to the other land uses based on current land uses. For example, while the buffer zone is formed of approximately 2,418 acres or 30.64% Commercial as its current land use, only 0.21% of the Commercial land use area accounts for Soil Group A, which is 20.05% of the entire Soil Group A. As the HANC is roughly 2.10 acres or 0.15% of land for Soil Group A, this means that Soil Group A Commercial would increase to about 5.45 acres or 0.23% of the area in the no HANC scenario.

<u>Results Summary of L-THIA Model</u>

The L-THIA model reports are broken into three parts: land use changes, runoff results, and nonpoint source pollutant results. The first section of results, shown in Table 3, indicate that all land use categories increased in their area except for the Grass/Pasture land use which decreased by almost half its area between the current land use and the land use change scenario.

Table 3: Description of land use changes in acres and percentages for each category

Land Use	**Current (acres)**	**Scenario (acres)**	**Overall Land Use Change (%)**
Commercial	2,418.31	2,804.64	15.98%
Industrial	487.64	560.54	14.95%
High Density Residential	248.52	289.07	16.31%
Low Density Residential	2,690.59	3,108.97	15.55%
Water/Wetlands	64.01	75.36	17.73%
Grass/Pasture	1,983.00	1,053.50	-46.87%

The second section, runoff results, describes the different runoff amounts for the current land use and land use change scenario. As the total average annual runoff volume and the average annual runoff depth are related to each other, the percent changes in the calculations for the two cases are nearly identical with the total average annual runoff volume increasing by 7.28% and the average annual runoff depth raised by 7.27% after the land use change. Also, the average annual rainfall depth by land use holds the same overall amount of 35.57 inches.

Table 4: Quantity of runoff and percent change between the current and scenario

Category	**Overall**	**Current**	**Scenario**	**Percent Change (%)**
Total Avg. Annual Runoff Volume (acre-ft)	N/A	7,968.86	8,548.68	7.28% (579.82 acre-ft)
Avg. Annual Runoff Depth (in)	N/A	12.11	12.99	7.27%
Avg. Annual Rainfall Depth by Land Use (in)	35.57			N/A

The nonpoint source pollutant results, the final section of the results, display two groups of pollutant types and their total amount present within the model, the chemical and compounds group and the bacterial group, shown in Table 5. Within each group, the pollutant categories are ranked based on the highest percent change between the current and scenario land use change.

For the chemicals and compounds groups, the categories that had the greatest amount of change between the current and scenario case were oil and grease at 15.83%, with COD being a close second at 15.79%. The third, fourth, and fifth-ranked categories entail a .01% difference each: nickel at 15.51%, suspended solids at 15.50%, and BOD at 15.49%. **The group's overall percent change between the current and scenario case was 15.62%**, which differed from the average percent change between all the group's pollutants categories.

As for the bacterial group, the fecal strep ranked first with a percent change of 15.64% and fecal coliform as second with a percent change of 15.43% between the two cases. The group's overall percent change of 15.58 was .05% greater than the group's average percent change of 15.53%

Table 5: Ranking for the percent change between the current and scenario of nonpoint source pollutants for the chemicals and compounds group and the bacterial group along with the average percent change for each group

	Rank	**Category**	**Current**	**Scenario**	**Percent Change (%)**	**Avg. Percent Change (%)**
Chemicals and Compounds	1	Total Oil & Grease (lbs)	112,084.56	129,825.61	15.83%	**13.01%**
	2	Total COD (Chemical oxygen demand) (lbs)	1,634,248.00	1,892,218.00	15.79%	
	3	Total Nickel (lbs)	202.86	234.33	15.51%	
	4	Total Suspended Solids (lbs)	966,203.39	1,116,000.27	15.50%	
	5	Total BOD (biochemical oxygen demand) (lbs)	435,173.11	502,602.05	15.49%	
	6	Total Phosphorous (lbs)	7,594.04	8,764.05	15.41%	
	7	Total Zinc (lbs)	2,884.40	3,326.42	15.32%	
	8	Total Lead (lbs)	233.83	263.26	12.58%	
	9	Total Nitrogen (lbs)	30,205.88	33,662.84	11.44%	
	10	Total Copper (lbs)	264.87	289.30	9.22%	
	11	Total Chromium (lbs)	149.33	161.44	8.11%	
	12	Total Cadmium (lbs)	20.17	21.36	5.91%	
		Overall (lbs)	3,189,264.44	3,687,368.91	15.62%	N/A
Bacterial	1	Total Fecal Strep (millions of coliform)	2,554,656.00	2,954,082.00	15.64%	**15.53%**
	2	Total Fecal Coliform (millions of coliform)	999,805.36	1,154,107.24	15.43%	
		Overall (millions of coliform)	3,554,461.36	4,108,189.24	15.58%	N/A

Sources:

HGAC. 2022. "Land Use & Land Cover Data | Houston-Galveston Area Council (H-GAC)." 2022. https://www.h-gac.com/land-use-and-land-cover-data.

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Limitations:

- Some Google Map imagery is not up-to-date which can impact the current accuracy of land use designation, especially for the parcels that fall under the "Parcel Dependent" category. Also, not all of the aerial photos or street views were clear, which caused some uncertainty in assigning some of the L-THIA land uses.
- We estimated the land-use composition of the HANC just based on the land-use composition 1 mile from HANC. The complex process of urbanization, including social, economic, ecological, and policy aspects, is hard to include in our estimation.

- ***Reduces overall metal-based pollutant load from parking lot runoff by 16% as compared to pollutant reductions achieved by more conventional green infrastructure at a comparable parking lot.***

Background:

The multiple types and systematic linkage of green infrastructure at the HANC are expected to reduce the pollutant load in the runoff compared to normal large-scale traditional parking lots that typically drain into one outlet.

Method:

This approach tests whether the stormwater infrastructure (specifically the rain gardens, ponds, impervious surface parking materials, riparian zones, and retention areas) at the HANC are performing better than other, more traditional, single-use green infrastructure approaches in traditional parking lots.

To do this, we do not compare the HANC site's condition before and after construction due to data availability limitations, but rather compare the HANC's stormwater runoff quality to a comparable, more traditional large-scale parking lot which drains into a simple bioswale at Texas A&M University. To test the performance of the HANC in purifying the runoff and water flowing from the adjacent road infrastructure and parking lots, the water quality of the stormwater runoff inside the pond in the HANC northern parking lot was tested. The test results were compared to the water quality from a samples bioswale/raingarden adjacent to a conventional parking lot in College Station, TX (See Figure 1).

After collecting the water samples in the pond in the HANC north parking lot on April 23rd, 2022, the sample was transferred to the Texas A&M AgriLife Extension Service Soil, Water and Forage Testing Laboratory for pollutant testing. The contaminants were tested through ICP, which is inductively coupled plasma, titration, ion-selective electrode, cadmium reduction, conductivity, and calculation by the Soil Testing Lab Texas A&M AgriLife Extension Service. Calcium (Ca), Sodium (Na), Potassium (K), Boron (B), Sulfate (SO4-calculated from total S), Phosphorus (P), Iron (Fe), Zinc (Zn), Copper (Cu), Manganese (Mn), Arsenic (As), Barium (Ba), Nickel (Ni), Cadmium (Cd), Lead (Pb), Chromium (Cr), and Fluoride (F) were tested by inductively coupled plasma (ICP). Carbonate (CO3), Bicarbonate (HCO3), and Chloride (Cl-) were tested by titration. The pH value was tested by ion-selective electrode. Nitrate-N (NO3-N) was tested by cadmium reduction. Hardness, Alkalinity, Total Dissolved Salts (TDS), sodium adsorption ratio (SAR), and Charge Balance (cation/anion*100) are tested through calculation.

Then, the data from the HANC sampling sites were compared to a baseline scenario sampled from the parking lot runoff at Texas A&M. These samples were taken from a rain garden which gathers runoff from a conventional parking lot in West Campus. The baseline scenario, which is a rain garden adjacent to a campus parking lot, is 3.59 acres in area. Due to the landform of the parking lot, about 50% of the runoff flows into the curb-cut and is treated by the rain garden during a typical rain event. Thus, the treated parking lot area of 1.8 acres is similar in size to the northern parking lot of the HANC, which is 1.72 acres. The similarity in area is the primary reason we are able to compare the performance of the HANC parking lot design with the conventional parking lot in Texas A&M University west campus. The HANC green infrastructure improvements include pervious parking material, riparian areas, detention ponds, filter strips, and a series of vegetated areas designed to slow, spread, and convey the stormwater runoff. Conversely, the TAMU parking lot drains directly into a bioswale, with relatively no green infrastructure treatment.

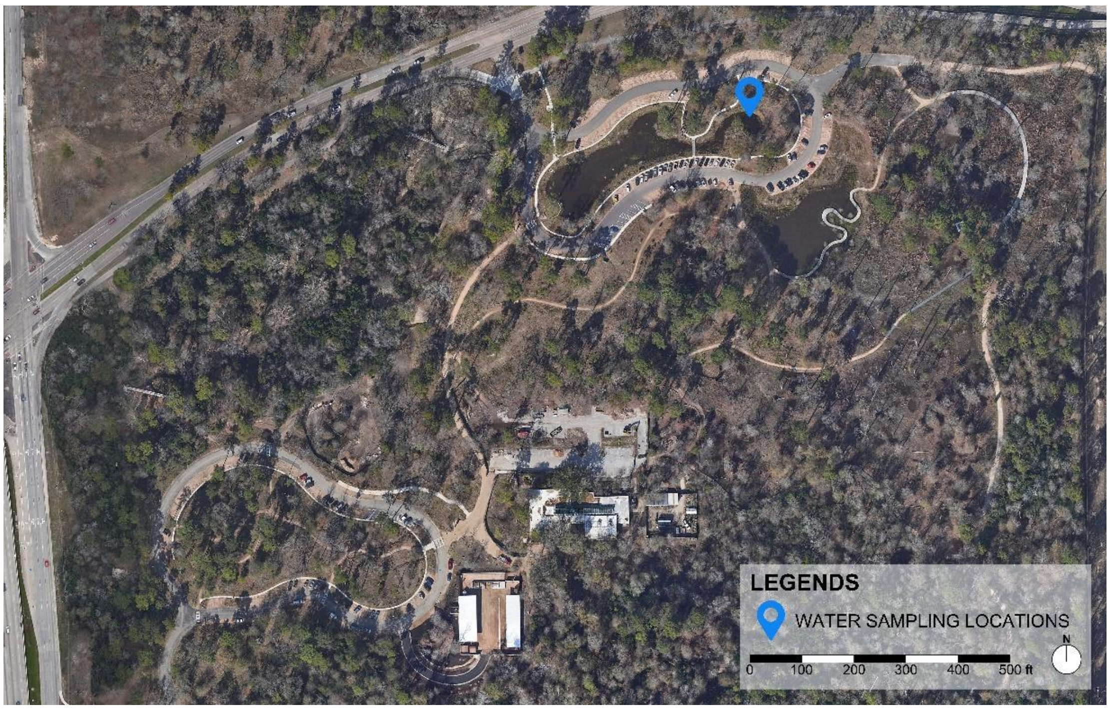

Figure 1. Sampling Location Map at the HANC

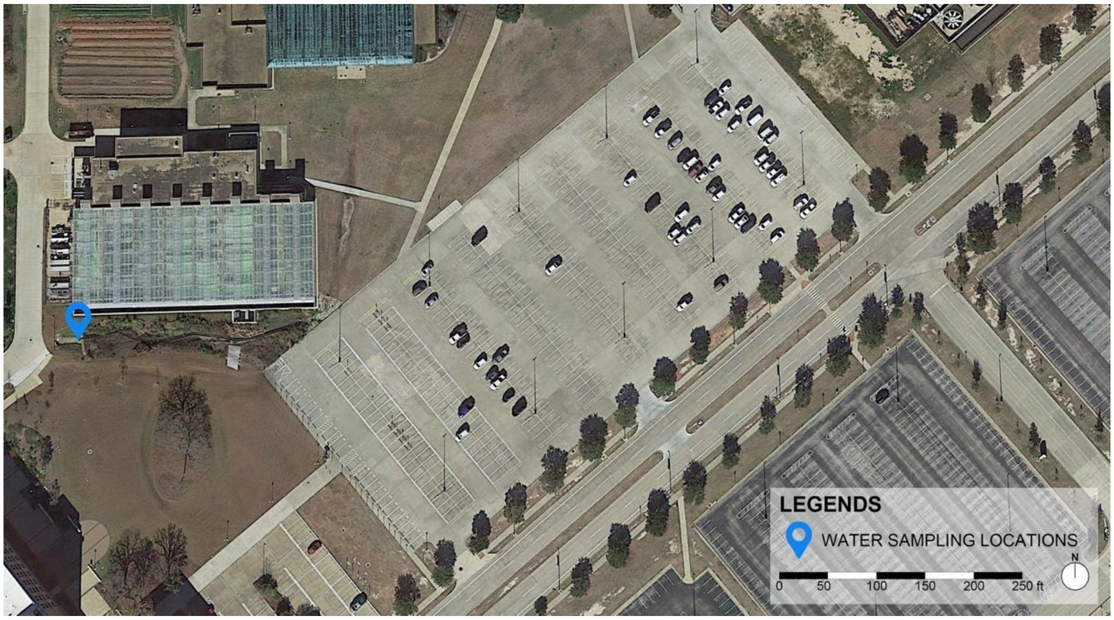

Figure 2. Conventional Raingarden Water Sampling Site in Texas A&M University

Calculations:
From the test results from the Texas A&M AgriLife Extension Service Soil, Water and Forage Testing Laboratory, all contaminants in the samples from the HANC were rated acceptable (Table 1 shows all sample results), which suggests that the water should not pose any long-term problems for irrigation or reuse. The sample collected in the pond in the HANC parking lot had 7.35% lower contaminants on average than the TAMU parking lot, showing 15.63% less metal-based contaminants, and 2.6% less other contaminants than the TAMU parking lot (See Table 1).

Table 1. TAMU conventional parking lot water sample testing results compared the HANC Parking lot.

Parameter Analyzed	Units	Method	TAMU Parking Lot	HANC Parking Lot	Comparison
Calcium (Ca)	ppm	ICP	24.667	53.000	114.86%
Magnesium (Mg)	ppm	ICP	4.000	5.000	25.00%
Sodium (Na)	ppm	ICP	62.000	25.000	-59.68%
Potassium (K)	ppm	ICP	4.000	3.000	-25.00%
Boron (B)	ppm	ICP	0.103	0.060	-41.94%
Carbonate (CO3)	ppm	Titr.	0.000	0.000	0.00%
Bicarbonate (HCO3)	ppm	Titr.	189.333	185.000	-2.29%
Sulfate (SO4-calculated from total S)	ppm	ICP	29.667	19.000	-35.96%
Chloride (Cl-)	ppm	Titr.	28.333	27.000	-4.71%
Nitrate-N (NO3-N)	ppm	Cd-red.	0.147	0.040	-72.73%
Phosphorus (P)	ppm	ICP	0.160	0.010	-93.75%
pH		ISE	6.860	7.090	3.35%
Conductivity	umhos/cm	Cond.	458.667	284.000	-38.08%
Hardness	grains CaCO3/gallon	Calc.	4.667	9.000	92.86%
Hardness	ppm CaCO3	Calc.	77.000	156.000	102.60%
Alkalinity	ppm CaCO3	Calc.	155.000	151.000	-2.58%
Total Dissolved Salts(TDS)	ppm	Calc.	342.000	317.000	-7.31%
Sodium Adsorption Ratio (SAR)		Calc.	2.700	0.900	-66.67%
Iron (Fe)	ppm	ICP	0.210	0.220	4.76%
Zinc (Zn)	ppm	ICP	0.060	0.020	-66.67%
Copper (Cu)	ppm	ICP	0.010	0.010	0.00%
Manganese (Mn)	ppm	ICP	0.060	0.010	-83.33%
Arsenic (As)	ppm	ICP	0.003	0.008	140.00%
Barium (Ba)	ppm	ICP	0.062	0.143	129.41%
Nickel (Ni)	ppm	ICP	0.004	0.004	-7.69%
Cadmium (Cd)	ppm	ICP	0.002	0.001	-40.00%
Lead (Pb)	ppm	ICP	0.003	0.008	140.00%
Chromium (Cr)	ppm	ICP	0.001	0.002	50.00%
Fluoride (F)	ppm	ICP	0.040	0.010	-75.00%
Charge Balance (cation/anion*100)		Calc.	89.667	103.000	14.87%
Avg. Metal-based Contaminants	**ppm**	**Calc.**	**6.947**	**5.861**	**-15.63%**
Avg. Other Contaminants	**ppm**	**Calc.**	**72.556**	**70.667**	**-2.60%**
Overall Avg. Contaminants	**ppm**	**Calc.**	**29.777**	**27.589**	**-7.35%**

Overall, the HANC parking lot pond contaminants are lower than the average from the conventional parking lot runoff at TAMU. Specifically, the HANC overall parking lot pond pollutant load is **15.63%** less than the TAMU parking lot site. For other contaminants, including the average of Carbonate (CO3), Bicarbonate (HCO3), and Chloride (Cl-), the HANC parking lot is 2.6% less compared to the TAMU average. The pH levels of both samples are quite similar. However, the HANC samples' hardness is significantly higher than the TAMU average. This could be caused by the excess amounts of both soil and mulch, which are significantly more in the context than the baseline scenario, brought by runoff into the water bodies at the HANC.

Among the results, there are multiple significantly lower levels of pollutants (more than 20%) in the water samples from the HANC compared to the TAMU samples. In the test results of the HANC parking lot pond, when compared to the TAMU sample, Sodium (Na) is 59.68% less, Potassium (K) is 25% less, Boron (B) is 41.94% less, Sulfate (SO4-calculated from total S) is 35.96% less, Nitrate-N (NO3-N) is 72.73% less, Phosphorus (P) is 93.75% less, sodium adsorption ratio (SAR) is 66.67% less, Zinc (Zn) is 66.67% less, Manganese (Mn) is 83.33 less, Cadmium (Cd) is 40% less, and Fluoride (F) is 75% less.

Meanwhile, a few contaminants in the HANC do show a higher level (more than 20%) than the TAMU site's average, including Calcium (Ca), Magnesium (Mg), Arsenic (As), Lead (Pb), Chromium (Cr).

The overall lower level of contaminants suggests that that there are fewer contaminants present in general that need mitigating at the HANC site. Thus, the use of the water sampled would need fewer treatments and have a less harmful impacts on local environment. More specifically, among the significantly fewer contaminants, less Potassium (K) may reduce potassium concentrations in forage grasses, and less Boron (B) could reduce potential risks to sensitive crops. In addition, less Sulfate (SO4-calculated from total S) would lessen the water's bitterness and medicinal taste, if reusing for drinking water. The decreases in Nitrate-N (NO3-N) can reduce environmental risks to pregnant women or infants, such as methemoglobinemia (e.g. blue-baby syndrome). Less Phosphorus (P) minimizes the occurrence of algal blooms and lower dissolved oxygen content, creating a better environment for aquatic life. A lower sodium adsorption ratio (SAR) level means that the water is more suitable for sensitive crops. More miniature Zinc (Zn) reduces unwanted taste in water and its chalky appearance. Less Manganese (Mn) also reduces taste problems and risks in staining plumbing fixtures and laundry. Finally, less Cadmium (Cd) reduces the chances of anemia and hypertension.

On the other hand, a higher level of some contaminants in the HANC, specifically, the aforementioned ones above, can also cause potential risks. Calcium (Ca) and Magnesium (Mg) can combine with bicarbonate and carbonates to increase extremely hard water and salinity. A high concentration of Arsenic (As) can eventually lead to harmful impacts on humans. High levels of Lead (Pb) can lead to brain damage in children. It should be noted that the Lead (Pb) level (0.008 ppm) of the parking lot pond is higher than the TAMU conventional parking lot but lower than the 0.015 ppm for the primary drinking water standard. Finally, Chromium (Cr) can be toxic to humans when numerous external exposures occur long-term. However, the Chromium (Cr) levels (0.04 ppm, 0.01 ppm, and 0.01 ppm) of the samples collected are far lower than the primary drinking water standard (0.1 ppm) as well.

Sources:
Water Samples Collected in the HANC Waterbodies

Water Samples Collected from Texas A&M University Lot 97

Water Testing in the Soil Testing Lab Texas A&M AgriLife Extension Service

Limitations:

- The TAMU parking lot is located on a university campus, which has less traffic than urban parking lots on average. Even though the treated parking areas are similar, the comparison results would underestimate the performance of the HANC landscape.
- Several contaminants show a higher level than the baseline average. Magnesium and Calcium are from dissolved rock, salts, and soil, which would be caused by more soil surface surrounding the sampling sites than in the conventional parking lot. Arsenic, Lead, and Chromium are mainly caused by industrial activities, which are much denser in the context of HANC than the Texas A&M campus. Overall, these higher levels of pollutants could be caused by significantly higher traffic in the adjacent area, more industrial activities in the context, and more soil and planting materials in the surrounding area, which leads to more pollutants carried by surface runoff to the waterbodies.

- ***Supports essential flood management for the City of Houston. If the site had been developed instead of being maintained as a green space, during the 2015 Memorial Day flood an additional 83,963 cu meters of water (approximately 34 Olympic-size swimming pools) would***

have run off into the Buffalo Bayou. Peak flow reduction within the HANC for the Memorial Day flood was 67%, and peak flow reduction for the 2016 Tax Day flood was 75%.

Method:

We calculated how much water is retained due to the presence of the HANC as opposed to if it were developed land. To calculate this, one must collect infiltration data in the field, create a Vflo model, run simulations of different storm scenarios, and analyze the results.

Infiltration measurements

The main tool used for this fieldwork was the SATURO Field Saturated Hydraulic Conductivity infiltrometer. This device automates most of the infiltration measurement process. The team carefully decided where to take measurements to maximize accuracy as well as reduce unnecessary testing. It was determined that the arboretum primarily consists of three different soil types. To gain an understanding of the infiltration rate of each type of soil, tests were selected for 2-3 different locations of each soil type. After a field visit and advice from the Conservation Director at the arboretum, the 8 locations shown in Figure 1 were definitively selected. The most important factor to take into consideration while planning infiltration field testing is to make sure that is didn’t rain any more than 1⁄2 inch in the 48 hours leading up to testing. Using the rain gauge located at “2245 Buffalo Bayou @ Woodway Drive” from the Harris County Flood Warning System website, this factor was checked every time testing was planned. Any day where there was rainfall greater than 1⁄2, testing was cancelled.

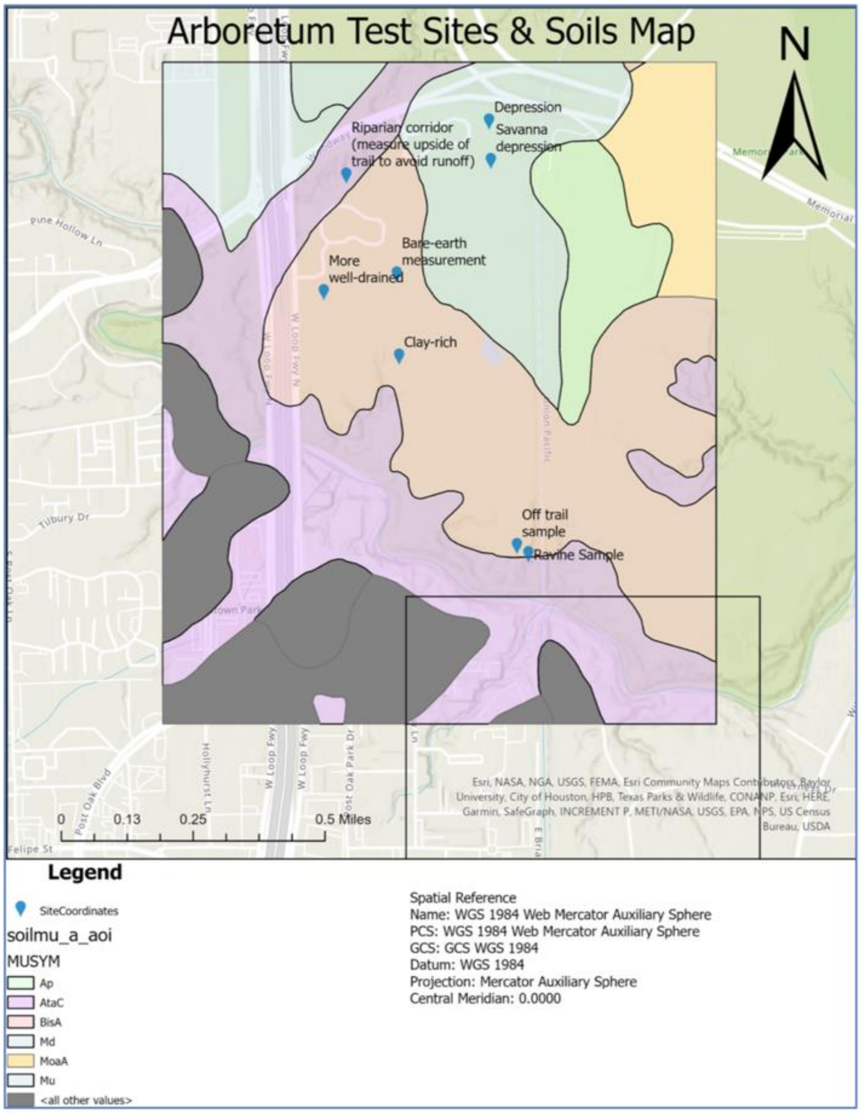

Figure 1: Arboretum Test Sites & Soils Map (Courtesy of True Furrh)

Vflo model

Vflo is a gridded, physics-based distributed hydrologic model. This tool simulates stormwater runoff based on geospatial data imported from GIS, including terrain, soils, and land use/land cover data. The model also requires gridded rainfall input, such as Gauge-Adjusted Radar Rainfall (GARR). GARR consists of gauge and radar input processed for bias correction, quality control, and filtered to user-specific grids, catchments, or basins in model-ready format. The runoff calculations involve a finite solution of the Kinematic Wave equations for overland cells and Modified Puls for the channel cells. The infiltration aspect of the model is calculated based on the Green and Ampt Equations. Finally, the model generates hydrographs at any location selected in the model and provides some other useful hydrologic outputs, such as average infiltration depth, which is critical for this project.

The outcome from this Vflo setup is two models. The first model is of the HANC itself (undeveloped) and the second model is of the HANC as if it were developed land. A developed section of Houston that was just west of the arboretum was used to define the developed scenario. This is slightly different from the developed scenario we defined in the L-THIA model above, where define the developed scenario as the HANC area developed proportionally to the land uses around the 1-mile buffer of the HANC. The purpose of using different ways to define the developed scenario is to allow later researchers to have multiple options when developing their own scenarios.

The AutoBOP feature on Vflo was used to create a flow grid of the domain, while other parameters were input as ASC files. Data from the 2018 Upper Coast LiDAR provided by the Texas Natural Resource Information System (TNRIS) was used to create a Digital Elevation Model (DEM) file of the Houston Arboretum. To choose the boundaries, it was imperative to include all the arboretum itself as well as any critical channels nearby. Therefore, the DEM file includes the arboretum and some of the surrounding area.

Since Vflo models best run when the number of cells is between 20,000 to 50,000, the cell size of the DEM file was modified to be 10m by 10m. This put the number of cells in the correct range. Another modification of the DEM file was to make some channel modifications. Within the site's boundaries, there is an overpass that runs over a tributary channel. That channel needed to be manually carved into the DEM, otherwise the flow grid would not be accurate. Additionally, there is a theoretical 99 m wall around the bounds of the arboretum. This allowed the model to run in a way that ignores some of the unnecessary areas around the arboretum, so that data could be obtained solely for the arboretum.

After creating the DEM file, it was then input into Vflo AutoBOP. The outputs from this Vflo AutoBOP step were used to clip the rest of the parameter maps. This is a critical step because Vflo is very finicky with maps that are not exactly the same as each other. Thus, it is imperative to check that every input map is the same size as the model and that every cell in the map is the same size.

For the GIS input parameter maps, the land use and land cover (LULC) data came from the Multi-Resolution Land Characteristics Consortium (MRLC) and the soil type and depth data came from the USDA's Natural Resource Conservation Service (NRCS). Using the LULC data, both roughness and percent impervious parameter maps were created. This was done by changing the cell size to be 10 m by 10 m, clipping the LULC data to match the DEM boundaries, and recreating the layer so that the attribute table was editable. Each land type was assigned specific Manning's roughness coefficients and percent impervious values. Additionally, the roughness map was corrected by ensuring that all channel cells had a roughness value of 0.04.

The same steps (other than the channel correction) were applied to the MRLC soil type data to obtain the capillary pressure, hydraulic conductivity, effective porosity, and soil depth input parameter maps. USDA soil series guide was utilized to classify all the soil types on the map and well as the soil depths. All soil depths had to be between 12 and 24 inches, so slight alterations were made to the soil depths if they were out of this range. Then, the Green-Ampt Infiltration paper was used to set the attribute table to the correct capillary pressure, hydraulic conductivity, and effective porosity values. Because we tested infiltration rate of all three soil types in the HANC, those hydraulic conductivity values were set to the value that we measured in the field.

At this point, all the parameter maps required to create the first undeveloped model were ready. After simply importing those parameter maps into the AutoBOP model, the rainfall data was uploaded. This model was run with rainfall data from the three worst flood events (Hurricane Harvey, the Tax Day flood, and the Memorial Day flood) in Houston over the past 10 years. Figure 2 shows an example of what the flow grid and the model cell selection look like when this model is run.

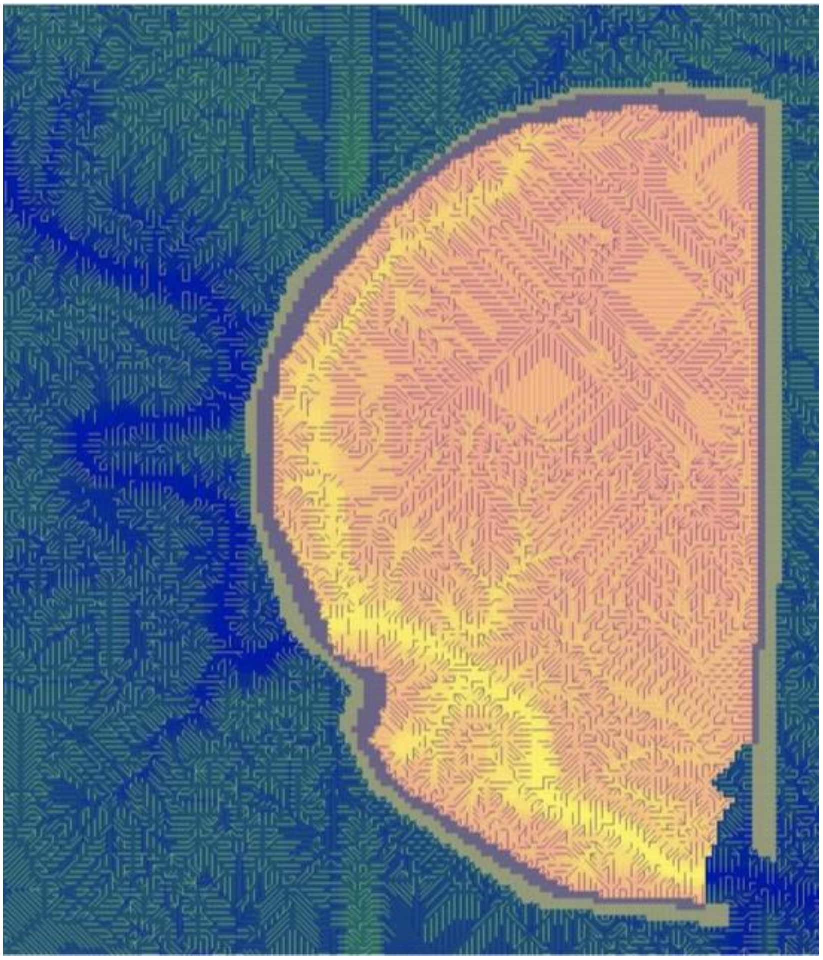
Figure 2: Flow Grid & Cell Selection of Arboretum in Vflo

The last thing that needed to be set up was the second, developed model. This model is essentially the same as the first, with three of the GIS parameter maps altered, including roughness, percent impervious, and the hydraulic conductivity. The roughness and percent impervious values are associated with LULC data. Essentially, a developed section of Houston that is just west of the arboretum was clipped and used in the model for the LULC data. This made it so that instead of the arboretum being mostly green space, it was now a mix of low, medium, and highly developed land. All the cell's hydraulic conductivity values were set to 0.024 in/hr, since this is what Harris County sets developed infiltration values to for HEC-RAS models. Then this model was run with the same rainfall event data as mentioned before.

Calculations:

<u>Infiltration measurements</u>

For each test conducted, the main result that is produced is the K-Value in cm/s. The infiltrometer automatically calculates this in the field. The purpose of this fieldwork was the determine more accurate hydraulic conductivity values for the three main soil types present in the arboretum. Table 1 summarizes results from each of the tests and averages out the values for each soil type.

Table 1: Ksat Obtained for the Three Main Soil Types

Soil Type	Ksat (cm/hr)
AtaC: Fine Sandy Loam	10.27
Md: Silty Clay Loam	1.19
BisA: Loam	0.53

Vflo model

Table 2 shows the results from the two models after running them with rainfall data from the 2017 Hurricane Harvey, 2015 Memorial Day, 2016 Tax Day flooding events in Houston. The volume of extra infiltrated water in arboretum column shows the additional water in terms of volume that can infiltrate into the soil because that area of land is natural, not developed. The peak flow reduction due to the arboretum shows how much the peak flow runoff from the arboretum is reduced, again since the land is natural in place of developed. Finally, the net rainfall reduction column demonstrates how much additional water, in terms of inches, infiltrates into the soil. It is the difference between the average infiltration of the Arboretum model and the developed model.

Table 2: Summary of Main Results from the Models

Storm	Volume of Extra Infiltrated Water in Arboretum (m3)	Peak Flow Reduction Due to the Arboretum (%)	Net Rainfall Reduction (in)
Harvey	65,596	19	2.75
Tax Day	81,339	75	3.41
Memorial Day	83,963	67	3.52

There is a significant increase in volume of water stored in the soil when the land is undeveloped instead of developed. For example, if the HANC were developed instead of being a natural green space and Houston were to experience a storm equivalent to that of the 2015 Memorial Day event, an additional 83,963 m3 of water would have run off into the Buffalo Bayou. To put that into perspective, that is about 34 Olympic-size swimming pools worth of water. Thus, since the HANC is not developed, that much extra water infiltrates into the soil and is stored instead of running off into the bayou. Similar results are shown for both Hurricane Harvey and the Tax Day flood in Table 2.

In addition to total volume stored, the peak flow of runoff from the arboretum is considerably reduced when that land is not developed. This impacts how much water flows into the Buffalo Bayou since a majority of the arboretum drains into that waterway. With a storm like that of Tax Day, the peak flow reduction is 75%, and for a storm like Memorial Day, it would be 67%. For a storm mimicking that of Harvey, the peak flow reduction was only 19%, but this is likely because Harvey occurred over a long period of time dropping record-amounts of rain. At a certain point the soil became saturated from so much water that most of the rain would turn to runoff regardless of the land type.

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Limitations:

- USDA soil series guide was utilized to classify all the soil types on the map and well as the soil depths. All soil depths had to be between 12 and 24 inches, so slight alterations were made to the soil depths if they were out of this range.
- Green infrastructure that can reduce runoff, such as bio-depressions and retention ponds, is not included in the model.

Overall Methods for Wildlife Benefits:

eBird and iNaturalist

Bird, mammal, amphibian, reptile, and insect species counts prior to and after the HANC's renovation were compared using outputs from both the eBird and iNaturalist tools. eBird is an online database that integrates birders' knowledge and experience and documents bird distribution, abundance, habitat use, and trends. Similarly, iNaturalist is a social network for sharing biodiversity information to help each other learn about nature and species richness. However, iNaturalist includes not only bird species, but also amphibian, reptile, mammal, and insect species. We explored bird species through eBird because it is more focused on bird observation than iNaturalist. Other species, such as amphibian, reptile, mammal, and insect were examined through iNaturalist. As of April 2022, 201 bird species with more than 1919 individuals have been documented using the eBird tool at the HANC. iNaturalist has documented 866 species in the HANC through 10,166 observations. Of these, there are 10 amphibian species with 798 observations, 26 reptile species with 1,534 observations, 22 mammal species with 377 observations, and 802 insect species with 7,386 observations.

Because during construction from 2013 to 2019, HANC's accessibility declined, and wildlife was disrupted to some extent, we did not include observation data prior to 2019. In addition, the 2022 calendar year was only partly completed when the data was recorded, so we did not include it in the calculations. “High count” refers to the highest number counted of one species submitted on a single checklist within a specified date range and region (eBird 2022). High counts were used (as opposed to counts from multiple checklists from multiple users) because they are just one individual user on one day (to avoid using multiple users' observations of potentially the same birds at the same time). In an attempt to understand whether the HANC was supporting an increase or decrease in the total number of species recorded, we selected data on bird species whose high counts were over a minimum of 5 counts in 2021 in eBird and tracked the total number of individuals counted in these species from 2019 to 2021.Those with less than 5 were not selected because it is difficult to observe trends for species with small numbers. Moreover, in order to reduce taxonomic bias, we restricted analyses to complete checklists. Complete checklists are those in which the participant reported all of the birds that they could detect and identify (Strimas-Mackey et al. 2020). Since iNaturalist does not offer high-count tracking like eBird, we collected data on non-bird species with more than 5 observations in 2021 and tracked count changes in these species from 2019 to 2021. Using the same method, we track changes in other species through iNaturalist.

As such, for both eBird and iNaturalist, we defined species diversity "increasing" using two criteria: 1) the number of individual species which increased continuously from 2019 to 2021 and 2) if there was a fluctuation during 2019–2021, the number of individual species in 2021 should be 3 counts higher than that of 2019. Tables 5-12 show all counts on non-bird species tracked in the iNaturalist Tool.

At the meantime, we examined whether endangered and threatened species that catered to habitat ranges found in the HANC were observed in eBird and iNaturalist. Endangered and threatened species data was compiled from the Texas Parks and Wildlife Department (TPWD) and cross-referenced with data from the Gap Analysis Project (GAP). Insect species were excluded because these datasets do not contain insect species. Spatial data available from the GAP for species that were listed as rare, threatened, and endangered was mapped to identify individual species located within the HANC based on their seasonal habitats. The species that were found in the park were then indexed, focusing on their relative status (threatened, endangered, and/or endemic). From the available species listed in the GAP from the TWPD list, the species’ raster data for their habitat from the GAP was downloaded and imported into ArcGIS Pro 2.9.1 to determine if the HANC provides potential habitat for these species. The GAP data categorized the species data into three seasonal categories to describe the habitat locations: summer, winter, and year-round. The layers were examined individually for if it was either present or not present for each seasonal category within the HANC boundary. The results showed that there were 27 different species were found within the HANC, 26 year-round and 1 in the summer, that are protected species or Species of Greatest Conservation Need (SGCN). Of all the species located in the HANC, four (4) of the species are threatened but none are listed as endangered, while others are classified simply as SGCN. Also, none of the species are endemic. These results are displayed in Table 1.

Table 1. 27 different species (not including insects) found within the HANC: 26 year-round and 1 in the summer, that are threatened species or Species of Greatest Conservation Need (SGCN)

Taxon	Scientific Name (TPWD | GAP)	Common Name (TPWD | GAP)	HANC			Endangered	Threatened	Endemic
			Summer	Winter	Year-Round			
Reptiles	Macrochelys temminckii	Alligator Snapping Turtle	No	No	Yes	N	Y	N
Mammals	Eptesicus fuscus	Big Brown Bat	No	No	Yes	N	N	N

Reptiles	Thamnophis sirtalis	Common Garter Snake | Common Gartersnake	No	No	Yes	N	N	N/A
Reptiles	Terrapene carolina	Eastern Box Turtle	No	No	Yes	N	N	N
Mammals	Lasiurus borealis	Eastern Red Bat	No	No	Yes	N	N	N
Mammals	Spilogale putorius	Eastern Spotted Skunk	No	No	Yes	N	N	N
Mammals	Lasiurus cinereus	Hoary Bat	Yes	No	No	N	N	N
Mammals	Mustela frenata	Long-tailed Weasel	No	No	Yes	N	N	N
Mammals	Puma concolor	Mountain Lion| Cougar	No	No	Yes	N	N	N
Mammals	Ondatra zibethicus	Muskrat| Common Muskrat	No	No	Yes	N	N	N
Mammals	Lasiurus intermedius	Northern Yellow Bat	No	No	Yes	N	N	N
Reptiles	Sistrurus miliarius	Pigmy Rattlesnake| Pygmy Rattlesnake	No	No	Yes	N	N	N
Reptiles	Plestiodon septentrionalis	Prairie Skink	No	No	Yes	N	N	N
Mammals	Corynorhinus rafinesquii	Rafinesque's Big-eared Bat	No	No	Yes	N	Y	N
Reptiles	Ophisaurus attenuatus	Slender Glass Lizard	No	No	Yes	N	N	N
Reptiles	Apalone mutica	Smooth Softshell	No	No	Yes	N	N	N
Mammals	Myotis austroriparius	Southeastern Myotis Bat| Southeastern Myotis	No	No	Yes	N	N	N
Amphibians	Lithobates areolatus areolatus| Lithobates areolatus	Southern Crawfish Frog| Crawfish Frog	No	No	Yes	N	N	N
Amphibians	Pseudacris streckeri	Strecker's Chorus Frog	No	No	Yes	N	N	N
Mammals	Sylvilagus aquaticus	Swamp Rabbit	No	No	Yes	N	N	N
Reptiles	Phrynosoma cornutum	Texas Horned Lizard	No	No	Yes	N	Y	N
Reptiles	Crotalus horridus	Timber (Canebrake) Rattlesnake| Timber Rattlesnake	No	No	Yes	N	N	N
Reptiles	Terrapene ornata	Western Box Turtle| Ornate Box Turtle	No	No	Yes	N	N	N
Birds	Athene cunicularia hypugaea	Western Burrowing Owl	No	No	Yes	N	N	N
Reptiles	Deirochelys reticularia miaria|	Western Chicken Turtle| Chicken Turtle	No	No	Yes	N	N	N

	Deirochelys reticularia							
Birds	Plegadis chihi	White-faced Ibis	No	No	Yes	N	Y	N
Amphibians	Anaxyrus woodhousii	Woodhouse's Toad	No	No	Yes	N	N	N
SUBTOTAL			1	0	26	N/A	N/A	N/A
TOTAL			27			0	4	0

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eBird. 2022. "Houston Arboretum and Nature Center, Harris County, TX, US - EBird Hotspot." 2022. https://ebird.org/hotspot/L685423.

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Limitations:

- The data on eBird and iNaturalist is not exhaustive, nor do they contain all species that may be present on-site. The results are determined by the frequency with which individuals visit, their ability to distinguish species, their knowledge of species, and their willingness to report species.
- The high counts and high observations were used to reflect true species counts as reported in eBird and iNaturalist, but may not be indicative of all species on the site at any one moment.
- Some species are more difficult to observe than others, so the accuracy of species counts and types can vary.
- There were discrepancies between the classifications of threatened and endangered species between USESA (federal protection status) and SPROT (state protection status). For example, one agency would list the species as threatened or endangered while the other may not. Therefore, the species was considered threatened or endangered if either agency indexed the species as such.

- ***Provides habitat for at least 133 observed bird species. Of 9 bird species with more than 5 individuals observed, 67% show an increasing trend in number of individuals after the HANC renovation (from 2019 to 2021).***

Calculations:

Bird Species Change (see table 1):
Average number of bird species per year from 2019 to 2021 (after construction): (161 + 152 +133) / 3 = 149
Average number of bird species per year from 2013 to 2019 (during construction): (89 + 98 + 115 + 138 + 147 + 158) / 6 = 124

Amount of change: 149 -124 = 25
Percent change: 25/124 = 20%
Because during construction from 2013 to 2019, HANC's accessibility to the public declined, and wildlife was disrupted to some extent, we did not report this percentage change in the benefit but include it here as a reference.

<u>Bird Species Trend:</u>
Percentage of bird species with an increasing trend: 6/9 = 67%
Percentage of bird species with a fluctuation or no change trend: 2/9 =22%
Percentage of bird species with a decreasing trend: 1/9 =11%

Table 1: Observed Bird Species in the HANC from eBird

Year	Observed Bird Species
2022 (until April)	82
2021	133
2020	152
2019	161
2018	158
2017	147
2016	138
2015	115
2014	98
2013	89
2012 and prior	132

Table 2: Counts trend change in bird species selected by high counts in the HANC from January 2019 to January 2021 from eBird

No.	Bird Species	2019	2020	2021	Trend
1	Sandhill Crane	0	0	10	Increasing
2	Eastern Phoebe	26	16	16	Deceasing
3	Gray Catbird	11	24	18	Increasing
4	Chimney Swift	50	20	80	Increasing
5	Purple Martin	5	8	14	Increasing
6	Yellow-bellied Sapsucker	8	14	12	Increasing
7	Hermit Thrush	14	22	16	Fluctuating
8	Song Sparrow	5	5	5	No change
9	American Robin	450	381	645	Increasing

Sources:
See overall methods for wildlife benefits.

Limitations:

- See overall methods for wildlife benefits.

- ***Provides habitat for at least 9 observed amphibian species. Of 6 amphibian species with more than 5 individuals observed, 50% show an increasing trend in number of individuals after the HANC renovation (from 2019 to 2021).***

Calculations:
Amphibian Species Change (see table 1):
Average number of amphibian species per year from 2019 to 2021 (after construction): (10 + 6 + 9) / 3 = 8
Average number of amphibian species per year from 2013 to 2019 (during construction): (0 + 0 + 7 + 7 + 7 +7) / 6 = 5
Amount of change: 3
Percent change: 3/5 = 60%
Because during construction from 2013 to 2019, HANC's accessibility declined, and wildlife was disrupted to some extent, we did not report this percentage change in the benefit but include it here as a reference.

Amphibian Species Trend (see table 2):
Percentage of amphibian species with an increasing trend: 3/6 = 50%
Percentage of amphibian species with a fluctuation or no change trend: 0/6 = 0%
Percentage of amphibian species with a decreasing trend: 3/6 = 50%

Protected species or Species of Greatest Conservation Need (SGCN) or Threaten species:
No observation.

Table 1: Observed Amphibian Species in the HANC from iNaturalist

Year	**Observed amphibian Species**	**Observations**
2022 (until April)	4	21
2021	9	272
2020	6	178
2019	10	164
2018	7	93
2017	7	35
2016	7	20
2015	7	15
2014	0	0
2013	0	0
2013 and prior	0	0

Table 2: Trend change in amphibian species selected by counts in the HANC from January 2019 to January 2021 from iNaturalist

No.	Amphibian Species	2019	2020	2021	Trend
1	American Bullfrog	41	80	97	Increasing
2	Gulf Coast Toad	13	5	76	Increasing
3	Green Treefrog	28	3	33	Increasing
4	Southern Leopard Frog	31	26	23	Deceasing
5	Green Frog	13	3	10	Deceasing
6	Gray Treefrog	28	28	5	Deceasing

Sources:
See overall methods for wildlife benefits.

Limitations:

- See overall methods for wildlife benefits.

- ***Provides habitat for at least 9 observed mammal species. Of 6 mammal species with more than 5 individuals observed, 50% show an increasing trend in number of individuals after the HANC renovation (from 2019 to 2021). Species of Greatest Conservation Need observed on-site include the hoary bat, Eastern red bat, Northern yellow bat, and swamp rabbit.***

Calculations:
<u>Mammal Species Change (table 1):</u>
Average number of mammal species per year from 2019 to 2021 (after construction): (8 + 9 + 9) / 3 = 9
Average number of mammal species per year from 2013 to 2019 (during construction): (1 + 0 + 4 + 8 + 9 + 11) / 6 = 6
Amount of change: 9 – 6 = 3
Percent change: 3/6 = 50%
Because during construction from 2013 to 2019, HANC's accessibility declined, and wildlife was disrupted to some extent, we did not report this percentage change in the benefit, but put it here as a reference.

<u>Mammal Species Trend (table 2):</u>
Percentage of mammal species with an increasing trend: 2/4 = 50%
Percentage of mammal species with a fluctuation or no change trend: 1/4 =25%
Percentage of mammal species with a decreasing trend: 1/4 =25%

<u>Protected species or Species of Greatest Conservation Need (SGCN) or Threaten species:</u>
According to data from iNaturalist, there are four species of SGCN were observed in the HANC. The Eastern Red Bat was observed once in HANC on April 18, 2022. The Hoary Bat was observed in HANC on April 29, 2018, and April 05, 2022. The Northern Yellow Bat was observed in HANC on April 28,

2018, and March 09, 2022. The Swamp Rabbit was observed 55 times from April 16, 2015, to April 09, 2022.

Table 1: Observed Mammal Species in the HANC from iNaturalist

Year	Observed Mammal Species	Observations
2022 (until April)	5	19
2021	9	106
2020	9	65
2019	8	63
2018	14	64
2017	9	34
2016	8	16
2015	4	7
2014	0	0
2013	1	2
2013 and prior	2	4

Table 2: Trend change in mammal species selected by counts in the HANC from January 2019 to January 2021 from iNaturalist

No.	Mammal Species	2019	2020	2021	Trend
1	Nine-banded Armadillo	8	26	57	Increasing
2	Swamp Rabbit	14	5	14	Fluctuating
3	Eastern Gray Squirrel	15	5	11	Deceasing
4	Fox Squirrel	8	8	11	Increasing

Sources:
See overall methods for wildlife benefits.

Limitations:

- See overall methods for wildlife benefits.

- ***Provides habitat for at least 465 observed insect species. Of 90 insect species with more than 5 individuals observed, 40% show an increasing trend (59% of which are pollinators) in number of individuals observed after the HANC renovation (from 2019 to 2021).***

Calculations:
Insect Species Change (table 1):
Average number of insect species per year from 2019 to 2021 (after construction): (338 + 297 + 465) / 3 = 367
Average number of insect species per year from 2013 to 2019 (during construction): (1 + 2 + 65 + 90 + 215 + 329) / 6 = 117
Amount of change: 367 – 117 = 250
Percent change: 250/117 = 214%

Because during construction from 2013 to 2019, HANC's accessibility declined, and wildlife was disrupted to some extent, we did not report this percentage change in the benefit but include it here as a reference.

Insect Species Trend (table 2):
Percentage of insect species with an increasing trend: 68/90 = 76 %
Percentage of insect species with a fluctuation or no change trend: 17/90 = 19 %
Percentage of mammal species with a decreasing trend: 5/90 = 5%

Percentage of pollinator:
The percentage of insect species that show an increasing trend is pollinators: 40/68 = 59%
The percentage of insect species that show a fluctuation or no change is pollinators: 13/17 = 76%
The percentage of insect species that show a decreasing trend is pollinators: 1/5 = 20%

Table 1: Observed Insect Species in the HANC from iNaturalist

Year	**Observed Insect Species**	**Observations**
2022 (until April)	35	49
2021	465	2606
2020	297	1492
2019	338	1381
2018	329	1101
2017	215	502
2016	90	150
2015	65	100
2014	2	2
2013	1	1
2013 and prior	5	6

* Note: Red: increase Black: fluctuation Blue: decrease

Table 2: Trend change in insect species selected by counts in the HANC from January 2019 to January 2021 from iNaturalist

No.	**Insect Species**	**Pollinators**	**2019**	**2020**	**2021**	**Trend**
1	Gulf Fritillary	Pollinators	69	99	181	Increasing
2	Turbulent Phosphila Moth	Pollinators	0	0	53	Increasing
3	North American Wheel Bug		34	25	45	Increasing
4	Differential Grasshopper		0	8	45	Increasing
5	Western Honey Bee	Pollinators	13	90	39	Increasing
6	Blue Dasher		21	19	39	Increasing
7	Eastern Leaf-footed Bug		13	8	30	Increasing

8	Eastern Carpenter Bee	Pollinators	14	17	26	Increasing
9	White-striped Longtail	Pollinators	13	6	25	Increasing
10	Asian Lady Beetle	Pollinators	13	21	21	Increasing
11	Eastern Pondhawk		11	6	21	Increasing
12	Carolina Mantis	Pollinators	11	0	20	Increasing
13	Two-lined Spittlebug		0	10	20	Increasing
14	Cloudless Sulphur	Pollinators	7	12	19	Increasing
15	Salt Marsh Moth	Pollinators	31	31	19	Deceasing
16	Eastern Black Carpenter Ant	Pollinators	10	16	19	Increasing
17	Monarch	Pollinators	0	13	17	Increasing
18	Obscure Bird Grasshopper		4	13	17	Increasing
19	Banded Sphinx	Pollinators	0	0	17	Increasing
20	Variegated Fritillary	Pollinators	10	2	16	Increasing
21	Io Moth	Pollinators	0	0	16	Increasing
22	American Bumble Bee	Pollinators	10	18	15	Increasing
23	Glassy-winged Sharpshooter		5	0	15	Increasing
24	Northern Plushback	Pollinators	4	13	14	Increasing
25	Spicebush Swallowtail	Pollinators	6	14	14	Increasing
26	Viceroy	Pollinators	0	0	13	Increasing
27	Clouded Skipper	Pollinators	0	0	13	Increasing
28	Spotted Cucumber Beetle	Pollinators	12	8	12	Fluctuating
29	Common Buckeye	Pollinators	6	10	11	Increasing
30	Fiery Skipper	Pollinators	6	15	10	Increasing
31	Gray Hairstreak	Pollinators	6	1	10	Increasing
32	Fork-tailed Bush Katydid		0	2	10	Increasing
33	Forest Tent Caterpillar Moth	Pollinators	0	2	10	Increasing
34	Great Blue Skimmer		11	1	10	Deceasing
35	Cypress Twig Gall Midge		0	7	10	Increasing

36	Milkweed Assassin Bug		9	9	10	Increasing
37	Aztec Spur-throated Grasshopper		13	7	10	Deceasing
38	Red Admiral	Pollinators	8	2	9	Fluctuating
39	Six-spotted Tiger Beetle	Pollinators	5	3	9	Increasing
40	Needham's Skimmer		0	1	9	Increasing
41	American Bird Grasshopper		11	5	9	Deceasing
42	Slaty Skimmer		0	2	9	Increasing
43	Common and White Checkered-Skippers	Pollinators	0	7	9	Increasing
44	Red-banded Leafhopper		6	1	8	Fluctuating
45	Powdered Dancer		3	3	8	Increasing
46	Blue Corporal		9	1	8	Deceasing
47	Graceful Twig Ant	Pollinators	7	9	8	Increasing
48	Pearl Crescent	Pollinators	2	1	7	Increasing
49	Question Mark	Pollinators	7	0	7	Fluctuating
50	Delta Flower Scarab	Pollinators	5	2	7	Fluctuating
51	Fragile Forktail		6	4	7	Fluctuating
52	Common Lovebug	Pollinators	0	18	7	Increasing
53	Genus Rivellia		0	0	7	Increasing
54	Hibiscus Turret Bee	Pollinators	6	2	7	Fluctuating
55	Virginia Giant	Pollinators	4	1	7	Increasing
56	Sculptured Pine Borer		4	2	7	Increasing
57	Ponderous Spur-throat Grasshopper		0	2	7	Increasing
58	Mischievous Bird Grasshopper		0	2	7	Increasing
59	Macleay's Owlfly		0	0	7	Increasing
60	Abbot's Bagworm Moth	Pollinators	0	6	7	Increasing
61	Brazilian Skipper	Pollinators	0	1	6	Increasing

62	Black Swallowtail	Pollinators	5	1	6	Fluctuating
63	Acanthocephala terminalis		0	0	6	Increasing
64	Rambur's Forktail		0	6	6	Increasing
65	Common Whitetail		5	5	6	Increasing
66	Green Cone-headed Planthopper		0	0	6	Increasing
67	Eight-spotted Forester Moth	Pollinators	0	1	6	Increasing
68	Spotless Lady Beetle	Pollinators	4	8	6	Fluctuating
69	Guinea Paper Wasp	Pollinators	0	1	6	Increasing
70	Oblong-winged Katydid		0	0	6	Increasing
71	Dark Flower Scarab	Pollinators	3	0	5	Fluctuating
72	American Snout	Pollinators	3	0	5	Fluctuating
73	Tawny Emperor	Pollinators	0	0	5	Increasing
74	Virginian Tiger Moth	Pollinators	7	9	5	Fluctuating
75	Ormenoides venusta		0	0	5	Increasing
76	Red Imported Fire Ant	Pollinators	0	5	5	Increasing
77	Yellow-collared Scape Moth	Pollinators	0	3	5	Increasing
78	Oblique Longhorn	Pollinators	3	0	5	Increasing
79	Horned Passalus Beetle	Pollinators	7	8	5	Fluctuating
80	Limnoporus canaliculatus		3	1	5	Increasing
81	Common Thread-waisted Wasp	Pollinators	0	2	5	Increasing
82	Fraternal Potter Wasp	Pollinators	2	1	5	Increasing

83	Yellow-striped Leafhopper		0	4	5	Increasing
84	Black-dotted Ruddy Moth	Pollinators	0	0	5	Increasing
85	Dieunomia heteropoda	Pollinators	0	0	5	Increasing
86	Carpenter-mimic Leafcutter Bee	Pollinators	11	22	5	Fluctuating
87	Hackberry Petiole Gall Psyllid		3	0	5	Fluctuating
88	Zethus spinipes	Pollinators	3	0	5	Fluctuating
89	Orsilochides stictica		4	23	5	Fluctuating
90	Tropical Checkered-Skipper	Pollinators	0	3	5	Increasing

Sources:
See overall methods for wildlife benefits.

Limitations:

- See overall methods for wildlife benefits.

- ***Increases plant species richness in the prairie with at least 22 newly planted species, achieving a Shannon Index value of 2.79, which is 34% higher (1.83 to 2.79) and a Reciprocal Simpson Index value that is 263% higher (5.64 to 29.49) than if the site had been replanted with individual trees and lawn.***

Background:
In 2012, more than 50% of the tree canopy of the Houston Arboretum and Nature Center (HANC) had been lost due to high winds caused by hurricanes and years of drought. Through a comprehensive analysis, landscape architects with Design Workshop and Reed Hilderbrand discovered that the areas of the arboretum most prone to tree loss were once grassland ecosystems and therefore not naturally suited to be woodlands. By removing trees and renovating 25 acres of original prairie and savanna in the 155-acre arboretum, the landscape architects designed a landscape naturally resilient to future climate shocks such as more frequent and severe hurricanes, flooding, and drought.

Methods:
There are two famous diversity indexes that take into account the number of species living in a habitat (richness) and their relative abundance (evenness). The Shannon index is a measure of information statistics. This means that it assumes that all species are represented in a sample and that the species were chosen at random. The Simpson index is a dominance index because it gives common or dominant species greater weight. In general, the presence of a few uncommon species with few individuals will not have an impact on biodiversity. We used the Reciprocal Simpson Index instead of the Simpson Index because it is easier to interpret as the inverse of the Simpson Diversity Index. Reciprocal Simpson Index is simply the inverse of the Simpson Index. The greater the biodiversity in an area, the higher the value of the Shannon biodiversity index and the Reciprocal Simpson Index. Both the Shannon biodiversity index

and the Reciprocal Simpson Index are appropriate because if actual plant quantities are not known, the species proportions from a planting list/seed mix can be used.

The Shannon Index and the Reciprocal Simpson Index were used to compare biodiversity between the currently planted prairie/savanna vegetation in the HANC and the scenario of replanting the HANC with trees, which was originally considered for this site. Except newly planted species, other species are the same in both scenarios. In the prairie/savanna scenario, these indexes were determined by counting the number of individuals of each species used in the prairie/savanna in phase 1 and entering the data into a spreadsheet using the following formulas to calculate the Shannon index and the Reciprocal Simpson Index. Plant species and quantities used in the prairie/savanna area, including savanna/prairie seed mix and savanna/prairie plug mix, were provided by the designer and HANC.

We used the tree inventory of the HANC woodland/savanna provided by the designer and HANC (see Appendix 1) as the basis to create the scenario of replanting the HANC with trees. This tree inventory focuses on the health condition of large living trees with trunk diameters (DBH) 18 inches and larger that remained on the prairie/savanna area after the damage happened. The health condition of trees is listed as good, fair, or poor. The risk of tree failure, or the structural health, of trees is qualified as low, medium, or high risk. Trees that are fair or poor or that have moderate or high risk of failure have been removed from the savanna area and therefore this number is an indication of how many trees would need to be replanted in the scenario of replanting the HANC with trees (see table 1). In addition to replanting trees, we assumed that in the scenario of replanting the HANC with trees, the remaining areas that were planted with savanna/prairie seeds and plugs were instead replaced by lawn seeds commonly used in the Houston area. The biodiversity value of the replanting trees scenario was calculated using the species proportions of trees and lawn seeds in place of actual quantities.

Table 1. Trees would need to be replanted in the scenario of replanting the HANC with trees

Species	**Replant quantity Total amount removed**
Post Oak	30
Loblolly Pine	21
Water Oak	3
Red Oak	2
American Elm	3
Sycamore	2
Willow Oak	2
Overcup oak	1
Total	64

Calculations:

The Shannon Diversity Index is denoted as H, this index is calculated as:
H = -Σpi * ln(pi)
where:
Σ: A Greek symbol that means "sum"
ln: Natural log
pi: The proportion of the entire community made up of species i
The greater the biodiversity in an area, the higher the value of H.

Table 2. Shannon index of the savanna/prairie scenario (actual)

Savanna/prairie seed mix: **H = -Σpi * ln(pi) = 2.79**				
Shannon index variable name	**Common name**	**Area (sf) of each species**	***p*i**	**Shannon index calculation (*p*i * ln(*p*i))**
=n1	Big bluestem	52848	0.05	-0.16
=n2	Bushy bluestem	20208	0.02	-0.08
=n3	Sideoats grama	80832	0.08	-0.21
=n4	Inland seaoats	60624	0.06	-0.17
=n5	Lanceleaf coreopsis	40415	0.04	-0.13
=n6	Plains coreopsis	40415	0.04	-0.13
=n7	Clasping coneflower	40415	0.04	-0.13
=n8	Purple coneflower	20208	0.02	-0.08
=n9	Prairie Wildrye	40415	0.04	-0.13
=n10	Indian Blanket	60624	0.06	-0.17
=n11	Lemon beebalm	40415	0.04	-0.13
=n12	Florida paspalum	53570	0.06	-0.16
=n13	Foxglove	20208	0.02	-0.08
=n14	Mexican hat	20208	0.02	-0.08
=n15	Black-eyed Susan	80832	0.08	-0.21
=n16	Scarlet sage	40416	0.04	-0.13
=n17	Little bluestem (Gulf)	56992	0.06	-0.17
=n18	Yellow indiangrass	61135	0.06	-0.17
=n19	Purpletop tridens	20208	0.02	-0.08
=n20	Eastern gamagrass	32640	0.03	-0.11
=n21	Blue mistflower	8288	0.01	-0.04
=n22	Cardinal flower	4144	0.00	-0.02
=N	TOTAL	971373	1	2.79

The Shannon Index of the savanna/prairie scenario = 2.79

Assumed average tree canopy = 860 sf
For example:
Post oak area = count of post oak * average tree canopy = 30 * 860 sf = 25800 sf

Table 3. Shannon index of the scenario of replanting the HANC with trees (hypothetical)

Replanting the HANC with trees: **H = -Σpi * ln(pi) = 1.83**					
Shannon index variable name	**Common name**	**Count of each species**	**Area (sf) of each species**	***p*i**	**Shannon index calculation (*p*i * ln(*p*i))**
=n1	Post Oak	30	25800	0.03	-0.10
=n2	Loblolly Pine	21	18060	0.02	-0.08
=n3	Water Oak	3	2580	0.00	-0.02
=n4	Red Oak	2	1720	0.00	-0.01
=n5	American Elm	3	2580	0.00	-0.02
=n6	Sycamore	2	1720	0.00	-0.01
=n7	Willow Oak	2	1720	0.00	-0.01
=n8	Overcup oak	1	860	0.00	-0.01
=n9	Bermudagrass		167230	0.19	-0.31
=n10	Centipedegrass		167231	0.19	-0.31
=n11	Seashore paspalum		167231	0.19	-0.31
=n12	St. Augustinegrass		167231	0.19	-0.31
=n13	Zoysiagrass		167231	0.19	-0.31
=N	TOAL		891194	1	1.83

The Shannon Index of the scenario of replanting the arboretum with trees = 1.83

Difference in the Shannon Index between the savanna/prairie scenario and the scenario of replanting the arboretum with trees = 2.79 -1.83 = 0.96

Percentage of the Shannon Index for the savanna/prairie scenario increased compared the scenario of replanting the arboretum with trees = 0.96/2.79 = 34.41%

<u>The Reciprocal Simpson Index is denoted as D, this index is calculated as:</u>
D = 1/[Σni(ni-1)/ N(N-1)]
where:
ni: The number of organisms that belong to species i
N: The total number of organisms
The greater the biodiversity in an area, the higher the value of D.

Table 4. Reciprocal Simpson Index of the savanna/prairie scenario (actual)

Savanna/prairie seed mix: **D = 1/[Σni(ni-1)/ N(N-1)] = 20.49**			
Reciprocal Simpson Index variable name	**Common name**	**ni (sf)**	**Reciprocal Simpson Index calculation (ni(ni-1)/ N(N-1))**
=n1	Big bluestem	52848	0.003
=n2	Bushy bluestem	20208	0.000
=n3	Sideoats grama	80832	0.007
=n4	Inland seaoats	60624	0.004
=n5	Lanceleaf coreopsis	40415	0.002
=n6	Plains coreopsis	40415	0.002
=n7	Clasping coneflower	40415	0.002
=n8	Purple coneflower	20208	0.000
=n9	Prairie Wildrye	40415	0.002
=n10	Indian Blanket	60624	0.004
=n11	Lemon beebalm	40415	0.002
=n12	Florida paspalum	53570	0.003
=n13	Foxglove	20208	0.000
=n14	Mexican hat	20208	0.000
=n15	Black-eyed Susan	80832	0.007
=n16	Scarlet sage	40416	0.002
=n17	Little bluestem (Gulf)	56992	0.003
=n18	Yellow indiangrass	61135	0.004
=n19	Purpletop tridens	20208	0.000
=n20	Eastern gamagrass	32640	0.001
=n21	Blue mistflower	8288	0.000
=n22	Cardinal flower	4144	0.000
=N	TOTAL	971373	20.49

The Reciprocal Simpson Index of the savanna/prairie scenario = 20.49

Table 5. Reciprocal Simpson Index of the replanting the HANC with trees scenario (hypothetical)

Replanting the HANC with trees: **D = 1/[Σni(ni-1)/ N(N-1)] = 3.08**				
Reciprocal Simpson Index variable name	**Common name**	**ni (counts)**	**Area (sf) of each species**	**Reciprocal Simpson Index calculation**

				(ni(ni-1)/ N(N-1))
=n1	Post Oak	30	25800	0.00
=n2	Loblolly Pine	21	18060	0.00
=n3	Water Oak	3	2580	0.00
=n4	Red Oak	2	1720	0.00
=n5	American Elm	3	2580	0.00
=n6	Sycamore	2	1720	0.00
=n7	Willow Oak	2	1720	0.00
=n8	Overcup oak	1	860	0.00
=n9	Bermuda grass		167230	0.04
=n10	Centipede grass		167231	0.04
=n11	Seashore paspalum		167231	0.04
=n12	St. Augustine grass		167231	0.04
=n13	Zoysia grass		167231	0.04
=N	TOTAL		891194	5.64

The reciprocal Simpson Index of the scenario of replanting the arboretum with trees = 5.64

Difference in the reciprocal Simpson between the savanna/prairie scenario and the scenario of replanting the arboretum with trees = 20.49 - 5.64 = 14.85

Percentage of the Shannon Index for the savanna/prairie scenario increased compared the scenario of replanting the arboretum with trees = 14.85/5.64 = 263.30%

Sources:
Plant species and quantities are provided by the designer and HANC.

Limitations:

- Some species may have been over-counted or under-counted because the counts utilized are based on the planting plan and not from on-site site sampling. Plants may have either reproduced or died on site after installation.

- ***Contributes to a reduction in urban heat island effect by decreasing air temperatures in vegetated areas by 0.54 °C (0.94 °F) on average, reducing wet bulb globe temperature by up to 1.5 °C (12.7 °F), and increasing relative humidity by up to 4.9% as compared to hard surfaces nearby.***

Method:
Traverse measurement: The hottest time of the day typically occurs 3 to 5 hours after solar noon. To catch the spatial distribution of the microclimate condition during the hottest time, we conducted a traverse

measurement on May 21, 2022 between 14:00 to 17:00. MaxiMet GMX501 All-in-one Climate Station was used, which provides research-grade measurements of air temperature, relative humidity, wind direction, wind speed, and other climatic conditions at a sampling rate of 1HZ. To conduct traverse measurement, MaxiMet equipment was attached to a golf cart to obtain measurement in areas accessible to the golf cart; and was hand held along narrower trails. In addition to a traverse, we also identified representative locations and made measurements during a three-minute static window.

Fixed Station Measurement: In addition to the traverse measurement, we installed a total of five fixed station measurement points at the Hard surface, Ravine, Savanna, Inner Loop and Meadow Pond areas to record continuous microclimate and biometeorological conditions during the summer (July 2, 2022 to July 19, 2022). The Kestrel 5400 Heat Stress Trackers were installed on the tripods at a 5-ft distance to the ground level, which takes measurements of the same set of microclimate conditions at a sampling interval of 10 minutes.

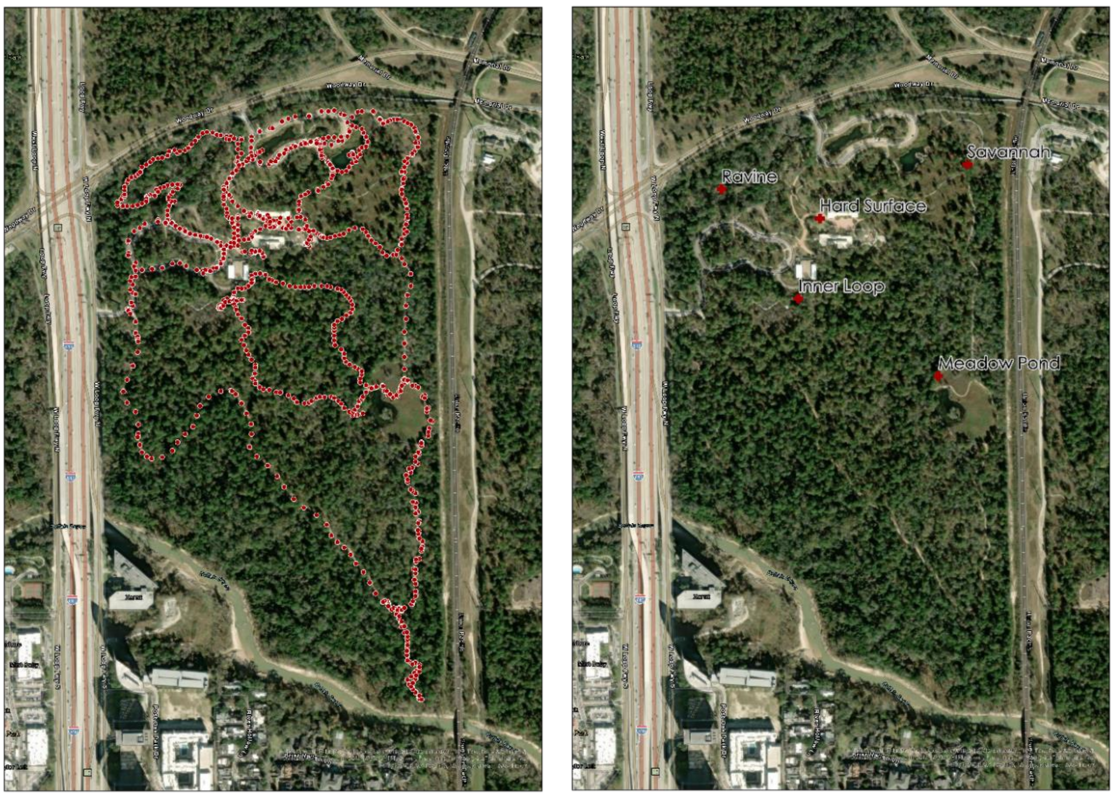

Figure 1. Traverse measurement points (left); Five fixed station measurement points (Right)

Figure 1. On-Site Microclimate measurements using MaxiMet GMX501

Calculations:

<u>Detrend for traverse measurement</u>
A time-series analysis was conducted through R packages to explore the distributions of the raw data. As the exploratory analysis indicated a time trend, the raw data were detrended based on a 1000 second (every 100 observations) moving average. To reduce the error caused by the response time of the sensor, the first 3 minutes of measurement results of each eco-zone were set to null. After the correction, the sample points of each eco-zone were summarized through the box plot to display the minimum, first quartile, median, third quartile, and maximum values of the microclimate indicators.

<u>Data filtration for the fixed-station measurement</u>
To catch the daytime condition of HANC, the data from 8:00 to 19:30 were included in the calculation. The sample points of five eco-zones were summarized through the box plot to display the minimum, first quartile, median, third quartile, and the maximum values of the microclimate indicators. WBGT utilizes ambient temperature, relative humidity, wind, and solar radiation from the sun to get a composite value

that can be used when monitoring environmental conditions during heat events. The equation below shows the calculation process of WBGT.

WBGT=0.7TW+0.2TG+0.1TD

, where:

Tw is the wet bulb temperature, which indicates humidity,
Tg is the globe temperature, which indicates radiant heat,
Td is the ambient air (dry) temperature.

Air temperature reduction

During the time of the day when air temperature reaches the peak, most of the vegetated area is cooler than the reference point (hard surface nearby). The median air temperature reduces by 0.52 °C (0.94 °F) and 0.31 °C (0.56 °F) in the donor board walk and meadow pond, respectively.

50^{th} percentile Ta of Hard surface 34.01°C – 50^{th} percentile Ta of donor board walk 33.49 °C = 0.52 °C
50^{th} percentile Ta of Hard surface 34.01°C – 50^{th} percentile Ta of meadow pond 33.70 °C = 0.31 °C

Hard Surface 1: 75^{th} percentile = 34.13°C , median = 34.01°C , 25^{th} percentile = 33.87 °C
Hard Surface 2: 75^{th} percentile = 34.11°C , median = 33.90°C , 25^{th} percentile = 33.63 °C
Inner Loop (Forest): 75^{th} percentile = 33.99°C , median = 33.81°C , 25^{th} percentile = 33.74°C
Ravine: 75^{th} percentile = 34.10°C , median = 33.87°C , 25^{th} percentile = 33.73°C
Donor Boardwalk: 75^{th} percentile = 33.62°C , median = 33.49°C , 25^{th} percentile = 33.40°C
Savanna: 75^{th} percentile = 34.25°C , median = 34.19°C , 25^{th} percentile = 34.10°C
Meadow Pond: 75^{th} percentile = 33.86°C , median = 33.70°C , 25^{th} percentile = 33.59°C

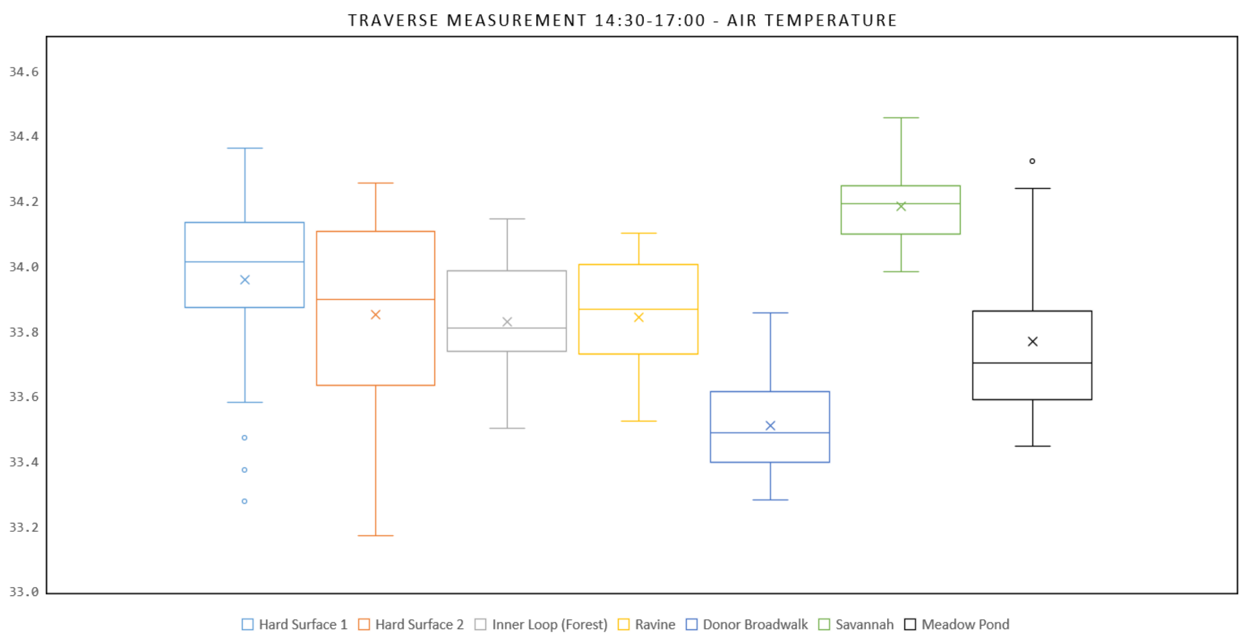

Figure 1. Box plot: Air temperature during the hottest time (14:30 – 17:00)

Wet Bulb Globe Temperature reduction

According to the threshold recommended by most sporting governing bodies (e.g., ITF,FIFA), the WBGT > 30°C is considered extremely dangerous thermal condition. In HANC, the forest area shows a significant effect in reducing the WBGT, where about a reduction of approximately 1.5°C median WBGT is observed in the Ravine area (18-days mean WBGT, 8:00 – 19:30). It can be further noted that the cooling effect could be amplified in extreme scenarios. About 1.8°C reduction of the 75th percentile WBGT is observed when comparing the Raving area to the hard surface. On the 15th of July, a 9.6°C of WBGT reduction was observed when comparing the inner loop forested area and the hard surface.

Hard Surface: 75th percentile = 31.1°C, median = 29.7°C , 25th percentile = 28.6°C
Savanna: 75th percentile = 29.9°C, median = 29.0°C , 25th percentile = 28.2°C
Meadow Pond: 75th percentile = 30.0°C, median = 29.0°C , 25th percentile = 28.0°C
Ravine: 75th percentile = 29.3°C, median = 28.4°C , 25th percentile = 27.7°C
Inner Loop (Forest): 75th percentile = 29.3°C, median = 28.4°C , 25th percentile = 27.5°C

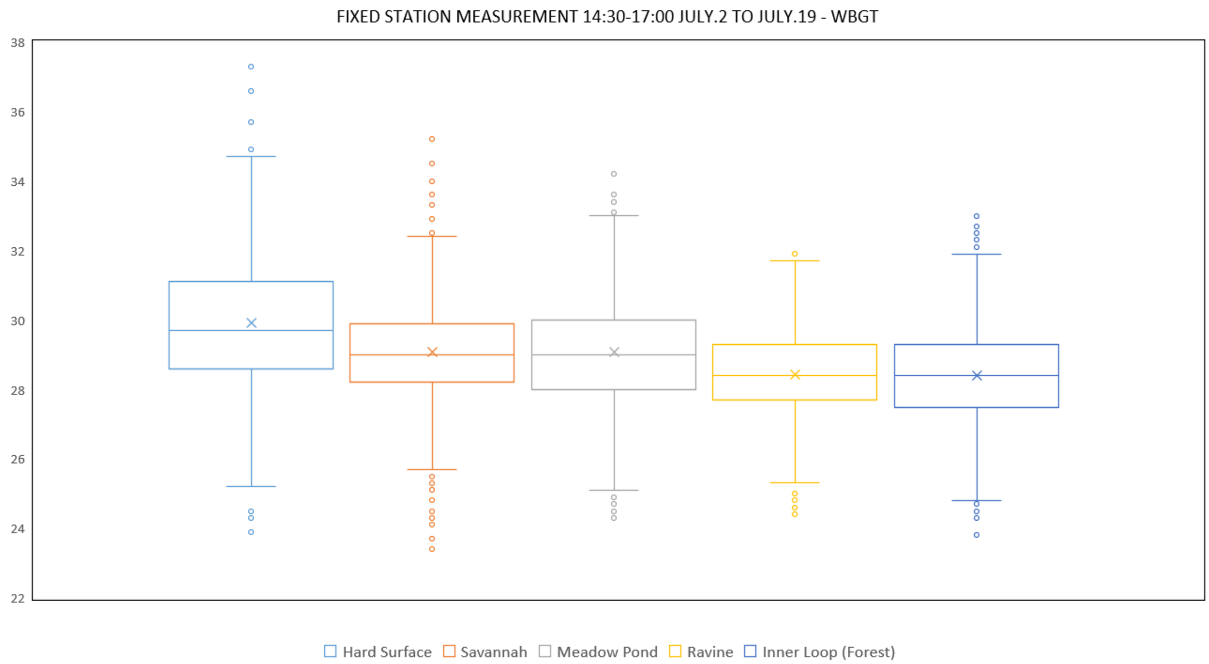

Figure 3. Box plot: Thermal stress during the typical summer daytime

Relative humidity increase

During the summer (July.2.2022 to July.19.2022), the forested area in HANC helps to increase the relative humidity. For Ravine and Inner Loop (Forest), the increase of mean relative humidity is 4.9% and 2.6%, respectively.

Hard Surface: 63.90% , median = 51.10% , 25th percentile = 43.20%
Savanna: 75th percentile = 65.00% , median = 51.10% , 25th percentile = 42.40%
Meadow Pond: 75th percentile = 61.10% , median = 50.70% , 25th percentile = 43.30%
Ravine: 75th percentile = 73.55% , median = 54.40% , 25th percentile = 45.10%
Inner Loop(Forest): 75th percentile = 71.50% , median = 52.40% , 25th percentile = 42.50%

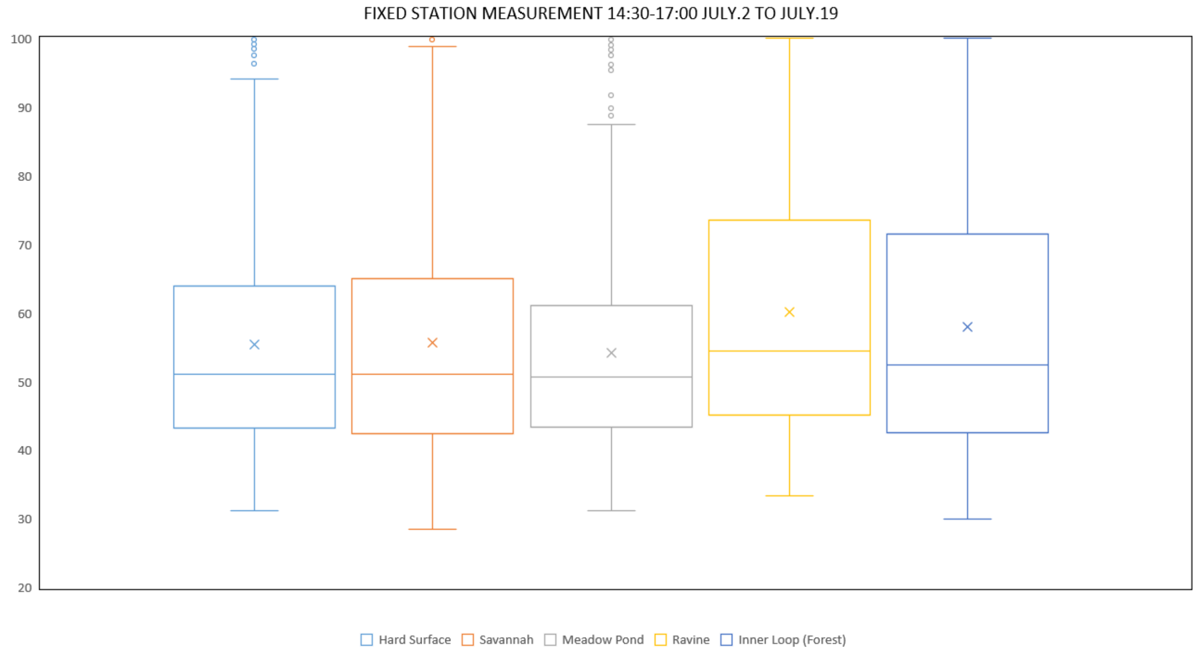

Figure 2. Box plot: Relative humidity during the typical summer daytime

Sources:

Budd, G. M. (2008). Wet-bulb globe temperature (WBGT)—its history and its limitations. Journal of science and medicine in sport, 11(1), 20-32.

Häb, K., Ruddell, B. L., & Middel, A. (2015). Sensor lag correction for mobile urban microclimate measurements. Urban Climate, 14, 622-635.

Limitations:

- The traverse measurement provides a temporal snapshot of each sampling location, while the fixed-station measurement can only be utilized in specific locations. Although we combined the two to strengthen the assessments, the spatial and temporal coverage was still limited.

- For the fixed-station measurement, data were collected on only 18 days in July. During this period of hot summer days, the weather conditions are relatively homogeneous. Future studies may need to consider the climate modification effects of the arboretum during other seasons.

- ***Reused salvaged materials including wood for parking stops, field stations, and mulch as well as 50,000 plant plugs collected from the field, saving an estimated $240,500 in new materials.***

Methods:

The HANC used several salvaged materials during the construction, including bald cypress transplants, parking stops made of Willow Oak trees, mulch made of woody invasive plants, field stations from salvaged post oak materials, and 50,000 plant plugs collected from the local field.

Bald Cypress transplants

Sixteen trees were moved from a location that is now one of the stormwater ponds. These trees were temporarily re-planted with another grove of bald cypress trees that were in a savanna restoration location. The Bald Cypress had been planted as a volunteer effort with hopes of eventually making a wood duck pond. This did not happen and many of the trees were planted too close together. 33 of the bald cypress trees were eventually transplanted to both of the stormwater ponds. The transplanted trees are significant features around the donor board walk and have added to the beauty of the ponds. The price of a Bald Cypress (10-11.5 ft) is about $495 (treeland 2021). The HANC saved $16,000 by not having to buy Bald Cypress trees.

Willow Oak tree wheel stops

Willow Oak trees were cut for savanna restoration purposes to restore open space densities that support grassland systems. These trees were milled and repurposed for 250 wheel stops in the two new parking loops. We assume if the HANC didn't use Willow Oak trees to create parking stops, it would use concrete parking stops instead as concrete parking stops are the most common type of wheel stop installation service requested for Houston. The price per standard concrete wheel stop is about $46 (Hampton concrete products 2022). Thus, the material saving for parking stops is $11,500.

Mulch

The clearing of the woody invasive layer, in addition to tree removal for development and restoration, created a significant amount of mulch. In total, approximately 30 acres of woody invasive understory plants were cleared. The arboretum took 154 mulch truckloads of 8 cy trucks to an adjacent SITES project, Memorial Park's Biocycling Center. The distance from the HANC to the Memorial Park's Biocycling Center is within 1 mile, thus it only cost about $300 for transport. This mulch was incorporated into mulch piles and converted into compost. At a later date, HANC retrieved 308 cu. yd of the compost for soil amenities and improvements. All other mulch was left in place at 2" to biodegrade on site. The mulch improved the soil composition and also helped suppress invasive species. The price of organic compost (per cu. Yd) is about $46 (Texas Garden Materials 2021), and the price of organic mulch (per cu. Yd) is about $50 (FIXR 2022). Thus, the savings from not buying mulch and compost is about $60,000.

Field station

7 field stations within the savanna were constructed using salvaged post oak material. Dead post oaks were milled on-site by a local miller and then used as material for the large beams and columns. Post Oaks are extremely rot-resistant and an ideal material for outdoor construction. To build a field station, the average cost of wood material is about $4,000 to $7,000 (HomeAdvisor 2022). Therefore, the HANC saved at least $48,000 in wood material costs.

Local seed collection

The conservation team and volunteers collected seeds from the HANC and other local prairies at multiple events over 2017. The seeds were used to grow about 50,000 plugs for the restoration areas. The general cost of a plant plug varies from $2.5 (very small size) to $8 (medium size) (Native Plant Society of Texas 2022). Therefore, the saving from the local seed collection is about $125,000.

Savings from local seed collection = $2.5*50,000 = $125,000

Calculations:

<u>Bald Cypress transplants</u>

The price per Bald Cypress (10-11.5 ft) = $495
Total Bald Cypress transplanted = 33
Savings from not buying Bald Cypress trees = $495 *33 = $16,335 ≈ $16,000

<u>Willow Oak trees</u>

$33,750
The price per standard concrete wheel stop = $46
The install fee per standard concrete wheel stop = $20.25
Total wheel stops created by Willow Oak trees = 250
Savings from reusing Willow Oak trees = ($46 + $20.25) * 250 = $11,500

<u>Mulch</u>

Cost of 154 truckloads = $300
Total amount of mulch created by clearing of the woody invasive layer = 154 * 8 cu. Yd = 1,232 cu. Yd
The compost created from mulch = 308 cu. Yd
The remaining mulch = 1,232 cu. Yd - 308 cu. Yd = 924 cu. Yd

The price of organic mulch (per cu. Yd) = $50
Total cost of organic mulch = 924 cu. Yd *$50 = $46,200

Organic compost cost per cu. Yd = $46
The price organic compost (per cu. Yd) = 308 cu. Yd *$46 = $14,168

Savings from not buying mulch and compost = ($46,200 + $14,168) -$300 = $60,368 ≈ $60,000

<u>Field station</u>

The average cost of wood materials = $4,000 to $7,000
The least saving from not have to buying wood materials = $4,000 * 7 = $28,000

<u>Local seed collection</u>

The general cost of a plant plug = $2.5 (very small size) to $8 (medium size)

The saving from the local seed collection (at least) = $2.5*50,000 = $125,000

<u>Total savings:</u>

Total savings = Savings from not buying Bald Cypress trees + Savings from reusing Willow Oak trees + Savings from not buying mulch and compost + The minimum savings from not have to buying wood materials + Savings from local seed collection = $16,000 + $11,500 +$60,000 + $28,000 + $125,000 = $240,500

Sources:
Information for salvaged materials and plants are provided by HANC.

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Limitation:
- This analysis does not consider costs associated with repurposing e.g. transplantation of Bald Cypress, milling of Willow Oak tree wheel stops, milling and transportation of post oak materials, and milling and transportation of mulch.

Social Benefits

- ***Supports increased visitorship, with over 1.6 million visitors from January 2019 to March 2022. Compared to 2016, which was the year before restoration, visitors increased by 151% in the first year after renovation completion (2019), 271% in the second year after renovation completion (2020), and 222% in the third year after renovation completion (2021).***

Method:
The renovation of the HANC for phase 1 began in 2013 and was completed in 2019. We used 2016 as the baseline to compare the number of annual visitors before and after renovation, rather than using the years before 2013 and any other years that during the construction because 2016 was the only year with a complete visitor record before the renovation was completed. Thus, we calculated the difference in the

number of annual visitors before (2016) and after renovation was completed (after 2019). The annual number of visitors is provided by HANC. They are based on car counters at each entrance.

Calculations:
The HANC assumes that there is an average of 3 people per car, based on the number of bus loads that come and can skew the numbers.
2016
2016 total car counts = 56,605
2016 total attendance = 56,605 * 3 = 169,815

2019
2019 total car counts = 141,919
2019 total attendance = 141,919 *3 = 425,757

2020
2020 total car counts =209,743
2020 total attendance = 209,743 *3 = 629,229

2021
2021 total car counts = 182,218
2021 total attendance = 182,218 *3 = 546,654

2022
2022 total car counts = 43,484
2022 total attendance (until March) = 43,484 *3 = 130,452

Total visitors after renovation (2019) until March 2022 = 2019 total attendance + 2020 total attendance + 2021 total attendance + 2022 total attendance (until March) = 425,757 + 629,229 + 546,654 + 130,452 = 1,601,641

Visitors increase rate in the first year of renovation completion (2019) compared to 2016 = (2019 total attendance – 2016 total attendance)/ 2016 total attendance = (425,757 - 169,815)/ 169,815 = 151%

Visitors increase rate in the second year of renovation completion (2020) compared to 2016 = (2020 total attendance – 2016 total attendance)/ 2016 total attendance = (629,229- 169,815)/ 169,815 = 271%

Visitors increase rate in the first year of renovation completion (2019) compared to 2016 = (2021 total attendance – 2016 total attendance)/ 2016 total attendance = (546,654 - 169,815)/ 169,815 = 222%

Sources:
The annual number of cars at each entrance is provided by HANC.

Limitations:
- The HANC only tracks and charges vehicles parked in the parking lot estimating 3 people per car, roughly accounting for buses. In this case, visitors using other modes of transport cannot be taken into account. The number of visitors was estimated by multiplying the number of vehicles parked in the parking lot by an average of 3 people per vehicle, which may have some discrepancies with the actual number of visitors.
- Data for 2017 and 2018 are incomplete and there are no data before 2016. The number of visitors may have been affected by construction in 2016.

Background of Survey Studies:
Attention Restoration Theory (ART) by the Kaplans (Kaplan et al., 1998) proposed that exposure to nature encourages more effortless ways of paying attention and restores attentional capacity after exerting mental energy, improving mental fatigue and concentration. Based on ART, the natural environment must have four qualities to provide this restorative effect:

- Being away (provides the sense of being separate and apart from one's usual thoughts and concerns)
- Fascination (involves one's attention being held without any effort expended)
- Extent (encourages someone to feel totally immersed and engaged)
- Compatibility (allows someone to feel enjoyment and congruence in the environment)

In addition to ART, previous research has consistently shown that spending time in nature help reduce stress and anxiety, and promotes positive feelings (Li & Sullivan, 2016; Li et al., 2019).

Overall Method of Survey Studies:
Survey methodologies were used to examine the social/health benefits of visiting the arboretum. This study comprises of two substudies: a retrospective user study and an on-site ecological momentary assessment.

Retrospective user study. This substudy recruited past and current users of the arboretum and assesses their behavior patterns, perceptions/satisfaction, and reported health benefits.

Ecological momentary assessment (EMA). This substudy recruited users of the arboretum and conducted concurrent assessment of their physical activity, mental health, and perceptions of their specific areas within the arboretum. EMA is a contemporary technical used in behavioral medicine and related fields to assess human behavior and health in naturalistic settings. In assessing environmental correlates of health, traditional survey approaches rely heavily on retrospective self-report, which suffer from recall bias and ecological validity related concerns. EMA, on the other hand, are particularly well-suited for evaluating the impacts of specific environments, as assessment scales are completed during visits when subjects are immersed in the environment.

Survey respondents were recruited mainly through three channels: 1) on the Arboretum's website and through Arboretum member listservs, 2) on social media (e.g., Facebook, Twitter), and 3) on-site by the entrance and parking areas. The inclusion/exclusion criteria are: 1) 18 years or older, 2) for substudy 2, have an Android phone or willing to use phone provided by the research team, and 3) If visitors came in groups of two or more, only one person from each group was eligible to participate.

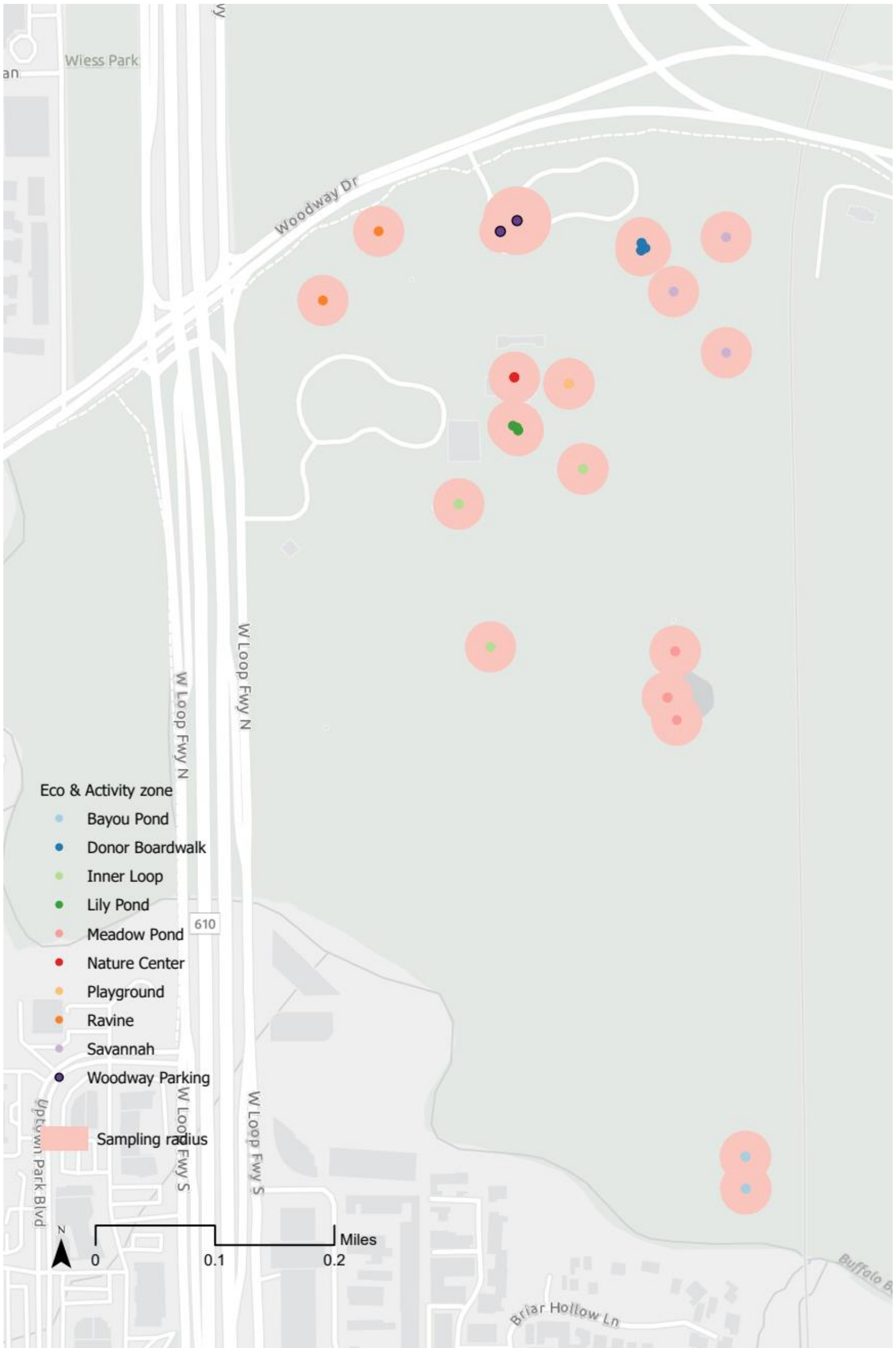

Figure 2. Spatial sampling of EMA survey (Important locations on trails and destinations in each ecozone were selected for spatial sampling.)

Potential participants could complete the online survey hosted on Qualtrics or the on-site survey in paper-and-pencil mode. The onsite survey was conducted between July 10th and July 31st on both weekdays and weekend days. The research team set up a booth at the main parking area of the arboretum. As visitors entered the arboretum, they were provided with flyers of the study and invited to participate. The researchers explained the purpose, process, benefits, and risks associated with participating in this study and answered any questions they may have. Once a potential participant was determined to be eligible and gave informed consent, they were included in this study. They filled out a pre-visit survey and was provided a Nokia phone with the EMA questions pre-programed. They then started their park visit as planned and without any intervention from the research team. When they finished their visit, they returned to the research desk to check out, received a small gift as a token of appreciation, and returned the phone.

Questions and measures.

The online and pre on-site visit questionnaire collected information on: previous experience of the arboretum, usage of facilities, trails, and programs, and perceived restorativeness of the environment; travel mode and purpose of the current visit; and sociodemographic conditions.

The EMA questionnaire collected information on perceived biodiversity, affect and mood state, and thermal comfort of the specific areas within the arboretum. Specifically, the restorativeness of the environment was measured using the Perceived Restorativeness Scale – Short with five items. Levels of anxiety was measured using the State Anxiety scale – Short with six items (three for positive and three for negative moods).

Sources:

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Limitations:

- The survey methods yield data that reveal correlations between the environment and health benefits, but these relationships cannot be interpreted as causal determinants.
- As we aimed to assess the experience and health benefits to users of the arboretum, the indirect benefits to surrounding residents through urban heat island reduction, air purification, and other pathways were not captured.

Demographic Information:

Based on the user survey, visitors represent 38% adults aged 18-44 years, 33.5% adults aged 45-64 years, and 28.4% adults aged 65 years and above. About 32% of survey-takers are non-White and 30.4% are Hispanic or Latino.

Calculations:

Retrospective user study
A total of 365 responses were received for the Retrospective user study.

Demographics:

4 respondents out of 292 were aged 18-24 years: 4/292 = 1.4%
24 respondents out of 292 were aged 25-34 years: 24/292 = 8.2%
83 respondents out of 292 were aged 35-44 years: 83/292 = 28.4%
41 respondents out of 292 were aged 45-54 years: 24/292 = 14.0%
57 respondents out of 292 were aged 55-64 years: 57/292 = 19.5%
83 respondents out of 292 were aged over 64 years: 24/292 = 28.4%

22 respondents out of 344 were Hispanic, Latino, or Spanish origin: 22/344 = 6.4%
301 respondents out of 344 were not Hispanic, Latino, or Spanish origin: 301/344 = 87.5%

275 respondents out of 344 were Caucasian: 275/344 = 79.9%
12 respondents out of 344 were African American: 12/344 = 3.5%
16 respondents out of 344 were Asian: 16/344 = 4.7%
2 respondents out of 344 were American Indian or Alaska Native: 2/344 = 0.6%
11 respondents out of 344 identified with two or more races: 11/344 = 3.2%
6 respondents out of 344 identified with other specific races (e.g., Middle Eastern, Arab): 6/344 = 1.7%

19 respondents out of 292 didn't receive college degrees: 1/292 + 4/292 + 14/292 = 6.5%
5 respondents out of 292 attained associate degrees: 5/292 = 1.7%
128 respondents out of 292 attained bachelor's degrees: 128/292 = 43.8%
140 respondents out of 292 attained graduate degrees: 140/292 = 48.0%

Socioeconomic:

135 respondents out of 290 were full-time employees: 135/290 = 46.6%
14 respondents out of 290 were part-time employees: 14/290 = 4.8%
39 respondents out of 290 were self-employed: 39/290 = 13.5%
85 respondents out of 290 were students or retired: 85/290 = 29.3%
17 respondents out of 290 were self-employed: 17/290 = 5.9%

14 respondents out of 252 identified a total household income of less than $50,000: 14/252 = 5.6%
30 respondents out of 252 identified a total household income of $50,000 to $74,999: 30/252 = 11.9%
34 respondents out of 252 identified a total household income of $75,000 to $99,999: 34/252 = 13.5%
52 respondents out of 252 identified a total household income of $100,000 to $149,999: 52/252 = 20.6%
37 respondents out of 252 identified a total household income of $150,000 to $199,999: 37/252 = 14.7%
85 respondents out of 252 identified a total household income of $200,000 or more: 85/252 = 33.73%

Sources:
See overall methods for survey study.

Limitations:

- See overall methods for survey study.

- ***Reduces anxiety as reported by 137 visitors while moving through the site. Over 40% of visitors reported feeling very calm, relaxed, and content and more than 65% reported not being tense, upset, or worried at all. Overall anxiety was significantly negatively correlated with perceived naturalness of the scenery/zone.***

Ecological Momentary Assessment
A total of 137 responses were received for the on-site ecological momentary assessment, and a total of 355 EMA surveys were completed, which averaged to 2.6 EMA surveys per participant.

Demographics*:
41 respondents out of 135 were Hispanic, Latino, or Spanish origin: 41/135 = 30.4%
94 respondents out of 135 were not Hispanic, Latino, or Spanish origin: 94/135 = 69.6%

74 respondents out of 131 were Caucasian: 74/131 = 56.5%
24 respondents out of 131 were African American: 24/131 = 18.3%
15 respondents out of 131 were Asian: 15/131 = 11.5%
3 respondents out of 131 were American Indian or Alaska Native: 3/131 = 2.3%
10 respondents out of 131 identified with two or more races: 10/131 = 7.6%
3 respondents out of 131 identified with other specific races (e.g., Middle Eastern, Arab): 3/131 = 2.3%

*The demographic of the ecological momentary assessment is somewhat different than the population who participated in the retrospective user study. As the EMA surveys were collected on-site, these statistics better represent the actual visitor population of the arboretum. The retrospective user survey, on the other hand, was limited by our recruitment methods and online survey mode. As a result, it may under-represent minority populations who have less access to digital resources.

Anxiety and affects
The six items of the STAI showed consistent high scores of positive affects and low scores of negative affects.

Calm: on average, the mean value was 3.2. Approximately 42.9% EMA instances reported that they felt very calm.

Relaxed: on average, the mean value was 3.2. Approximately 44.3% EMA instances reported that they felt very relaxed.

Content: on average, the mean value was 3.1. Approximately 44.6% EMA instances reported that they felt very content.

Tense: on average, the mean value was 1.5. Approximately 65.1% EMA instances reported that they did not feel tense at all.

Upset: on average, the mean value was 1.2. Approximately 87.5% EMA instances reported that they did not feel upset at all.

Worried: on average, the mean value was 1.3. Approximately 75.0% EMA instances reported that they did not feel worried at all.

Overall anxiety is significantly negatively correlated with perceived naturalness of the scene (rho = -.222, $p<.001$). Specifically, higher levels of perceived naturalness were positively correlated with feelings of calmness (rho =.223, $p<.001$), relaxation (rho =.216, $p<.001$), and content (rho =.219, $p<.001$). The negative relationship between perceived naturalness and feelings of being upset was also approaching statistical significance.

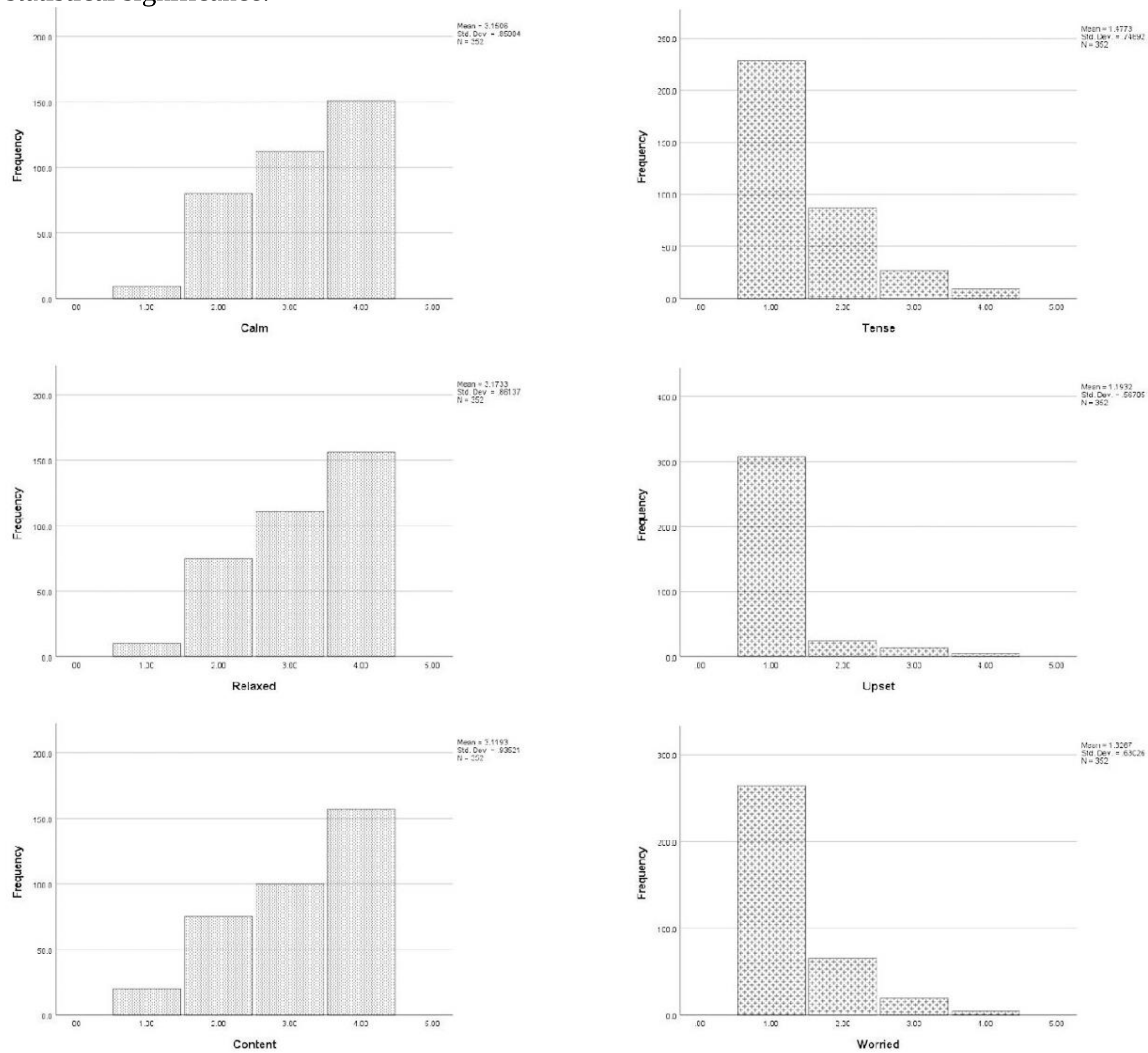


Figure 4. State anxiety measured concurrently during arboretum activities

Table 1. Bivariate correlation between perceived naturalness and affects (Spearman Correlation)

	Naturalness	Calm	Relaxed	Content	Tense	Upset	Worried
Naturalness	1.000	.223**	.216**	.219**	-0.047	-0.099	-0.033
Calm		1.000	.824**	.633**	-.420**	-.293**	-.446**
Relaxed			1.000	.670**	-.471**	-.268**	-.395**
Content				1.000	-.335**	-.243**	-.376**
Tense					1.000	.513**	.539**
Upset						1.000	.598**
Worried							1.000

**. significant at the 0.01 level (2-tailed).

Sources:
See overall methods for survey study.

Limitations:
- See overall methods for survey study.

- ***Offers restorative experiences according to 365 surveyed visitors who agreed that the HANC provides a sense of being away (92%), fascination (87%), coherence—having orderly scenes and activities (61%), scope—serving as a world of its own (85%), and compatibility—ease of moving around (83%).***

Calculations:
Retrospective user study
A total of 365 responses were received for the Retrospective user study.

<u>Perceived restorativeness:</u>
<u>Being away:</u>
271 respondents out of 294 agreed that the Arboretum is a place that is away from everyday demands and where someone would be able to relax and think about what interests him/her: 271/294 = 92.17%

<u>Fascination:</u>
255 respondents out of 294 agreed that the Arboretum is fascinating, and it is a place where someone could discover and be curious about things: 255/294 = 86.74%

<u>Coherence:</u>
180 respondents out of 294 agreed that the Arboretum is a place where scenes and activities are ordered and organized.: 180/294 = 61.22%

<u>Scope:</u>
249 respondents out of 294 agreed that the Arboretum is large and a world of its own.: 249/294 = 84.7%

<u>Compatibility:</u>
243 respondents out of 294 agreed that it is easy to orient and move around so that someone could do what he/she likes in the Arboretum: 243/294 = 82.65%

<u>Total restorativeness:</u>
Based on the 5-point rating scale, the mean values of five key facets that characterize the restorative environment in the Arboretum are as follows: 4.46 for the being-away, 4.30 for the fascination, 3.84 for the coherence, 4.19 for the scope, and 4.13 for the compatibility. So, the total restorative is 4.46 + 4.30 + 3.84 + 4.19 + 4.13 = 4.184.

Sources:
See overall methods for survey study.

Limitations:
- See overall methods for survey study.

- ***Provides desirable nature experiences, with 365 surveyed visitors identifying nature (17%), trails (13%), and plants and vegetation (11%) as their favorite aspects of the HANC.***

Calculations:
Retrospective user study
A total of 365 responses were received for the Retrospective user study.

<u>User reported benefits of the Arboretum</u>
An open-ended question was asked about users' favorite aspect regarding the benefits of the arboretum. A total of 72 words appeared at least twice, and the total frequency of these keywords was 456. The top-three popular aspects were as follows:
Nature: 79/456 = 17.3%
Trails: 59/456 = 12.9%
Plants/Trees/Flowers: [15(plants) + 12 (flora) + 11 (trees) + 10 (flowers)]/456 = 10.5%

Figure 3. A word cloud displaying the favorite aspects of the Arboretum voted by the users.

Sources:
See overall methods for survey study.

Limitations:
- See overall methods for survey study.

Economic Benefits

- ***Increased average property value within 1 mile by 42% during the beginning period of the HANC renovation (2010-2015), which is 24% higher than average property value for the period before the renovation (2005-2010). Property values increased by 13% and 14% from 2015-2020 and 2020-2022, respectively.***

Method:
To determine the effect of the Houston Arboretum and Nature Center (HANC) on the property values of the surrounding area, data was collected from the Harris County Appraisal District (HCAD). The spatial data were analyzed and mapped within a one-mile buffer around the continuous Memorial Park (the

HANC and the adjacent memorial park) to examine the trends of the property value in 2005, 2010, 2015, 2020, and 2022. These years were chosen is because the interval between property value data is 5 years. The primary property related measures that were used to determine patterns of increase or decreases within the area were the land, building, assessed, appraisal, market, and replacement cost new (RCN) values.

Geographic Information Systems (GIS) and real property data for the Houston area were collected from the Harris County Appraisal District (HCAD) public data. The spatial data contained parcel polygons and HCAD account numbers of real property information. The property data include information such as owner name, mailing address, and certified property value components at parcel levels for the years 2005, 2010, 2015, 2020, and 2022. The property data was exported from the original text file format into Excel for each year. A one-mile buffer around the HANC was utilized. The buffer's parcel identification numbers were exported and cross-referenced to those within the real property data.

The property data Excel sheets for each year were imported into ArcGIS Pro 2.9.1 and were then joined to the previously downloaded GIS parcels that were trimmed to the one-mile buffer around Memorial Park from the L-THIA model. The property values of land, building, assessed, appraisal, market, and RCN were classified into 5 categories based on a Natural Break (Jenks) for each year. Each year was then joined into a single layer so that the attribute tables could be exported back into Excel. In Excel, the compiled table of parcel property data was used to determine trends of the property value from 2005 to 2022. For each property value component and year, the average was calculated which was used to determine the percent change between each of the years.

Calculations:
The percent changes were calculated based on the average values for each year between two sequential years.

For example:
The average market price for the year 2005 = $699920.74
The average for 2010 = $837606.10
The percent change between the 2005 – 2010 = ($837606.10 - $699920.74)/ $837606.10 = 19.67%.
This process was repeated for each year's average

Average percentage change in property value from 2005 to 2010 = (35.69% + 5.12% +19.48% + 21.36% + 19.67% + 6.48%) / 6 = 17.97%
Average percentage change in property value from 2010 to 2015 = (34.70% + 50.37% + 41.81% + 33.57% + 41.62% + 50.82%) / 6 = 43.15%

Average percentage change in property value from 2015 to 2020 = (17.67% + 10.43% + 13.99% + 21.38% + 14.26% + 0.53%) / 6 = 13.04%

Average percentage change in property value from 2020 to 2022 = (3.54% + 25.27% + 14.34% + 11.49% + 14.30% + 17.30%) / 6 = 14.37%

Table 1. Percentage change in the property value within the 1-mile buffer of the continuous Memorial Park

Category	2005-2010	2010-2015	2015-2020	2020-2022
Land	35.69%	34.70%	17.67%	3.54%
Building	5.12%	50.37%	10.43%	25.27%

Assessed	19.48%	41.81%	13.99%	14.34%
Appraisal	21.36%	33.57%	21.38%	11.49%
Market	19.67%	41.62%	14.26%	14.30%
RCN	6.48%	50.82%	0.53%	17.30%
Average	17.97%	42.15%	13.04%	14.37%

* The HANC phase I renovation started in 2013, completed in 2018, and ravine was opened in May 2019

Over the years from 2005-2022, the property values of all the components have increased. In addition, there was a continuous positive increase of percent changes for all the property value categories across each year with the highest percent change occurring between the years 2010 and 2015 for all the categories except land value. However, it is interesting to note that the percent change of 2015-2020 had a drastic fall in percent change (although still increasing), the most significant being the RCN value. These results are displayed in Table 1. This may be helping to reduce the occurrence of gentrification.

As the largest increase in percent change in values for most of the categories occurred between 2010-2015, which correlates to the beginning of the HANC project in 2013; it can be assumed that the establishment of the HANC supported the increase in the property values. Because of this, the property values may continue to rise as the parcels around the park are affected by the HANC's master plan.

Sources:

HCAD. 2022. "Harris County Appraisal District." HCAD. 2022. https://hcad.org/.

Limitations:

- The downloadable data for the property values does not contain all the parcels within the buffer.
- The number of parcels containing property information data differed for each of the years due to replatting over time. For example, the parcel-ID of 1357010010028 had no available property data information for the year 2005, but in 2010, there was data present.
- The interval between property value data is 5 years, which makes it difficult to analyze specifically to each year.

- ***Generates an estimated $27,200 annually in additional parking revenue, driven by goat management and burning and their appeal to visitors, even after covering the costs of these approaches.***

Background:

Natural disturbances such as fire and the grazing of buffalo have historically maintained a more open prairie and savanna landscape in the Houston region. With the growth of the metropolis, these natural disturbances disappeared—the HANC became overly wooded. To prevent the HANC from becoming overly wooded again, HANC uses seasonal prescribed burning and goats to mimic natural processes to maintain the prairie and savanna of the site. Prescribed burning is used once a year, mostly employed to manage invasive late-season annual broadleaf and grass species. Goat control is deployed twice a year, providing effective, sustainable pasture management that helps conventional control techniques. The first occurred in the 1.573 acres (68,519.88 sf) north and south woodway pond areas and the second occurred in the 4.277 acres (186,306.12 sf) savanna field area and the 2.9 acres (126324 sf) savanna extension area.

Method:

The area with native plants that require regular weeding is about 11.75 acres (511,830 sf). This area may vary slightly from year to year depending on the condition of the plant. The prescribed burning applies to an area of 3 acres (130,680 sf), and the remaining 8.75 (381,150 sf) acres were controlled by goats due to the density of shrubs and woody species. According to the HANC, burning occurs once a year and costs $3,500 per burn, plus $200 per acre. Goat control is deployed twice a year in two different regions, and costs vary from region to region. The first occurs in the 1.573 acres (68,519.88 sf) north and south woodway pond areas at a cost of $3,539 and the second occurred in the 4.277 acres (186,306.12 sf) savanna field area and the 2.9 acres (126324 sf) savanna extension area, at a cost of $8,660 and $6,525 respectively. On average, each "goat mowing" event has seen an increase of about 10,000 more vehicles than usual, which generates additional revenue for the HANC. Using these numbers, we calculated the HANC earns $27,200 in additional funds after covering costs of goat management and burning with increased ticket revenue. Calculations provided demonstrate specific information.

Calculations:
<u>Burning</u>
Burning Time Spent
Average number of times burning occurs per year = 1
Burning Costs
Expense per burn = $3,500 per burn + $200/acre
Expense to burn the HANC = $3,500 + $200 * 3 acres = $4,100

<u>Grazing</u>
Grazing Costs
For the first time of year:
North and south woodway ponds (1.573 acres) = $3,539
For the second time of year:
Savanna field (4.277 acres) = $8,660
Savanna extension (2.9 acres) = $6,525
Expense to graze the HANC = $3,539 + $8,660 + $6,525 = $18,724 ≈ $18,700

<u>Income from Tourists Attracted by Goats:</u>
Attracted vehicles for the “Goat Mowing” event = 10,000
The HANC Parking fee = $5 per car
Increased parking fee for the “Goat Mowing” event = 10,000 * $5 = $50,000
Costs of goat management and burning saved through ticket revenue = (Income from tourists attracted by goats) - (Expense to burn the HANC + Expense to goat mowing/grazing) = $50,000 -($4,100 + $18,700) = $27,200

Sources:
Information on prescribed burning and goats are provided by HANC.

Limitations:

- Numbers used for time spent burning and goats are estimates based on discussion with the HANC staff. Due to strict burn constraints and the possibility of shifting weather, it is hard to know exact timing and length of burns.

- ***Generates parking revenue, with a 151% increase in revenue in the first year after renovation (2019), 271% in the second year after renovation (2020), and 222% in the third year after renovation (2021), as compared to pre-renovation parking revenue from 2016.***

Method:
The renovation included in Phase 1 of the HANC plan, which began in 2013 and was completed in 2019. We used 2016 as the baseline to compare parking revenue earned by the HANC before and after renovation, rather than using the years before 2013 and any other years that during the construction because 2016 was the only year with a complete record before the renovation was completed. The annual parking fee is equal to the annual number of cars at each entrance multiplied by $5 per vehicle parking fee.

Calculations:
<u>2016</u>
2016 total car counts = 56,605
2016 total parking fee = 56,605 * 5 = 283,025

<u>2019</u>
2019 total car counts = 141,919
2019 total parking fee = 141,919 * 5 = 709,595

<u>2020</u>
2020 total car counts = 209,743
2020 total parking fee = 209,743 * 5 = 1,048,715

<u>2021</u>
2021 total car counts = 182,218
2021 total parking fee = 182,218 * 5 = 911,090

Parking revenue increase rate in the first year of renovation completion (2019) compared to 2016 = (2019 total parking fee – 2016 total parking fee)/ 2016 total parking fee = (709,595 - 283,025)/ 283,025 = 151%

Parking revenue increase rate in the second year of renovation completion (2020) compared to 2016 = (2020 total parking fee – 2016 parking fee)/ 2016 parking fee = (1,048,715 - 283,025)/ 283,025= 271%

Parking revenue increase rate in the first year of renovation completion (2019) compared to 2016 = (2021 total parking fee – 2016 total parking fee)/ 2016 total parking fee = (911,090 - 283,025)/ 283,025 = 222%

Implementing paid parking has provided the Arboretum with an important revenue stream that supports its dual mission of nature education and conservation. The nominal fee has not impacted visitation, and the income generated from parking fees enables the Arboretum to provide better and more effective services to its rapidly growing audience of visitors. This additional income has allowed the organization to expand its educational offerings, grow program staff, and perform maintenance and upkeep on the site's many beautiful new spaces.

Sources:
The annual number of cars at each entrance is provided by HANC.

Limitations:
- Data for 2017, 2018, and 2022 are incomplete and there are no data before 2016.

- ***Contributes to a 43% average increase in median property tax revenue for owner-occupied homes in the surrounding census tracts before and after the construction of the HANC, while***

median property tax revenue for Harris County as a whole increased by only 7% over the same period.

Method:
The median real estate taxes data were obtained from American Community Survey data before construction and after the construction of the HANC. For comparison, census tracts with 1 mile buffer zone around continuous Memorial Park (the HANC and the adjacent memorial park) were analyzed and compared to Harris County median data. The city developed the HANC within Memorial Park to provide nature education as well as an urban wildlife sanctuary. Therefore, it is reasonable to include Memorial Park in the analysis of HANC.

Calculations:
There are 18 census tracts within a 1-mile buffer around the HANC (see figure 1). 6 census tracts were excluded in our analysis due to missing data in 2013. Total median real estate taxes paid for owner-occupied housing units (dollars), both with a mortgage and without a mortgage, of these 12 census tracts and Harris County were obtained from 2013 and 2019 American Community Survey (ACS) 5-year estimates. Property taxes estimates in the 2009-2013 ACS 5-year data set are inflation-adjusted to 2013 dollars. Property taxes estimates in the 2015-2019 ACS 5-year data set are inflation-adjusted to 2019 dollars. To compare estimates between the two, multiply the 2009-2013 dollar estimates by 1.09927007 (CPI-U-RS) in order to inflation-adjust 2013 dollars to 2019 dollars.

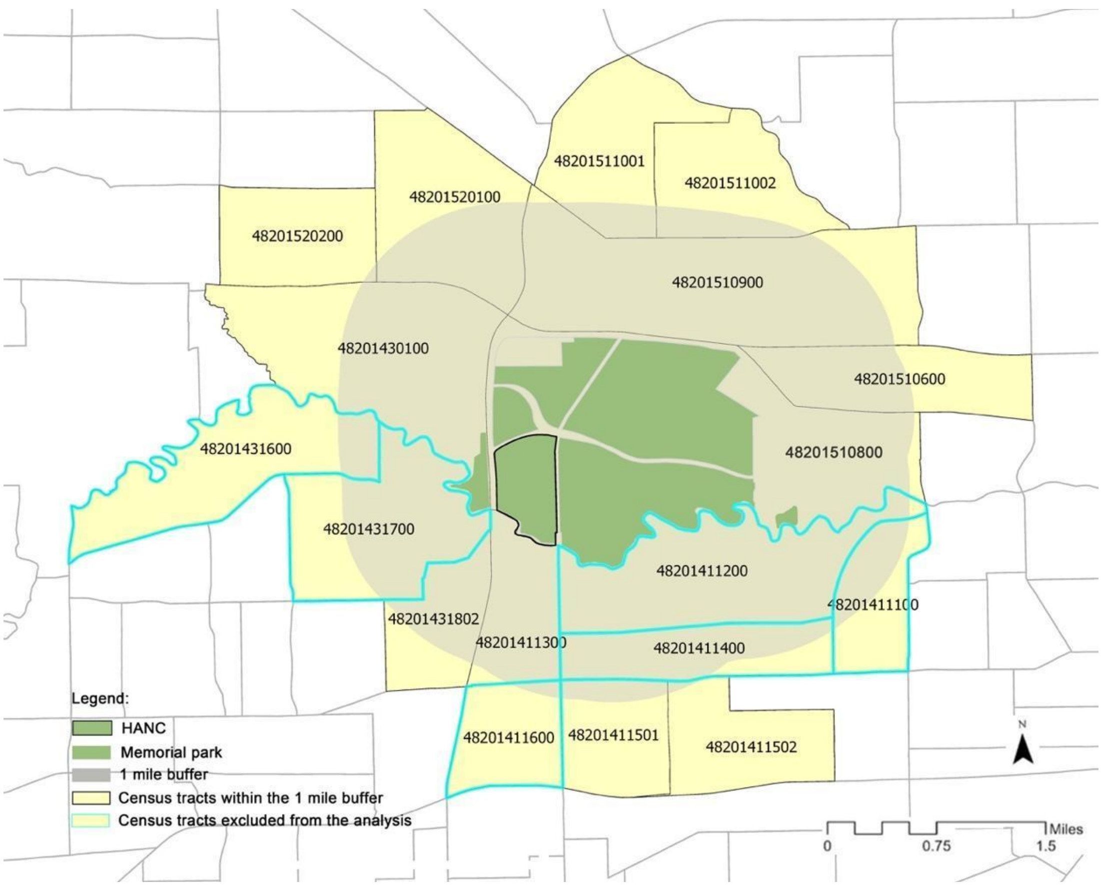


Figure 1: Census Tracts within 1-mile buffer around the HANC (ESRI ArcGIS)

Table 1: Median real estate taxes paid for owner-occupied housing units of these 12 census tracts and Harris County (Adjusted for inflation)

		Harris County, Texas	482015 20100	482014 31802	482015 11002	482014 11501	482015 11001	482014 11502	482015 10900	482014 30100	482015 10600	482014 11300	482015 10800	482015 20200
2019	**Total**	**3527**	**7130**	**5630**	**7016**	**6168**	**6734**	**5724**	**7434**	**9048**	**7766**	**10000**	**7738**	**9862**
	Median real estate taxes paid for units with a mortgage	3968	10000	5344	8365	10000	7798	5927	7813	8543	7989	10000	8013	10000
	Median real estate taxes paid for units without a mortgage	2660	3676	5750	3780	3577	4645	4750	6481	10000	6598	10000	7125	7896
2013	**Total**	**3308**	**1891**	**4181**	**5566**	**5799**	**5817**	**5878**	**5911**	**5968**	**6248**	**7156**	**8175**	**8245**
	Median real estate taxes paid for units with a mortgage	3717	2784	5862	6064	8104	6372	8087	6322	7245	6633	7781	8829	9346
	Median real estate taxes paid for units without a mortgage	2323	674	3817	4747	3913	3619	3289	2795	3829	2022	4695	7035	5681
	Amount of change	**219**	**5239**	**1449**	**1450**	**369**	**917**	**-154**	**1523**	**3080**	**1518**	**2844**	**-437**	**1617**
	Percentage change	**7%**	**277%**	**35%**	**26%**	**6%**	**16%**	**-3%**	**26%**	**52%**	**24%**	**40%**	**-5%**	**20%**

<u>Average percent change of total median real estate taxes paid for units in these 12 census tracts (adjust for inflation):</u>
Average percent change: (277% + 35% + 26% + 6% + 16% - 3% + 26% + 52% + 24% + 40% -5% + 20%) / 12 = 43%

<u>Percent change of total median real estate taxes paid for units in Harris County (adjust for inflation):</u>
Percent change: (3527-3308)/3308 = 7%

Sources:
2013 and 2019 American Community Survey (ACS) 5-year estimates.

Limitations:

- Many factors outside of the HANC can also contribute to these increases. The data used in this calculation is only collected for owner-occupied units.
- Because of the close relationship between HANC and Memorial Park, it is difficult to separate HANC's impact on real estate taxes from that of Memorial Park.
- 6 census tracts were excluded in the analysis due to missing data in 2013.

Cost Comparison

- ***Converting areas of trees damaged by natural disasters to prairie/savanna ecosystems through seeding will save an estimated $2,832,000 in potential replacement costs and water savings over***

the next 15 years as compared to the original strategy of replanting the HANC with individual trees and lawn. The projected 15-year cost savings on plant materials and installation labor is $934,00 and cost savings on water is $1.9 million when comparing the prairie/savanna seeding and plugs to the original strategy of trees and lawn.

Background:
More than 50% of the tree canopy of the Houston Arboretum and Nature Center (HANC) had been lost due to high winds caused by hurricanes and years of drought from 1998 to 2013. Through a comprehensive analysis, landscape architects with Design Workshop and Reed Hilderbrand planting native wildflowers and grasses that matched the area's historic native prairie and savanna, rather than planting trees and large lawns like traditional botanical gardens. This makes the HANC more resilient to future climate shocks such as more frequent and severe hurricanes, flooding, and drought. There are 25 acres of prairie/savanna area renovated in the HANC, of which 18.6 acres were savanna/prairie seed mixed application and 1.9 acres were savanna/prairie plug mix application, and the remaining 4.5 acres were conserved.

Method:
We compared the cost of currently planted prairie/savanna vegetation in the HANC with the scenario of replanting the HANC with trees over the next 15 years under alternating hurricanes and droughts. According to the climate impact assessment for the City of Houston, climate and weather extremes are projected to be more frequent and intense in the future. Due to climate change, more frequent hot, dry summers may occur in the greater Texas region. Heavy precipitation is also expected to continue to increase. Daily 20-year extreme precipitation in the Southern Great Plains is expected to rise by 9% and 13% by mid-century under lower and higher scenarios, respectively. It is expected to rise by 12 to 20% by the end of the century under a lower and higher scenario. Hurricanes are expected to be stronger and bring more rain. The intensity of hurricane-related rainfall is also expected to rise (Stoner and Hayhoe 2020). This cost comparison consists of two parts. The first part is about the difference in costs (plant purchasing costs and the costs of actually planting them) between the two scenarios over the next 15 years, and the second part is about the difference in water consumption between the two scenarios over the next 15 years. In the scenario of replanting the HANC with trees, it is assumed that the removed 64 trees would be replanted in the HANC prairie/savanna area and the remaining areas that were planted with savanna/prairie seeds and plugs would instead replaced by lawn seeds commonly used in the Houston area. Planting large lawns is a traditional method practiced by arboretums in the United States.

<u>Difference in costs (plant purchasing and planting costs) between the two scenarios over the next 15 years</u>
We compared the cost of the savanna/prairie seed mix and plug mix used in the HANC prairie/savanna area with the cost of replanting trees and planting large lawn. According to the HANC, the savanna/prairie seed mix and plugs cost is about $200,000 and planting them is about $800,000. There are 65,770 plugs in the savanna/prairie plug mix, but about 50,000 plugs were cultivated from local seeds collected by conservation teams and volunteers. Therefore, the total cost of the savanna/prairie seed mix and the savanna/prairie plug mix used in the HANC prairie/savanna area is about $1,000,000.

The scenario of replanting the HANC with trees assumes that 64 removed trees would be replanted in the grassland/savanna area and the remaining 19.2 acres (836,154 sf) would be covered by lawn. The average cost for trees 14 to 20 feet tall is $2,118, including transportation, site preparation and cleanup, equipment, and miscellaneous supplies. The average tree planting cost is approximately $38 per hour. Planting a tree takes an estimated 8 hours and costs $304 in labor (howmuch.net 2022). Therefore, the cost of replanting trees would be about $155,072 (see table 1). The remaining 19.2 acres (836,154 sf) would be covered by lawn sods commonly used in Houston, such as Augustine, Zoysia, and Bermuda. Generally, they cost about $2 per square foot when including sod cost, soil preparation, delivery, and installation fees (HomeGuide 2020). Thus, the cost of planting lawn would be about $1,672,308. The total cost of the scenario of replanting the HANC with trees would be about $1,827,380.

The total cost of the savanna/prairie seed mix and plug mix used in the HANC prairie/savanna area is about $1,000,000 and the total cost of the scenario of replanting the HANC with trees is about $1,827,380. The plant purchasing and planting costs of savanna/prairie seed and plug scenario is $827,380 less than the scenario of replanting the HANC with trees. Moreover, it is necessary to account for the fact that the savanna/prairie plants are more resilient to future climate shocks such as more frequent and severe hurricanes, flooding, and drought. Since over 50% of the tree canopy was lost from the impact of alternating hurricanes and drought over the last 15 years, and hurricanes and droughts are expected become more severe in the future, we assume at least another 50% of newly planted trees would be lost in the next 15 years. The average price of tree removal is $1,200 (Wallender 2021). Assuming 32 (50% of 64) trees dying, removing them will cost $38,400. Again, to make up for this loss, 32 new trees would be replanted, which would cost about $67,776. As a result, the total cost of removing dead trees and replanting new trees would be $106,176 over the next 15 years, not accounting for potential multiple losses of individual trees. Conversely, savanna/prairie plants will be more sustainable than trees. Local seeds collected by conservation groups and volunteers will suffice to compensate for the loss of savanna/prairie plants, so that the HANC will not spend any funds on replacement savanna/prairie plants. These costs were covered by volunteers and group engagement. In this way, the cost of using the savanna/prairie seed mix and the savanna/prairie plug mix was about $933,556 less expensive than replanting trees over the next 15 years.

<u>Difference in water consumption between the two scenarios over the next 15 years</u>

The WaterSense Water Budget Tool (V 1.04) was used to calculate the water consumption of these two scenarios. EPA developed this tool to help facility managers, building owners, and other stakeholders with a variety of resources and initiatives to ensure a measure of efficiency and regional suitability for the amount of water applied to a landscape based on local climate data. Even though the water budget approach generally serves as a design tool for building owner, this takes into account the critical elements that determine the amount of water used in the landscape of the park, such as plant type, plant water demand, irrigation system design, and applied water that the landscape obtains through irrigation or precipitation. Therefore, it can be adapted to calculate the water consumption for the landscape of the built park.

Inputs to this calculator include the location of the landscape, zip code, the area, plant type, how much water the designed landscape requires, and irrigation system design. Zip code and landscaped area are used to create the baseline. The baseline is about the amount of water required by the site during the peak watering month if watered at 100 percent of reference evapotranspiration. The results of this tool determine whether the designed landscape's water requirement is less than the calculated landscape water allowance and calculate the percentage difference from the baseline (EPA 2022).

Required inputs were entered into the WaterSense Water Budget Tool (V 1.04). The savanna/prairie seed mix and plug mix area is 20.5 acres, which is 891,194 sf. For the replanting trees scenario, we estimated the canopy of a tree is 860 sf; thus the area of 64 trees is 55,040 sf and area of lawn is 836,154 sf. The plant types for the savanna/prairie scenario is chosen as "groundcover", and the replanting tree scenario are selected as "tree" and "turfgrass". The water requirements (high, medium, and low water use) of each species for both scenarios were obtained from the Lady Bird Johnson Wildflower Center plant databases (The University of Texas at Austin 2022). Based on the water requirement information of plants, we calculated the high, medium, and low water use areas for both scenarios (see appendix 2 & 3). In the savanna/prairie scenario, the irrigation type was selected as "Drip – Press Comp" for high water-use areas, and "No irrigation" was selected for medium and low water-use areas. In the tree planting scenario, the irrigation types of the high and medium water-use areas were selected as the “Drip - Standard” (see figure 1 and figure 3).

The results show that the savanna/prairie scenario’s water requirement is a 90% reduction in water use from the baseline, while the replanting trees scenario’s water requirement is 11% above in water use from the baseline. The savanna/prairie scenario basically uses 370,236 gallons per month for irrigation, while the replanting tree scenario use 399,626 gallons per month for irrigation (see figure 2 and figure 4). Based on the City of Houston, the outdoor water utility rate is $11.04 per 1000 gallons (City of Houston 2022). Therefore, the monthly utility bill is $735,733 for the savanna/prairie scenario and $794,137 for the replanting trees scenario. The savanna/prairie scenario will save $58,404 in water utility fees compared to the replanting tree scenario after 15 years.

<u>Difference in total cost between the two scenarios after 15 years</u>
The cost of using the savanna/prairie seed mix and the savanna/prairie plug mix would be about $43,603 cheaper than replanting trees in next 15 years. The savanna/prairie scenario will save $58,404 water utility fee than the replanting tree scenario after 15 years. Thus, total cost saving for the savanna/prairie scenario after 15 years is $102,007 less expensive than the replanting tree scenario.

Calculations:
<u>Difference in plant purchasing and planting costs between the two scenarios over the next 15 years</u>

The savanna/prairie seeding scenario
The total plant purchasing and planting costs for the savanna/prairie seeding scenario = The savanna/prairie seed mix and plugs cost + The cost to plant seeds and plugs in the ground = $200,000 + $800,000 = $1,000,000

The replanting trees scenario

Table 1. The replanting trees scenario plant costs

Item	Unit Cost	Quantity	Line Cost
Large tree: each tree is 14 to 20 fts tall delivered in a 1 cubic yard box; includes transport, site preparation and clean up, equipment, and miscellaneous supplies	2119	64	135616
Planting cost	38	512	19456
Total cost	2423	64	155,072

The purchasing cost of 64 trees = The average purchasing cost for trees 14 to 20 feet tall * 64 = $2,119 * 64 = $135,616

The planting cost of 64 trees= The average planting cost per hour * The average hours for planting a tree * 64 = $38/hour * 8 hours *64 = $19,456
The total plant purchasing and planting costs for 64 trees = $135,616 + $19,456 = $155,072

The total purchasing and planting costs for lawn sod and labor of planting = The average purchasing and planting cost for lawn sod * The area of lawn = 836,154 sf * $2 per sf = $1,672,30

The total purchasing and planting costs of the scenario of replanting the HANC with trees = The total cost for 64 trees + The total cost for lawn sod = $155,072 + $1,672,30 = $1,827,380.

Difference in the total purchasing and planting costs between the two scenarios = The total purchasing and planting costs of the scenario of replanting the HANC with trees **-** The total purchasing and planting costs for the savanna/prairie seeding scenario = $1,827,380 - $1,000,000 = $827,380

Over the next 15 years
50 % of trees are assumed to be dead = 64*50% = 32
The average price of tree removal = $1,200
The remove cost of 32 trees = $1,200*32 = $38,400
The cost of replanting 32 trees = $2423*32 = $67,776
The total cost of removing dead trees and replanting new trees over the next 15 years = $38,400 + $67,776 = $106,176

Difference in the total purchasing and planting costs between the two scenarios over the next 15 years = Difference in the total purchasing and planting costs between the two scenarios + The total cost of removing dead trees and replanting new trees over the next 15 years = $827,380 + $106,176 = $934,156

The savanna/prairie scenario saves $934,156 in terms of plant and labor costs for replacement over the next 15 years.

<u>Difference in water consumption between the two scenarios over the next 15 years</u>
The savanna/prairie seeding scenario

WaterSense New Home Specification: Water Budget Tool (V 1.04)

Enter your information in these columns.		These columns will automatically populate.	
This water budget tool shall be used to determine if the designed landscape meets Criteria 4.1.1 of the specification.			
Please refer to the WaterSense Water Budget Approach for additional information.		Peak watering month:	jul
Your Name:	TAMU		
Builder Name:	HANC	1B: Average monthly reference	
Lot Number/Street Address:	4501 Woodway Dr.	evapotranspiration (ETo):	6.98 inches/month
City, State:	Houston, Texas	2A: Average monthly rainfall:	3.04 inches/month
Zip Code (required):	77024		
* In Canada, enter just the frst three characters of your postal code (e.g. A1A)			
		Monthly **baseline** (gallons/month) based	
Enter information about your landscape here:		on the site's peak watering month:	3,878,158 gallons/month
STEP 1A - ENTER THE LANDSCAPED AREA (A)		Monthly **landscape water allowance** or **LWA** (gallons/month) based	
891,194	Area of the designed landscape (square feet)	on the site's peak watering month:	2,714,711 gallons/month
Is an irrigation system installed on this site?			
Yes			

Need help?
See the WaterSense website for help on what to plant or search for a certified irrigation pro!

Step 2B/Table 1.

Zone	Hydrozone/Landscape Feature Area (sq. ft.)	Plant Type or Landscape Feature	Water Use	Irrigation Type	Landscape Coefficient (K_L)	Default DU (hidden)	Distribution Uniformity (DU_{LQ})	LWR_H (gal/month)
1	129535	Groundcover	High	Drip - Press Comp	0.7	65%	90%	370,236
2	587053	Groundcover	Medium	No Irrigation	0.5	65%	NA	-
3	174,606	Groundcover	Low	No Irrigation	0.2	70%	NA	-
4								-
5								-
6								-
7								-
8								-
9								-
10								-
11								-
12								-
13								-
14								-
15								-
Total Area =	891,194 of 891194 square feet				Landscape Water Requirement or LWR for the Site (gal/month)			370,236
					You have used		14%	of your allowance.
					This is		90%	below the baseline.

Fig1. Inputs of Water Budget Tool for the savanna/prairie seeding scenario

WaterSense New Home Specification: Water Budget Tool (V 1.04)
This water budget tool shall be used to determine if the designed landscape meets Criteria 4.1.1 of the specification.
Please refer to the WaterSense Water Budget Approach for additional information.

Your Name:	TAMU
Builder Name:	HANC
Lot Number/Street Address:	4501 Woodway Dr.
City, State, Zip Code:	Houston, Texas
Peak Watering Month:	jul
Is an irrigation system being installed on this site?	Yes

This worksheet determines if the designed landscape meets the water budget.

If the landscape water requirement is LESS than the landscape water allowance, then the water budget criterion is met.
If the landscape water requirement is GREATER than the landscape water allowance, then the landscape and/or irrigation system needs to be redesigned to use less water.

STEP 3A - REVIEW THE LWA AND LWR FROM PART 1 AND PART 2

LWA 2,714,711 (gallons/month) LWR 370,236 (gallons/month)

STEP 3B - REVIEW THE TOTAL AREA OF TURFGRASS* IN THE DESIGNED LANDSCAPE FROM STEP 2B

The designed landscape contains 0 square feet of turfgrass.* This is 0% of the landscaped area.

*This includes the area of any pools, spas, and/or water features, designated by WaterSense to be counted as turfgrass.

OUTPUT - DOES THE DESIGNED LANDSCAPE MEET THE WATER BUDGET?

YES If YES, then the water budget criterion is met.
If NO, then the landscape and/or irrigation system needs to be redesigned to use less water.

The designed landscape water requirement is a 90% reduction in water use from the baseline calculated in Part 1.

Fig 2. Results of Water Budget Tool for the savanna/prairie scenario

Landscape water requirement for the savanna/prairie scenario = 370,236 gallons/month
The outdoor water utility rate = $11.04 /1000 gallons
The monthly water utility bill for the savanna/prairie scenario = 370,236 gallons/month * $11.04 /1000 gallons = $4,087
The water utility bill for the savanna/prairie scenario over 15 years = $4,087 *12 *5 = $245,244

The replanting trees scenario

WaterSense New Home Specification: Water Budget Tool (V 1.04)

Enter your information in these columns. | **These columns will automatically populate.**

This water budget tool shall be used to determine if the designed landscape meets Criteria 4.1.1 of the specification.
Please refer to the WaterSense Water Budget Approach for additional information.

Your Name:	TAMU
Builder Name:	HANC
Lot Number/Street Address:	4501 Woodway Dr.
City, State:	Houston, Texas
Zip Code (required):	77024

* In Canada, enter just the frst three characters of your postal code (e.g. A1A)

Peak watering month:	jul	
1B: Average monthly reference evapotranspiration (ETo):	6.98	inches/month
2A: Average monthly rainfall:	3.04	inches/month
Monthly **baseline** (gallons/month) based on the site's peak watering month:	3,878,158	gallons/month
Monthly **landscape water allowance** or **LWA** (gallons/month) based on the site's peak watering month:	2,714,711	gallons/month

Enter information about your landscape here:
STEP 1A - ENTER THE LANDSCAPED AREA (A)
891,194 **Area of the designed landscape (square feet)**
Is an irrigation system installed on this site?
Yes

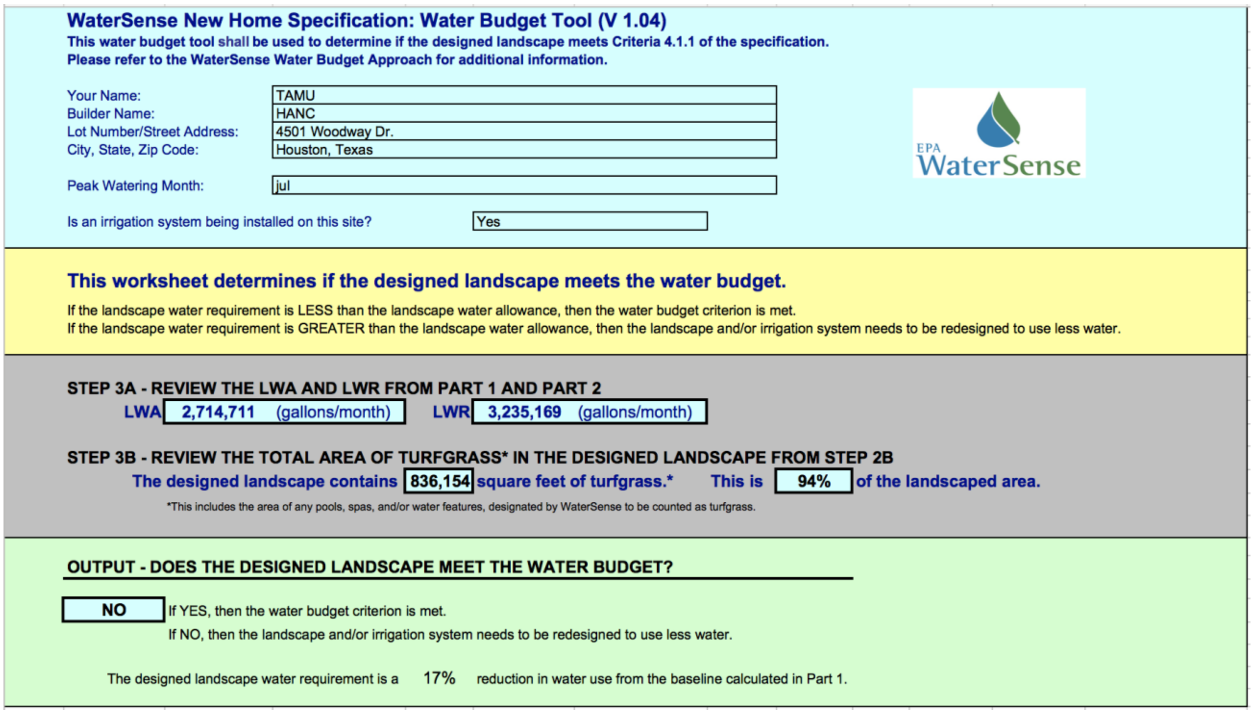
Need help?
See the WaterSense website for help on what to plant or search for a certified irrigation pro!

Step 2B/Table 1.

Zone	Hydrozone/Landscape Feature Area (sq. ft.)	Plant Type or Landscape Feature	Water Use	Irrigation Type	Landscape Coefficient (K_L)	Default DU (hidden)	Distribution Uniformity (DU_{LQ})	LWR_H (gal/month)
1	53320	Trees	High	Drip - Standard	0.9	65%	70%	262,235
2	1720	Trees	Medium	Drip - Standard	0.5	65%	70%	4,182
3	334,461	Turfgrass	Low	Drip - Standard	0.6	65%	70%	1,021,161
4	334,462	Turfgrass	Medium	Drip - Standard	0.7	65%	70%	1,229,086
5	167,231	Turfgrass	High	Drip - Standard	0.8	65%	70%	718,505
6								-
7								-
8								-
9								-
10								-
11								-
12								-
13								-
14								-
15								-
Total Area =	891,194 of 891194 square feet		Landscape Water Requirement or LWR for the Site (gal/month)					3,235,169

You have used 119% of your allowance.
This is 17% below the baseline.

Figure 3. Inputs of Water Budget Tool for the replanting trees scenario


WaterSense New Home Specification: Water Budget Tool (V 1.04)
This water budget tool shall be used to determine if the designed landscape meets Criteria 4.1.1 of the specification.
Please refer to the WaterSense Water Budget Approach for additional information.

Your Name: TAMU
Builder Name: HANC
Lot Number/Street Address: 4501 Woodway Dr.
City, State, Zip Code: Houston, Texas

Peak Watering Month: jul

Is an irrigation system being installed on this site? Yes

This worksheet determines if the designed landscape meets the water budget.

If the landscape water requirement is LESS than the landscape water allowance, then the water budget criterion is met.
If the landscape water requirement is GREATER than the landscape water allowance, then the landscape and/or irrigation system needs to be redesigned to use less water.

STEP 3A - REVIEW THE LWA AND LWR FROM PART 1 AND PART 2
LWA 2,714,711 (gallons/month) LWR 3,235,169 (gallons/month)

STEP 3B - REVIEW THE TOTAL AREA OF TURFGRASS* IN THE DESIGNED LANDSCAPE FROM STEP 2B
The designed landscape contains 836,154 square feet of turfgrass.* This is 94% of the landscaped area.
*This includes the area of any pools, spas, and/or water features, designated by WaterSense to be counted as turfgrass.

OUTPUT - DOES THE DESIGNED LANDSCAPE MEET THE WATER BUDGET?

NO If YES, then the water budget criterion is met.
If NO, then the landscape and/or irrigation system needs to be redesigned to use less water.

The designed landscape water requirement is a 17% reduction in water use from the baseline calculated in Part 1.

Figure 4. Results of Water Budget Tool for the replanting trees scenario

The monthly water utility bill for the replanting trees scenario = Landscape water requirement for the replanting trees scenario * The outdoor water utility rate = 3,235,169 gallons/month * $11.04 /1000 gallons = $35,716
The water utility bill for the replanting trees scenario over 15 years = $35,716 *12 *5 = $2,142,960

Difference in water consumption between the two scenarios over the next 15 years = The water utility bill for the replanting trees scenario over 15 years - The water utility bill for the savanna/prairie seeding scenario over 15 years = $2,142,960 - $245,244= $1,897,716

The savanna/prairie seeding scenario saves $1,897,716 in terms of water consumption costs over the next 15 years.

<u>Difference in total costs between the two scenarios over the next 15 years</u>

Difference in the total purchasing and planting costs between the two scenarios over the next 15 years = $934,156
Difference in water consumption between the two scenarios over the next 15 years = $1,897,716
Difference in total costs between the two scenarios over the next 15 years = $934,156 + $1,897,716 = $2,831,872

The savanna/prairie scenario saves an estimated $2,831,872 in total over the next 15 years.

Sources:

City of Houston. 2022. "2022 Water & Wastewater Rates."
https://www.houstonsecured.org/docs/2022%20APRIL%20WATER%20RATES%204-5-22.pdf.

EPA. 2022. "Water Budget Tool | US EPA." 2022. https://www.epa.gov/watersense/water-budget-tool.
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Native American Seed. 2022. "Native American Seed - Wildflowers and Native Prairie Grasses." 2022. https://www.seedsource.com/.

The University of Texas at Austin. 2022. "Lady Bird Johnson Wildflower Center - The University of Texas at Austin." 2022. https://www.wildflower.org/plants/index.php.

Wack, Margaret. 2022. "A Full Breakdown of the Cost to Reseed or Overseed a Yard." Angi. 2022. https://www.angi.com/articles/how-much-does-it-cost-reseed-or-overseed-yard.htm.

Wallender, Lee. 2021. "How Much Does Tree Removal Cost?" Forbes Advisor. November 4, 2021. https://www.forbes.com/advisor/home-improvement/tree-removal-cost/.

Limitations:

- We only used the average cost of trees to represent all tree species. The cost of each species may vary in reality.
- Based on the percentage of canopy lost over the past 15 years, we assume that another 50% of the canopy will be lost over the next 15 years. In reality, the canopy loss may be higher than 50%.
- WaterSense Water Budget tool does not account for other factors that affect landscape irrigation needs, such as soil type and sun exposure. The data chosen for the WaterSense Water Budget tool represent conservative estimates for the major variables included in the tool. Using local sources of real-time data may result in more accurate estimates.
- Management costs other than irrigation, such as mowing and invasive species removal, were not included in the estimates.

Features

- ***Increases habitat quality within 31% of the HANC's area by providing fruit and seed sources for wildlife in 52% of the newly planted native savanna/prairie species, nectar sources in 29%, larval host habitats in 58%, conservation biological control in 9%, and nesting materials/structure for native bees in 15%. 58% of newly planted species are also designated as having Special Value for native pollinators.***

Methods:
HANC's groundcover and shrub composition were initially evaluated. To determine whether any species had been designated Special Value for pollinators, we compared them to the Xerces Society for Invertebrate Conservation Pollinator Conservation Program Special Collections Lists. The Xerces Society defines Special Value as attracting significant numbers of native bees, bumble bees, honey bees, butterflies, and moths, as determined by pollination ecologists. The habitat supplies offered for animals, such as fruit and seeds, nectar, and nesting habitat, were then cross-referenced with the Lady Bird Johnson Wildflower Center plant database. Finally, we estimated the total area of species within each of these habitat benefit categories as a proportion of total groundcover and shrub area.

Calculations:

	TOTAL
HANC PHASE I	65 acres (2,831,000 sf)
IMPROVED SAVANNA/PRAIRIE ZONE	891,194 sf
SAVANNA/PRAIRIE SEED MIX	808,315 sf
SAVANNA/PRAIRIE PLUG MIX	82,879 sf

HANC phase 1: 2,831,000 sf (65 acres)
Improved savanna/prairie zone: 891,193 sf
Percentage of increases savanna/prairie habitat quality of the HANC: 891,194 sf/2,831,000 sf = 31%

Table 1. Special value of the savanna/prairie seed mix

			THE XERCES SOCIETY FOR INVERTEBRATE CONSERVATION				LADY BIRD JOHNSON WILDFLOWER CENTER		
Scientific name	Common name	Area (sf)	Notes (pollinators)	Pollinator value	Supports conservation biological control	Nesting materials/structure for native bees	Fruit and seed source	Nectar source	Larval host
Andropogon gerardii	Big bluestem	40416		40416	40416				40416
Andropogon glomeratus	Bushy bluestem	20208			20208		20208		20208
Bouteloua curtipendula	Sideoats grama	80832	Butterflies/Moths	80832			80832		80832
Chasmanthium latifolium	Inland seaoats	60624					60624		60624
Coreopsis lanceolata	Lanceleaf coreopsis	40416	Bumble Bees	40416				40416	
Coreopsis tinctoria	Plains coreopsis	40416					40416	40416	
Dracopis amplexicaulis	Clasping coneflower	40416						40416	
Echinacea purpurea	Purple coneflower	20208	Bumble Bees	20208				20208	
Elymus canadensis	Prairie Wildrye	40416					40416		40416
Gaillardia pulchella	Indian Blanket	60624	Bumble Bees	60624					
Monarda citriodora	Lemon beebalm	40416	Honey Bees/Bumble Bees/Butterflies/Moths	40416				40416	
Paspalum floridanum	Florida paspalum	40416							
Penstemon cobaea	Foxglove	20208	Honey Bees/Bumble Bees/Butterflies/Moths	20208				20208	20208

Ratibida columnifera	Mexican hat	20208	Bumble Bees/Butterflies/Moths	20208				20208	20208
Rudbeckia hirta	Black-eyed Susan	80832	Bumble Bees/Butterflies/Moths	80832			80832	80832	80832
Salvia coccinea	Scarlet sage	40416	Bumble Bees	40416				40416	
Schizachyrium scoparium	Little bluestem (Gulf)	40416					40416	40416	40416
Sorghastrum nutans	Yellow indiangrass	40416	Butterflies/Moths	40416	40416		40416		40416
Tridens flavus	Purpletop tridens	20208	Butterflies/Moths	20208					20208
Tripsacum dactyloides	Eastern gamagrass	20208	Butterflies/Moths	20208			20208		20208
TOTAL	TOTAL	808315		525408	101040	0	424368	383952	484992
%POLLINATOR/BENEFIT	%POLLINATOR/BENEFIT			65%	13%	0%	53%	48%	60%

Table 2. Special value of the savanna/prairie plug mix

			THE XERCES SOCIETY FOR INVERTEBRATE CONSERVATION				LADY BIRD JOHNSON WILDFLOWER CENTER		
Scientific name	Common name	Area (sf)	Notes (pollinators)	Pollinator value	Supports conservation biological control	Nesting materials/ structure for native bees	Fruit and seed source	Nectar source	Larval host
Andropogon gerardii	Big bluestem	12432	Butterflies/Moths	12432		12432	12432		12432
Paspalum floridanum	Florida paspalum	16576							
Schizachyrium scoparium	Little bluestem (Gulf)	20719					20719		20719
Sorghastrum nutans	Yellow indiangrass	12432	Butterflies/Moths	12432		12432			
Tripsacum dactyloides	Eastern gamagrass	8288	Butterflies/Moths	8288			8288		8288
Conoclinium coelestinum	Blue mistflower	4144	Native Bees	4144	4144				
Lobelia cardinalis	Cardinal flower	4144						4144	
Rudbeckia hirta	Black-eyed Susan	4144	Native Bees/Butterflies/Moths	4144			4144	4144	4144

TOTAL		82879		41440	4144	24864	45583	8288	45583
%POLLINATOR /BENEFIT				50%	5%	30%	55%	10%	55%

Savanna/Prairie Seed Mix Example (table 1):
Big bluestem: 40416 sf
Attract pollinator? Y
The total square footage for all species within the pollinator habitat benefit category was then divided by the total savanna/prairie seed mix square footage.
525,408sf/808,315sf = 65%

Savanna/Prairie Seed Plug Example (table 2):
Big bluestem: 12432 sf
Attract pollinator? Y
The total counts for all species within the pollinator habitat benefit category was then divided by the total savanna/prairie seed mix counts.
12432 sf /82879 sf = 50%

Average Percentage of Pollinator/Benefit:
Pollinator value: (65% + 50%)/2 = 58%
Supports conservation biological control: (13% + 5%)/2 = 9%
Nesting materials/structure for native bees: (0% + 30%)/2 = 15%
Fruit and seed source: (53% + 50%)/2 = 52%
Nectar source: (48% + 10%)/2 = 29%
Larval host: (60% + 55%)/2 = 58%

Sources:

Plant species and quantities are provided by the designer and HANC.

"Plant Lists & Collections." Lady Bird Johnson Wildflower Center - The University of Texas at Austin. Accessed May 18, 2019. https://www.wildflower.org/collections/.

"Pollinator Conservation Program." The Xerces Society for Invertebrate Conservation. Accessed May 18, 2019. https://xerces.org/pollinator-conservation/.

Limitation:

- The HANC also contains a large and wide variety of tree species that provide habitat value. These trees are not considered using this method.

Appendix 1. Tree inventory of the HANC prairie/savanna area

Tree #	Species	DBH	Condition	Risk
1	American Elm	26	F	L
2	American Elm	19	F	L
3	American Elm	27	G	L
4	American Elm	30	F	L
5	American Elm	18	G	L
6	American Elm	18	G	L
7	Baldcypress	20	G	L
8	Baldcypress	19	G	L
9	Baldcypress	19	G	L
10	Baldcypress	21	G	L
11	Baldcypress	20	G	L
12	Bur Oak	18	G	L
13	Crapemyrtle	24	G	L
14	Crapemyrtle	29	G	L
15	Hickory	18	G	L
16	Live oak	34	G	L
17	Loblolly Pine	27	G	L
18	Loblolly Pine	25	G	L
19	Loblolly Pine	18	G	L
20	Loblolly Pine	21	G	L
21	Loblolly Pine	21	G	L
22	Loblolly Pine	23	G	L
23	Loblolly Pine	19	G	L
24	Loblolly Pine	24	G	L
25	Loblolly Pine	18	G	L
26	Loblolly Pine	18	F	L
27	Loblolly Pine	28	G	L
28	Loblolly Pine	23	G	L
29	Loblolly Pine	24	G	L
30	Loblolly Pine	30	G	L
31	Loblolly Pine	20	F	L
32	Loblolly Pine	23	G	L
33	Loblolly Pine	23	G	L
34	Loblolly Pine	28	F	L

35	Loblolly Pine	21	P	M
36	Loblolly Pine	27	G	L
37	Loblolly Pine	30	G	L
38	Loblolly Pine	23	G	L
39	Loblolly Pine	23	G	L
40	Loblolly Pine	23	F	L
41	Loblolly Pine	20	G	L
42	Loblolly Pine	20	G	L
43	Loblolly Pine	18	G	L
44	Loblolly Pine	26	G	L
45	Loblolly Pine	20	G	L
46	Loblolly Pine	32	G	L
47	Loblolly Pine	26	G	L
48	Loblolly Pine	21	G	L
49	Loblolly Pine	22	P	M
50	Loblolly Pine	19	F	L
51	Loblolly Pine	20	F	L
52	Loblolly Pine	19	G	L
53	Loblolly Pine	20	G	L
54	Loblolly Pine	22	G	L
55	Loblolly Pine	18	G	L
56	Loblolly Pine	24	G	L
57	Loblolly Pine	20	G	L
58	Loblolly Pine	26	G	L
59	Loblolly Pine	32	G	L
60	Loblolly Pine	20	G	L
61	Loblolly Pine	21	G	L
62	Loblolly Pine	25	G	L-M
63	Loblolly Pine	21	G	L
64	Loblolly Pine	18	G	L
65	Loblolly Pine	19	G	L
66	Loblolly Pine	22	G	L
67	Loblolly Pine	22	G	L
68	Loblolly Pine	21	G	L
69	Loblolly Pine	21	G	L
70	Loblolly Pine	22	G	L
71	Loblolly Pine	18	F	L
72	Loblolly Pine	21	G	L
73	Loblolly Pine	25	G	L

74	Loblolly Pine	21	F	L
75	Loblolly Pine	19	G	L
76	Loblolly Pine	24	G	L
77	Loblolly Pine	22	G	L
78	Loblolly Pine	18	G	L
79	Loblolly Pine	27	F	L
80	Loblolly Pine	18	G	L
81	Loblolly Pine	22	G	L
82	Loblolly Pine	19	G	L
83	Loblolly Pine	24	G	L
84	Loblolly Pine	18	G	L
85	Loblolly Pine	21	G	L
86	Loblolly Pine	21	G	L
87	Loblolly Pine	21	G	L
88	Loblolly Pine	21	G	L
89	Loblolly Pine	22	G	L
90	Loblolly Pine	20	G	L
91	Loblolly Pine	21	G	L
92	Loblolly Pine	19	G	L
93	Loblolly Pine	19	G	L
94	Loblolly Pine	18	G	L
95	Loblolly Pine	18	G	L
96	Loblolly Pine	26	G	L
97	Loblolly Pine	19	G	L
98	Loblolly Pine	32	G	L
99	Loblolly Pine	20	G	L
100	Loblolly Pine	26	G	L
101	Loblolly Pine	26	G	L
102	Loblolly Pine	22	G	L
103	Loblolly Pine	19	G	L
104	Loblolly Pine	22	G	L
105	Loblolly Pine	18	G	L
106	Loblolly Pine	18	G	L
107	Loblolly Pine	18	G	L
108	Loblolly Pine	22	G	L
109	Loblolly Pine	20	G	L
110	Loblolly Pine	18	G	L
111	Loblolly Pine	20	G	L
112	Loblolly Pine	19	G	L-M

113	Loblolly Pine	22	G	L
114	Loblolly Pine	22	G	L
115	Loblolly Pine	26	G	L
116	Loblolly Pine	22	G	L
117	Loblolly Pine	23	G	L
118	Loblolly Pine	26	G	L
119	Loblolly Pine	22	G	L
120	Loblolly Pine	21	G	L
121	Loblolly Pine	20	G-F	M-H
122	Loblolly Pine	19	F	L
123	Loblolly Pine	18	G	L
124	Loblolly Pine	19	G	L
125	Loblolly Pine	20	G	L
126	Loblolly Pine	20	G	L
127	Loblolly Pine	27	G	L
128	Loblolly Pine	19	G	L
129	Loblolly Pine	16	G	L
130	Loblolly Pine	16	G	L
131	Loblolly Pine	10	G	L
132	Loblolly Pine	12	G	L
133	Loblolly Pine	10	G	L
134	Loblolly Pine	16	G	L
135	Loblolly Pine	6	F	M
136	Loblolly Pine	6	D	
137	Loblolly Pine	6	F	M
138	Loblolly Pine	6	F	M
139	Loblolly Pine	10	F	M
140	Loblolly Pine	17	G	L
141	Loblolly Pine	10	F	L
142	Loblolly Pine	11	G	L
143	Loblolly Pine	11	G	L
144	Loblolly Pine	10	G	L
145	Loblolly Pine	11	G	L
146	Loblolly Pine	12	G	L
147	Loblolly Pine	9	G	L
148	Loblolly Pine	14	G	L
149	Loblolly Pine	12	G	L
150	Loblolly Pine	14	G	L
151	Loblolly Pine	17	G	L

152	Loblolly Pine	14	G	L
153	Loblolly Pine	16	G	L
154	Loblolly Pine	14	G	L
155	Loblolly Pine	18	G	L
156	Loblolly Pine	17	G	L
157	Loblolly Pine	8	G	L
158	Loblolly Pine	9	G	L
159	Loblolly Pine	8	F	L
160	Loblolly Pine	16	G	L
161	Loblolly Pine	21	G	L
162	Loblolly Pine	8	G	L
163	Loblolly Pine	10	G	L
164	Loblolly Pine	18	G	L
165	Loblolly Pine	8	G	L
166	Loblolly Pine	6	G	L
167	Loblolly Pine	9	G	L
168	Loblolly Pine	21	G	L
169	Loblolly Pine	32	G	L-M
170	Loblolly Pine	9	G	L
171	Loblolly Pine	13	G	L
172	Loblolly Pine	9	G	L
173	Loblolly Pine	10	G	L
174	Loblolly Pine	15	G	L
175	Loblolly Pine	12	G	L
176	Loblolly Pine	8	G	L-M
177	Loblolly Pine	10	G	L-M
178	Loblolly Pine	12	G	L-M
179	Loblolly Pine	12	G	L
180	Loblolly Pine	14	G	L
181	Loblolly Pine	20	G	L
182	Loblolly Pine	6	G	L
183	Loblolly Pine	8	G	L
184	Loblolly Pine	14	G	L
185	Loblolly Pine	26	G	L
186	Loblolly Pine	33	G	L
187	Loblolly Pine	7	G	L
188	Loblolly Pine	11	G	L
189	Loblolly Pine	13	G	L
190	Loblolly Pine	25	G	L

191	Loblolly Pine	12	G	L
192	Loblolly Pine	12	G	L
193	Loblolly Pine	17	G	L
194	Loblolly Pine	8	G	L
195	Loblolly Pine	18	G	L
196	Loblolly Pine	16	G	L
197	Loblolly Pine	21	G	L
198	Loblolly Pine	18	G	L
199	Loblolly Pine	18	G	L
200	Loblolly Pine	32	G	L
201	Loblolly Pine	14	G	L
202	Loblolly Pine	16	G	L
203	Loblolly Pine	10	G	L
204	Loblolly Pine	21	G	L
205	Loblolly Pine	25	D	M
206	Loblolly Pine	29	G	L
207	Loblolly Pine	8	G	L
208	Loblolly Pine	27	G	L
209	Loblolly Pine	22	G	L
210	Loblolly Pine	8	G	L
211	Overcup oak	22	G	L-M
212	Overcup oak	22	G	M
213	Overcup oak	19	G	L
214	Post Oak	24	G	L
215	Post Oak	24	G	L
216	Post Oak	23	F	L
217	Post Oak	20	G	L-M
218	Post Oak	18	F	L
219	Post Oak	25	G	L
220	Post Oak	25	G	L-M
221	Post Oak	22	G	L-M
222	Post Oak	18	G	L-M
223	Post Oak	23	G	L-M
224	Post Oak	22	G	L-M
225	Post Oak	20	G	L
226	Post Oak	21	G	L-M
227	Post Oak	18	G	L
228	Post Oak	21	G	L
229	Post Oak	19	F	L

230	Post Oak	19	G	L
231	Post Oak	18	G	L
232	Post Oak	20	G	L
233	Post Oak	18	F	L-M
234	Post Oak	21	F	L
235	Post Oak	25	F-P	M
236	Post Oak	19	G	L
237	Post Oak	25	G	L
238	Post Oak	32	G	L
239	Post Oak	18	G	L
240	Post Oak	18	F	L
241	Post Oak	19	P	M
242	Post Oak	20	G	L
243	Post Oak	21	G	L
244	Post Oak	22	G	L
245	Post Oak	20	G	L
246	Post Oak	23	G	L
247	Post Oak	23	P	M
248	Post Oak	20	G	L
249	Post Oak	18	F	L
250	Post Oak	20	G	L
251	Post Oak	18	G	L
252	Post Oak	20	G	L
253	Post Oak	27	G	L
254	Post Oak	18	F	L
255	Post Oak	18	F-P	M
256	Post Oak	26	G	L
257	Post Oak	22	G	L
258	Post Oak	21	G	L
259	Post Oak	26	G	L
260	Post Oak	24	G	L
261	Post Oak	19	G	L
262	Post Oak	20	G	L
263	Post Oak	24	G	L
264	Post Oak	19	G	L
265	Post Oak	19	G	L
266	Post Oak	19	G	L
267	Post Oak	19	G	L
268	Post Oak	22	G	L

269	Post Oak	19	G	L
270	Post Oak	19	G	L
271	Post Oak	26	G	L
272	Post Oak	23	F	L
273	Post Oak	22	G	L
274	Post Oak	20	G	L
275	Post Oak	18	F	L
276	Post Oak	20	G	L
277	Post Oak	22	G	L
278	Post Oak	18	G	L
279	Post Oak	23	G	L
280	Post Oak	22	G	L
281	Post Oak	23	G	L
282	Post Oak	23	F	L
283	Post Oak	18	G	L
284	Post Oak	28	G	L
285	Post Oak	18	G	M
286	Post Oak	30	G	L
287	Post Oak	22	G	L
288	Post Oak	12	G	L
289	Post Oak	23	G	L
290	Post Oak	22	G	L-M
291	Post Oak	16	G	L
292	Post Oak	16	F	L
293	Post Oak	13	G	L
294	Post Oak	14	G	L
295	Post Oak	13	G	L
296	Post Oak	13	G	L
297	Post Oak	17	G	L
298	Post Oak	9	G	L
299	Post Oak	9	G	L
300	Post Oak	9	G	L
301	Post Oak	9	G	L
302	Post Oak	14	G	L
303	Post Oak	15	G	L
304	Post Oak	19	G	L
305	Post Oak	18	G	L
306	Post Oak	6	F	L
307	Post Oak	20	G	L

308	Post Oak	17	G	L
309	Post Oak	19	G	M
310	Post Oak	9	G	L
311	Post Oak	22	F	M
312	Post Oak	30	G	L
313	Post Oak	20	F	L
314	Post Oak	20	F	L
315	Post Oak	9	F	M
316	Post Oak	25	G	L-M
317	Post Oak	11	F	L-M
318	Post Oak	20	G	L
319	Post Oak	23	F	L
320	Post Oak	16	G	L
321	Post Oak	25	F	L
322	Post Oak	14	P	M
323	Post Oak	14	F	L
324	Post Oak	20	G	L
325	Post Oak	26	G	L
326	Post Oak	16	G	L
327	Post Oak	14	F	M
328	Post Oak	16	G	L
329	Post Oak	14	P	H
330	Red Oak	28	G	L
331	Red Oak	22	F	L
332	Red Oak	21	F	L
333	Red Oak	26	G	L
334	Sugarberry	18	G	L
335	Swamp chestnut oak	26	G	L
336	Sweetgum	34	G	L
337	Sycamore	26	G	L
338	Sycamore	24	G	L
339	Sycamore	20	G	M
340	Sycamore	38	G	L
341	Sycamore	41	G	L
342	Sycamore	40	F	L-M
343	Sycamore	30	G	L
344	Sycamore	33	G	L
345	Water Oak	22	G	L
346	Water Oak	18	F-P	L-M

347	Water Oak	21	F	L
348	Water Oak	19	G	L
349	Water Oak	27	G	L
350	Water Oak	25	G	L
351	Water Oak	22	G	L
352	Water Oak	20	P	M
353	Willow Oak	20	G	M
354	Willow Oak	19	G	L
355	Willow Oak	18	G	L
356	Willow Oak	18	F-P	L-M
357	Willow Oak	23	G	L-M
358	Willow Oak	25	G-F	L
359	Willow Oak	20	G	L
360	Willow Oak	26	G	L
361	Willow Oak	20	G	L
362	Willow Oak	22	G	L
363	Willow Oak	19	G	L
364	Willow Oak	23	G	L
365	Willow Oak	18	G	L
366	Winged elm	29	G	L
367	Winged elm	20	G	L

*Note: G: good F: fair P: poor D: dead H: high M: moderate L: low Red font: trees have been removed

Appendix 2. The savanna/prairie scenario plant water requirement

Common name	sf	Water requirement
Bushy bluestem	32640	High
Plains coreopsis	40416	High
Clasping coneflower	40416	High
Eastern gamagrass	28496	High
Big bluestem	40416	Low
Lemon beebalm	40416	Low
Little bluestem (Gulf)	61135	Low
Purpletop tridens	20208	Low
Blue mistflower	4144	Medium
Black-eyed Susan	4144	Medium
Cardinal flower	4144	Medium
Sideoats grama	80832	Medium
Inland seaoats	60624	Medium
Lanceleaf coreopsis	40416	Medium
Purple coneflower	20208	Medium
Prairie Wildrye	40416	Medium
Indian Blanket	60624	Medium
Florida paspalum	56992	Medium
Foxglove	20208	Medium
Mexican hat	20208	Medium
Black-eyed Susan	80832	Medium
Scarlet sage	40416	Medium
Yellow indiangrass	52848	Medium
Total	891194	

High water requirement area for the savanna/prairie seed and plug mix = 129,535 sf
Medium water requirement area for the savanna/prairie seed and plug mix = 587,053 sf
Low water requirement area for the savanna/prairie seed and plug mix = 174,606 sf

Appendix 3. The replanting trees scenario water requirement

Tree species	Total amount removed	Water use	sf
Loblolly Pine	21	High	18060
Water Oak	3	High	2580
American Elm	3	High	2580
Sycamore	2	High	1720
Willow Oak	2	High	1720
Overcup oak	1	High	860
Post Oak	30	high	25800
Red Oak	2	Medium	1720
Lawn species		Water use	sf
Bermuda grass		Low	167230
Centipede grass		High	167231
Seashore paspalum		Medium	167231
St. Augustine grass		Medium	167231
Zoysia grass		High	167231
Total			891194

Estimated canopy of one tree = 860 sf,
High water requirement area for trees= 53,320 sf
Medium water requirement area for trees = 1,720 sf
Low water requirement area for trees = 0 sf

High water requirement area for turfgrass = 334,461 sf
Medium water requirement area for turfgrass = 334,462 sf
Low water requirement area for turfgrass = 167,231 sf